A Measurement of Conservation Agriculture's Effect on Nitrogen and Carbon Mineralization Rates for Agricultural Recommendations in Haiti's Central Plateau

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ABSTRACT

Much of Haitian agriculture is characterized by subsistence farming systems on eroded and nutrient-poor soils. Implementation of Conservation Agriculture systems has proven effective at improving soil quality and crop yield in many areas of the world, including areas similar to those in Haiti. While most Haitian smallholder farmers are highly resource-limited and adoption of new technologies is limited, these farmers are known to adopt new crops and practices if benefits that outweigh risks are demonstrated. Cover crops that help provide soil cover and increase nutrient mineralization are one of the most potentially beneficial changes that could be made on most smallholder farms. However, before specific cover crop recommendations can be made, their potential benefits need to be quantified. One field experiment in the summer of 2013 assessed decomposition rates and nutrient mineralization from common cash crops and two potential cover crops either on the soil surface or buried at 15 cm. The relative difficulty and expense of conducting these types of field trials led to the development and assessment of a laboratory-based system that could be used to simulate plant residue decomposition and nutrient release under controlled conditions. Additional benefits of a laboratory-based study include the ability to test significantly more treatment combinations than would likely be possible under field conditions and to control nearly all other experimental variables, other than the desired treatment comparisons.

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LIST OF ABBREVIATIONS

C	Carbon
CA	Conservation Agriculture
C:N	Carbon to nitrogen ratio
CT	Conservation tillage
FAO	Food and Agriculture Organization of the United Nations
LWF	Lightweight molecular fraction of soil organic matter
N	Nitrogen
HWF	Heavyweight molecular fraction of soil organic matter
LOI	Loss in ignition
NT	No-tillage
POM	Particulate organic matter
PVC	Polyvinyl chloride
RMSE	Root mean square error
SOC	Soil organic carbon
SOM	Soil organic matter
TT	Traditional tillage

CHAPTER 1 INTRODUCTION

OVERVIEW OF AGRICULTURE IN HAITI

Haiti was founded in 1804 when imported African slaves won independence from French colonial rule. The republic of Haiti officially became the only successful slave revolution of recorded history (Verner, 2007). This newly acquired independence came at an enormous cost of lives, with an estimated one-third of the Haitian population killed and countless injured (Verner, 2007). Domesticated livestock, sugar factories, and irrigation systems were also decimated in the war, resulting in damages of over 1 billion francs (Dupuy, 1989). In addition to these costly damages, Haiti was forced to pay 150 million francs in compensation for the slaveholders' property and slave losses (Dupuy, 1989). France urged world leaders to cease trade with Haiti until financial retribution was received essentially halting the island's ability to trade. In 1838, Haiti's political administration agreed to the debt of indemnity and the country struggled for over 80 years to remit payment to France (Dupuy, 1989).

The inheritance of debt and severely reduced agricultural output produced a comparative test of different economic institutions. Policies evolved that resulted in a division of social classes and privilege between the merchant class and agrarians. This division of wealth still exists in contemporary Haiti where the richest 1% of the population controls nearly half of all Haiti's wealth. Meanwhile, 81% of rural farmers are in poverty (Smucker et al., 2000). Haiti is consistently ranked among the 10 most corrupt countries in the world and, in 2010, Transparency International's Corruption Perception Index ranked Haiti the most corrupt country in the Caribbean region. Distrust of government by the peasant class makes the adoption of new agricultural technologies on behalf of government reforms or international aid difficult.

Smallholder farmers' distrust of government can be traced to Haiti's formative years when attempts to retain the large-scale plantation agriculture of the recently ended colonial period occurred. The government sought to increase agricultural exports through the restoration of plantation-style production in efforts to stabilize a broken economy. This effort was largely unsuccessful as former-slaves collectively resented the parallels to colonization. By 1809, former colonial land was redistributed, abolishing the plantation system and allowing peasants to acquire land. This led to a system of fragmented, small-scale farms primarily disseminated by familial inheritance (Lundahl, 2002; Verner, 2007; MARDNR, 2010).

Limited arable land

This system of subdivision has reduced modern Haitian farm sizes to an average of 1.5 hectares (MARNDR, 2010). Inadequate reserves of land do not allow enough production to sustain domestic food needs or export sufficient volume to sustain strong gross domestic product (GDP). Haiti's agricultural contributions to GDP have been reduced from 40% in the 1970s to 26% today (Verner, 2007). Eventually however, the labor force of agricultural smallholder farms was primarily provided by procreation. As generations continued to pass, land was subdivided after the owner's death amongst children or relatives. These familial divisions of land diminished plot sizes with each generation's inheritance. Current land estimates are that 60% of Haitians have less than one hectare, while less than 4% have more than five hectares (MARDNR, 2010). In the 1970's, the population of Haiti grew beyond domestic food production capability and an influx of foreign food aid began (Lundahl, 2002). As of 2014, USAID reports that over 50% of the country's food needs continue to be met by foreign imports and international aid (Groarke, 2014), while 70% of the nation's economy is attributed to international aid (Smucker et al., 2000).

Deforestation

Reducing dependence on imported food is urgent because of high international prices and Haiti's trade deficit. However, the demands of food production for both domestic and export needs have depleted natural resources. This decline in resources began when forests were cleared to produce monoculture cash crops like coffee and tobacco to compensate for the losses such as sugar plantations and human capital after warring for independence (Lundahl, 2002). Unfortunately, even after the eventual settlement of debt, slash-and-burn farming and mono-crop plantations resulted in continued reduction in forested land.

Additionally, Smucker (2007) estimates that over 75% of current energy needs in Haiti continue to be met by charcoal. Because of this continued demand for charcoal, current estimates are that less than 1% of Haiti's forests remain (Williams, 2011). In an attempt to increase production and avoid food insecurity, farmers cleared hillsides regardless of suitability and expanded into steeper and steeper hillside cultivation, worsening soil erosion. Due to severe deforestation, Haiti's sloping landscape, and heavy annual rainfall, 60-80% of Haiti is affected by erosion and approximately one third of the land considered arable in colonial times is no longer suitable for agriculture due to erosion (Wahab et al., 1987). Since over half of Haiti's agricultural regions have slopes over 40% and lack vegetative cover, soil fertility deficiencies and watershed management issues are common (Kayombo and Lal, 1986). Nearly 85% of land in Haiti is "greatly damaged or in the process of rapid destruction." Additionally, 25 of the 30 watersheds in Haiti are unprotected, which leads to soil erosion, and rapid flooding and sedimentation in lowlands (MARNDR, 2010).

Erosion

Erosion occurs when energy transmitted from rainfall and wind displaces soil particles. Retaining crop residue on the soil surface after harvest rather than incorporating via tillage, can intercept and reduce this energy transmission upon soil aggregates (Pimentel et al., 1995). Crop residue retention increases the soil organic carbon (SOC) content of a soil. Soil organic matter (SOM) facilitates the formation of soil aggregates which increases soil porosity, as these structures regulate the storage of plant available water, and the movement of air and water infiltration (Oades, 1984; Pimentel et al., 1995). In soils, there exists a differentiation of aggregate stability in structures known as macroaggregates and microaggregates. While the occurrence of both types of aggregates increase with the presences of SOM, microaggregates bind with labile SOM to form macroaggregates through the interactions of microorganisms, plant roots, polysaccharides and aromatic humic materials (Gupta and Germida, 1988). Macroaggregates therefore contain higher amounts of SOC and are more stable than microaggregates.

Reduced aggregate stability combined with the lack of residue cover and the exposure of soil to high-intensity weather effects results in decreased SOM content and increased nutrient loss from the agricultural system. Zero tillage combined with crop rotation and crop residue retention results in a higher proportion of macroaggregates (Álvaro-Fuentes et al., 2008). Soil organic matter and increased aggregate stability are directly correlated with aggregation formation, which decreases erosive losses (Montgomery, 2007).

In 1990, the Association Internationale de Développement estimated the annual soil loss rate in Haiti at 36.6 million tons (Badrie, 2007). In 2006, Arias et al. reported annual estimates of 10-15,000 hectares of once-fertile land lost to erosion.

Economy

For 60% of Haitians, agriculture is the primary source of income (Verner, 2007). Improving efficiency of the sector could dramatically increase production and raise export volumes. Whereas food availability in Haiti has stagnated over the past 60 years, it has increased by 45% in the Dominican Republic despite Haiti's possession of considerably more arable land. Additionally, a much higher proportion of Haiti's population is agrarian compared to the Dominican Republic (Bargout and Raizada, 2013).

Agriculture accounts for 25% of Haiti's current national GDP, a decrease from 40% since the 1990s. As the country's population continues to grow, so too do food needs; by 2% each year while food production grows at a rate of 0.4% annually. To worsen matters, the average Haitian caloric intake is 73% of the daily minimum recommended by the World Health Organization (MARDNR, 2010). Over-exploitation of soil resources is largely responsible for food insecurity and reliance upon food imports for over 50% of the national food supply and the degradation of 85% of the country's natural watersheds (MARDNR, 2010). Such conditions call for immediate rectification of current natural resource exhaustion if Haiti ever hopes to achieve independent food production.

Current agricultural practices

Plowing and burning are the most prevalent land clearing practices with 40% of surveyed farmers in the lower Central Plateau region reporting the use of ox driven plows, and less than 1% utilizing tractors (N. Kennedy, personal communication, 2012). Plowing incurs additional cost and, as previously discussed, damages soil structure (Lal, 2004). Secondary soil preparation is generally done by hand with basic tools such as hoes, a small pick, or a shovel. Land is only plowed by animal traction,when work animals are available and when slopes allow it

(MARDNR, 2010).

According to the MARDNR (2010), “80% of family agricultural operations raise a total of 4 million poultry, 65% raise goats (2.5 million young goats), 55% raise cattle (1.5 million of cattle of which approximately a third are adult cows) and 45% keep a total of about 1 million pork.” Overall, McClintock (2004) reports that only 15% of farmers corral their livestock following harvest. Otherwise, animals are permitted to roam unregulated which has not only lead to an acknowledged endemic of inbreeding in domestic livestock, but allows unchecked grazing of the residues farmers rely upon for fertilization (MARNDR, 2010). Despite known benefits as a source of fertilization; manure from livestock is not widely collected or applied to agricultural fields.

In the rural Lower Plateau of Haiti, a survey of 600 farmers reported only 5.7% of households used compound fertilizer, less than 0.5% applied manure, and none applied compost (N. Kennedy, personal communication, 2012). Therefore, an opportunity exists to assess cover crop residues for decomposition rate and nutrient mineralization as an important step in making informed choices about crop selection for rotation and the potential benefits of green manure cover crop integration.

Climate

Haiti’s topography and geologic history have created a wide range of climatic and soil conditions within a relatively small geographic area. Haiti has a tropical climate with a temperature range of 21-35°C along the coasts, and 10-24° C in the mountains. A wet season of May to November, and a dry season of December to April is typical of the region. Despite exposure to tropical storms and hurricanes, accurate weather data is lacking in Haiti. Annual rainfall is estimated to be 300 mm in the northwest and as much as 3,000 mm in the southwest. Between the wet seasons, severe drought is common (Bargout and Raizada, 2013). Precipitation in the Central Plateau varies somewhat depending on elevation, but generally follows a bi-modal distribution. The first rainy season usually begins in March, tapering in June with a dry period of a month to six weeks. A second rainy season begins in July and extends until November, and the remaining months constitute the dry season. The bi-modal rainfall pattern dictates the cropping system, as the principal staple crop, maize (*Zea mays* L.), is typically planted in April and harvested prior to a second maize planting in July (Clermont-Dauphin et al., 2003).

Soil

A recent study evaluated physical and chemical characteristics of soils from four sites in the Central Plateau. Soil carbon (C) and nitrogen (N) did not vary with depth (0-15 cm), ranging from a maximum of 2.0% C at the Maissade site to a minimum of 1.3% C at Lachateau. Total N varied from 0.13% at Lachateau to 0.25% at Bas Cange. Cation exchange capacity (CEC) ranged from 3.7 to 42.5 among the sites (Stewart, 2012).

Based on Natural Resources Conservation Service (NRCS) soil maps of Haiti, the largest areas are composed of Inceptisols and Entisols (NRCS, 2010a, 2010b). Smaller portions of Aridisols, Alfisols, or Ultisols in an udic or ustic soil moisture regime coexist in the five principle watershed regions (NRCS, 2010a, 2010b). These young, recently deposited soils are often shallow and lack profile development due to erosion and downslope deposition (Hylkema, 2011). The parent material of over 80% of the soil in Haiti is limestone, with basalt being the second most prevalent (Isaac et al., 2004).

In an analysis of 1,500 soil samples from Haiti's Port Au Prince and Matheiux corridor, it was concluded that N is the most limiting nutrient for crop production followed by phosphorus (P) (Hylkema, 2011). Due to the extent of calcareous soil, "the majority of sites had neutral to moderately alkaline pH's between 7 and 8.2" --suitable for agricultural production (Hylkema, 2011). Isaac et al. (2000) studied five agricultural soils formed from differing parent materials, elevation, and moisture regimes and all areas were found to be P deficient. Isaac et al. (2004) measured plant available P and confirmed these results with five out of six soils in southern Haiti considered very low in available P. Nutrient deficiencies are likely due to several factors, such as the topography, warm climate, bimodal rainfall distributions, and unsustainable farming practices including: removal of crop residues, lack of synthetic fertilization or manuring, lack of mulching, and extensive tillage (Bargout and Raizada, 2013). As a consequence of land use practices, 94.8% of Haitian soils are considered very severely degraded, as Eichler (2006) states, such soils have "greatly reduced agricultural productivity, biotic functions largely destroyed, and possibly non-reclaimable at farm level."

SOIL ORGANIC MATTER IN AGRICULTURE

Soil organic matter consists of plant and animal residues in various stages of decomposition, living organisms and substances released by microorganisms, and plant roots (Brady and Weil, 2008). As Palm et al. (1996) observed: "soil organic matter itself represents a set of attributes rather than an entity." This compiled list of SOM's proffered attributes include: a simultaneous source and a sink for nutrient elements which can form organic moieties; it has charge properties which make it a site of ion exchange properties which facilitate aggregation with mineral particles, particularly clays, and in turn modify soil physical structure and influence soil water regimes, and it is a source of energy for the soil biota and thus mediates many of the biologically mediated processes of the soil (Palm et al., 1996). Practically every soil property, chemical, physical, and microbial, is therefore affected by SOM. Moreover, modern SOM research literature contains many studies attempting to fractionate the structural, biological, and chemical components of SOM in order to differentiate individual functions at different stages of decomposition.

The earliest studies of SOM tended to be concerned with either physical or chemical structure or biological activity. Physical fractionation methods include those that separate SOM based on aggregation, particle size, density, and magnetism. Chemical procedures consist of a variety of wet chemical methods that isolate fractions based on their hydrolyzability, solubility, oxidation, and by destruction of the mineral phase (Von Lützow et al., 2002). All methods have been utilized to isolate 'labile' or partially decomposed transitory pools of organic matter between fresh residues and stabilized SOM considered non-labile, recalcitrant, or stable. As decomposition progresses, humus is formed, which is the recalcitrant form of SOM that resists further decay. Fresh residues decompose into different fractions of SOM which have half-lives that vary from only a few months for labile non-humic substances, to centuries for the most resistant non-labile humic substance.

Moreover, humic and non-humic fractions of SOM are commonly separated into functional pools. Wander (2004) indicates that the SOM fractions used to estimate kinetically distinct pools can be divided into three functional classes, young and intermediate-age materials being associated with physical activity, and materials with the longest half-life contributing most to chemical reactivity, such as changes in cation exchange capacity. These theoretically defined SOM pools are separated by differential kinetics into active, slow, and passive pools (Wander, 2004; Brady and Weil, 2008). Terminology is often confusing in regards to these sinks and sources of nutrients as terms such as labile (active) and non-labile (slow and passive) are frequently interchanged with pool kinetics. Because this research is primarily concerned with soil nutrient mineralization mechanisms, it is critical to understand the relationships between active SOM, total SOM, and nutrient retention and supply characteristics over time (Wander et al., 2004).

Through the review of 150 laboratory methods for SOM fractionation, Strosser (2010) associates the active pool with "the quickly reactive SOM that provides energy and nutrients for soil microorganisms and releases part of the nutrients for plant usage." According to Wander (2004), it is the pool with the most dynamic SOM constituents being most closely identified with biological activity. The length of active pool SOM decay has been estimated at 1-2 years for short-term SOM turnover (Ladd and Paul, 1973; Parton et al., 1993). The active fraction is composed of non-humic substances that are can be chemically defined by organic C and N contents of low molecular weight and are often referred to as particulate organic matter (POM), free organic matter, lightweight molecular fractions (LWF) (Gregorich and Janzen, 1996). Consensus for the classification of the components of the LWF has not been achieved, however "low molecular weight aliphatic and aromatic acids, carbohydrates, amino acids, and their polymeric derivatives such as polypeptides, proteins, polysaccharides, and waxes" have been identified within this procedurally defined pool (Schnitzer, 1991). In terms of crop residue decomposition, the greatest amount of carbon in a plant is cellulose, which gives plants structural rigidity, and allows plants to grow erect. The quantity and quality of free organic matter both play an important role in the structure and function of the soil ecosystem by providing a ready source energy and labile C for soil microbes, as well as plant available nutrient supplies.

Recalcitrant remnants of the active pool compose the slow pool of SOM (Wander, 2004). This pool consists primarily of detritus, partially broken down cells, and tissues that are gradually decomposing. Slow SOM pools also include bound organic-mineral aggregates with heavy molecular weight (HWF) and humic properties. It is the intermediary pool in nutrient mineralization which is somewhat resistant to decay, and contains compounds that may take years to decades to completely break down. Gregorich and Janzen (1996) report that more than 75% of SOM exists as compounds that are only slowly decomposable and therefore the slow pool serves as a stable reservoir of less decomposable organic complexes (Strosser, 2010).

Lastly, the passive fraction represents a pool of humic substances that are physico-chemically protected against decomposition. Its half-life is between decades and centuries (Strosser, 2010). Gregorich and Janzen (1996), define the chemical structure of the passive fraction as "complex polymeric organic compounds with high molecular weight and intimately associated with soil inorganic constituents." These complexes of humus colloids bonded to soil minerals make them highly resistant to decomposition which creates protected complexes of SOC stores. The C:N ratio of recalcitrant humus is constant in the stable portion of SOM. Kirkby et al. (2011) affirmed this theory in an international meta-analysis over a wide range of soils from 23 countries.

Soil carbon

The largest terrestrial reservoir of earth's C is the soil, and therefore agriculture plays an important role in the management of this relationship (Lal, 2004). Lal (2004) states that the "conversion of natural to agricultural ecosystems causes depletion of the soil organic carbon pool (SOC) by as much as 60% in soils of temperate regions and 75% or more in cultivated regions of the tropics." Despite such reductions, agricultural soils can be a significant sink for atmospheric C through increasing soil organic matter (SOM) concentrations because C is the primary component of SOM and comprises from 48 to 58% of the total weight according to Nelson and

Summers (1982). Therefore, SOC determinations are often used as the basis for SOM estimates and according to Amundsen (2001), the amount of organic matter in soil at any given time reflects the long-term balance of input and loss rates. Through the addition of crop residues in conservation agriculture, C is therefore sequestered in the topsoil.

Decreases of 12-25% in soil organic carbon (SOC) have been reported under traditional tillage (TT) in comparison to no-till (NT) systems due to this relationship (Dick, 1983). Because of the greater overall SOC source, greater microbial biomass and diversity often exist in aggregates under NT comparative to TT (Helgason et al., 2010). Therefore, the greater the contact of the community with SOM, the greater the energy supply, resulting in increased populations of the microbial community and more rapid decomposition rate of SOM.

The addition of SOC via crop residues encourages biological activity in soil. In general, soil respiration rates reflect the availability of SOM for microbial growth and maintenance and are a measure of basic microbial turnover rates in soils (Insam et al., 1991). According to McBride (2004, p. 271), under aerobic conditions, solar energy “catalyzes non-photosynthetic organisms [to] use O_2 to oxidize the energy-rich organics” after which the system eventually returns to equilibrium. When tillage or other disturbances are employed, SOM is depleted and aeration rates are increased. Microbial respiration increases as the SOM is oxidized producing CO_2 and water as a by-product (Brady and Weil, 2008). However, soils also act as a sink for CO_2 via plants through photosynthesis. Sainju et al. (2002) observed such processes of soil C storage achieving equilibrium between: “the amount of plant residue C added to the soil and the rate of C mineralized as CO_2 emission in un-manured soil.” Gregorich and Janzen (1996) describe C mineralization determination as: “the gross flux of CO_2 from the mineralizable fraction, indicates the total metabolic activity of the heterotrophic soil organisms.” Better understanding of this demonstrated correlation between soil fertility and soil microbial respiration is necessary for maintenance of healthy soil biomass.

Mineralizable C is usually measured as CO_2 produced by the respiration of the soil microbial biomass. Alkali traps that are sealed with incubated residue and soil samples are the most prevalent way of determining CO_2 content as Rochette (1997) describes: "CO_2 emitted at the soil surface is chemically trapped by an absorbing substance (NaOH, KOH)." Upon removal of the alkali trap, a titration reacts chemically with CO_2 and $BaCl_2$ and is next back titrated with HCl to a phenolphthalein endpoint that is relative to the amount CO_2 amassed over the duration of incubation (Haney et al., 2008). Brookes et al. (1982) fumigated samples with $CHCl_3$ vapor before incubation and calculated biomass from the difference between the amounts of CO_2 evolved during incubation by fumigated and unfumigated soil. Other techniques have been developed including methods summarized by Gregorich and Janzen (1996) for: "scrubbing of CO_2 from air passed over incubating soils, measurement of CO_2 accumulated in headspace air above incubating soils, and automated methods using electrolytic detectors or infrared gas analyzers."

Most recently, the Solvita® gel system has been developed to measure CO_2 generated by the exposure of a colorimetric gel to a compost sample placed in an incubation jar for four hours. Haney et al. (2008) compared this newer test to the pre-existing infrared gas analyzer and titration methods noting that the "Solvita chemistry gel technology is different from alkali traps in that it does not absorb all the CO_2 but absorbs a relative concentration of CO_2." The method comparisons included soils from seven states and varying pH, clay, and SOM contents. The results of all methods were well correlated and indicated promising indexes of microbial activity.

However, limitations in these current methods certainly exist. The Solvita® system is only applicable to incubations of a 30-day time frame or less and therefore isn't suitable for long-term incubations. Moreover, alkali traps often under or overestimate the CO_2 flux by the alkali trap. According to Rochette et al. (1997) this is due to: "inadequate absorption efficiency of the alkali solution, oxygen depletion of the chamber and soil atmosphere, lack of air turbulence and modification of soil temperature and moisture regimes during exposure." Better results have been found with a system that circulates air through the chamber with a pumping system after being scrubbed by the caustic alkaline solution (Freijer and Bouten, 1991). Along with the need for continual respiration measurement, there coexists a lack of cost-effective and commercially available units for sampling. Future research endeavors on more cost-effective and standardized analysis are desired to remediate this issue for long-term incubations.

Soil nitrogen

Similar to C, soil N concentration increases with SOM content. In comparison however, N is more complicated in nutrient mineralization than SOC and according to Melillo et al. (1989) is therefore best described through a two-phase model: a phase of N net immobilization followed by a stage of N net mineralization. Net N immobilization refers to N entering the organic pool of soil N, while mineralization results in N leaving the system in the inorganic forms such as nitrate (NO_3^-) and ammonia (NH_4^+). The addition of materials high in N favor mineralization, while those with low N content favor immobilization. It has been estimated that 90% of inorganic N in soil is derived from the mineralization of organic matter. Therefore, not surprisingly, rates of mineralized N tended to be greatest in soils with greatest SOM content (Powlson, 1993).

In the development of SOM content, the microbial community present regulates both C and N concentrations in soils. In the most general terms, this microbial community consists of millions to billions of microscopic organisms consisting both of hetero, and autotrophic meso and micro flora and fauna. Nitrogen is scavenged by the microbial community and incorporated into their protein and DNA structures, while C is consumed as the primary energy source of most organisms (Brady and Weil, 2008). Microbial communities are responsive to disturbances such as tillage. Alvaro-Fuentes et al. (2008) report that mechanical tillage stimulates and hastens decomposition of SOM by aerating the soil, which increases the contact between soil microorganisms and crop residue. Chemical nutrients in the bodies of living organisms or fresh organic matter are considered immobilized and cannot be utilized by other plants because they are bound in complex forms. Therefore, microbial decomposition is responsible for supplying growing plants' need for simple inorganic forms of N via the process known as mineralization (Brady and Weil, 2008). Functional diversity of the microbial community and other early decomposing soil organisms can be determined by native SOM, organic inputs, and their interaction (Bending et al., 2002).

AGRICULTURE'S ROLE IN NUTRIENT MANAGEMENT

Large scale intensive cropping can disrupt the long-term balance of SOC and inorganic N supply through the removal of SOM from agricultural production systems. Continuous cultivation removes SOC from the system and narrows C:N ratios each harvest. However researchers have achieved various levels of nutrient loss mitigation via the addition of crop residues in many production systems of the world (Pimentel et al., 1995; Wander, 2004; Kirkby et al., 2011). Despite the complexity of functions and factors, organic materials decay and equilibrium between C and N is achieved over time in all ecosystems. It is therefore possible to regulate the provision of energy source for the soil microbial community and the storage of nutrients via humification.

Crop residue decomposition rates are contingent upon many variables including initial SOM content (Palm et al., 1996), soil moisture regime (Hamdi et. al, 2013), and litter quality (Tian et al., 1992; Isaac et al., 2004) to name a few. One of the most commonly used measures for assessing crop residue quality and nutrient mineralization is the C:N ratio of the residue. Plant C:N ratios have a primary effect on both the net N mineralization and immobilization rates from residues (Tian et al., 1992; Nicolardot et al., 2001; Abera et al., 2012). The decomposing organisms of the soil food web typically possess a C:N ratio of approximately 8:1, but in order to maintain body maintenance and energy needs, soil organism diet ratios climb to 24:1 (Brady and Weil, 2008). A low residue C:N ratio (less than 30:1) provides sufficient N through residue decomposition to meet the N needs of the decomposing organisms. As a result, mineralization results in net N release from residue and increased inorganic N in soil (Wander, 2008). Mineral soils in an equilibrium state contain relatively constant ratios of C and N, regulated by the soil microbial community. When residues with a high C:N are added to the soil, the N is quickly immobilized and the microbial community must draw N from the soil system to compensate. Tian et al. (1992) therefore characterized plant residue with a high C:N as low residue quality that lacked measurable influence on active pool decomposition rates because this residue type is largely avoided by soil fauna. Nicolardot et al. (2012) derived a model from 48 residues and results “indicated that the C:N ratios of decomposers increased with the residue C:N ratio.” Therefore, choosing rotations of crop residues which maximize soil C inputs while maintaining a high proportion of active C are important factors in increasing the health and productivity of the soil microbial biomass. As the soil microbial community receives continuous inputs of SOM and grows more robust, decomposition and nutrient mineralization rates increase (Unger et al., 1991; Von Lützow et al., 2002; Jeranyama et al., 2007).

CONSERVATION AGRICULTURE

Conservation Agriculture is an umbrella term for resourceful agriculture attempting to reduce loss of inputs and counter challenges to soil productivity associated with SOM degradation. The FAO defines CA as adhering to the following agricultural practices: “continuous minimum mechanical soil disturbance, permanent organic soil cover, and diversification of crop species grown in sequences and/or associations (FAO, 2011).”

Cover crops

Cover cropping, a practice used in CA systems is defined by Gliessman (1998) as “plant cover that is grown specifically to produce plant matter for incorporation as a ‘green manure’ into the soil as an important source of organic matter.” Cover crops are normally grown in rotation with another crop and are most successful in combinations of legume and non-legume species. Crop rotations that include cover crops, cereal grains such as maize or sorghum, and legumes, with reduced tillage are important in SOM management and can produce greater cash crop yields (Thierfedler and Wall, 2010; Lauriault and Kirksey, 2004). Maize and other perennial grasses have higher C:N ratios than leguminous plant species. Therefore, cereal–legume intercropping often results in increased productivity, weed suppression, and N supply. Murbarak and Rosenani (2003) report a study in which a cowpea-maize rotation in tropical Malaysia allowed slashed crop residues to decompose on the surface for four years. The active pool of SOM increased C content by 49% and N by 94% as opposed to the previous practice of continuous maize with removal of residues. Abera et al. (2012) support these findings with the recommendation that “legumes are vital sources of N that could offset nutrient depletion resulting from continued cereal cropping.” Synchronization of net N mineralization with plant growth can be manipulated to maximize N delivery for the crop. The application of residues with high C:N ratio results in immediate net N immobilization while the application of residues with low C:N ratio results in net N mineralization.

Additionally, legumes participate in biological N fixation in their root biomass where transfers of N take place when cereals and legumes are intercropped and with the decay of legumes in rotation. For example, Sullivan et al. (1991) compared a rye (*Secale cereale* L.)-hairy vetch (*Vicia villosa* L.) bi-culture to a rye monoculture, and found C:N ratios of 47:1 and 59:1, respectively. Consequently, a grass-legume cover crop bi-culture would have a lower C: N ratio and facilitate faster decomposition than a strictly grass monoculture.

Sunn hemp (C*rotalaria juncea* L.) is native to India and is a promising cover crop for the Central Plateau. Due to its origins, this plant is well adapted to tropical climates like that of Haiti. Sunn hemp is a high biomass-producing N-rich legume that has produced 13 Mg ha^{-1} in 60-90 days (Clark, 2007). Sunn hemp grows best in soils with a pH of 5.0-7.5 making it highly compatible with the neutral to high pH soils found in much of Haiti. The USDA has utilized mixtures of sunn hemp with sorghum sudangrass (Sorghum bicolor x S. bicolor var. *Sudanese)* as cover crops because sunn hemp has an upright habit that competes well for light when matched with sorghum sudangrass cultivars of similar height and has been shown to offer effective weed suppression (Clark, 2007). In a three year cover crop and tillage experiment conducted in the Central Plateau of Haiti, a sunn hemp cover crop significantly reduced weed populations compared to no cover at all sites (Himmelstein, 2013).

Additional benefits of sunn hemp include natural resistance to plant parasitic nematodes. In a Florida study, sunn hemp was used as a summer cover crop as well as cowpea (*Vigna unguiculata* L.), velvetbean (*Mucuna deeringiana L.*) and sorghum sudangrass. Increased okra (*Abelmoschus esculentus* L.) yield was associated with all cover crops. Sunn hemp resulted in substantial inhibition of root-knot nematode throughout the okra growing season (Yang et al., 2013).

Sorghum sudangrass grows in both rainy and semi-arid environments and has been grown in the Central Plateau demonstrating significant weed suppression (Himmelstein, 2013). Compared with maize, Sorghum sudangrass has less leaf area, more secondary roots, and a waxier leaf surface, traits that help withstand drought (Clark, 2007) which is a seasonal occurrence in the Central Plateau.

Minimum tillage

Conservation tillage (CT) and especially, no-tillage (NT) reduces the flow of oxygen into the soil and therefore slows residue decay resulting in increases SOC and SOM over time. This relationship has been reported in numerous studies comparing CT to TT across numerous geographic locations and soil types in both field and laboratory trials. In a field study conducted in El Batán, Mexico comparing TT, NT, and CT of wheat and maize mono-culture rotations in a clayey soil, the authors reported that TT treatments contained less SOC then NT or CT in both corn and maize in all study plots at 0-5 and 5-10 cm (Alvaro-Fuentes et. al, 2008). Similarly, in an analysis of TT vs. CT over a 19 year period in a silty clay loam soil, the SOC content of surface soil in NT plots was 2.5 times greater than in TT (Dick, 1983). The results of an experiment conducted over 10 years by Arsahad et al. (1990) with continuous barley production in a TT vs. CT system in Alberta Canada on a silty loam soil: “showed that the NT soil had a higher content of C and N (26%) than the conventionally tilled soil.” Lastly, a study on a sandy clay loam in South Texas with 16 years of corn and cotton production was examined. In both crops, NT soils had 64% more organic carbon and 78% greater total N in the soil surface than TT (Salinas-Garcia et al., 1997).

Intercropping

In attempts to mitigate food insecurity, Haitian farmers cultivate a large variety of crops and livestock on very small plots. An average farm will generally produce some combination of root and tubers, grains, fruits, vegetables, and legumes in a relay intercropping system (MARDNR, 2010). Intercropping is practiced in many nutrient-depleted, low input, tropical regions of the world and is simply defined as: a cropping system in which two or more crop species are planted within sufficient spatial proximity to result in competition or complementation, thus enhancing yields (Gliessman, 1998).

While encouraging the competition of crops for resources seems undesirable, intercropping often results in more resilient and stable cropping systems. While individual crop yields typically do suffer, the combined yield of an intercropped system often rises. For example, the yield stability of cassava (*Manihot esculenta* Crantz), maize, soybean (*Glycine max* L.) and cowpea (*Vigna unguiculata* L. Walp) intercrop systems were examined in Ethiopia. A 20 to 67% yield benefit over sole crop was reported, saving 38% more farmland as opposed to mono-cropping. Intercropping resulted in higher land equivalence ratios, has the potential to generate greater mean net income (Molatudi and Mariga, 2012), and suppress weeds (Workeyehu, 2014). These results were similar to those in Molatudi and Mariga's (2012) maize/bean (P*haseolus vulgaris* L.) intercrop of South Africa. They found that 37,000 plants ha^{-1} produced higher maize yields than 24,700 plants ha^{-1} in mono-culture. In semi-arid India, crop yields in a soybean-chickpea (*Cicer arientinum* L.) intercrop system, increased with a yield advantage 60% higher than sole soybean (Ghosh et al., 2006). Additionally, Inal et al. (2007), reported an increase in phosphatase activity under interspecific nutritional competition creating a high requirement for phosphorus, which was responsible for the increase in P concentrations in the rhizosphere where the intercropping took place (Inal et al., 2007). Gleissman (2007) confirms these findings with yield increases as much as 50% in a Mexican maize-bean-squash polyculture. In P deficient soils, P tends to be bound in non-labile compounds that don't dissolve in water, however, roots secrete organic acids which dissolve soil compounds and make P plant available (Taghipour and Jalali, 2013).

Weed management is commonly very labor intensive in smallholder farm systems and inadequate weed control can often prove to be a major constraint to yield (Wortman et al., 2013). This is of particular concern in regions where tillage is reduced or non-existent. Therefore, according to Baunman et al. (2001), the increase in these competitive intercrop interactions proffers stewardship strategies, which decrease weeds due to "increased soil cover and light interception by a crop canopy and reduces the growth and fecundity of late-emerging weed." By increasing competition and plant diversity through intercropping it is possible to increase food security.

Therefore, crop rotations that enhance the productivity of all crops in the rotation can be achieved utilizing a cereal-legume intercrop or rotation. Intercropping in particular benefits the soil as a result of more effective use of water, mineral nutrients, and solar energy (Inal et al., 2007). Additional advantages of a well-managed crop rotation include: disrupting plant pest cycles (Lithourgidis et al., 2011), improving soil fertility (Lauriault and Kirksey, 2004; Molatudi and Mariga, 2012) and reducing the need for fertilizer inputs and therefore lessening nutrient losses in gaseous or leached forms that cause environmental degradation (Abera et al., 2012).

Justification for CA adoption in the Central Plateau

The adoption of CA is particularly appealing to the intensive agricultural systems of Haiti where fallow periods are often non-existent due to food insecurity. Rather than fallow a field after a main crop is harvested, Hartwig and Ammon (2002) found: “the integration of cover crops into cropping systems may serve to provide and conserve nitrogen for grain crops, reduce soil erosion, reduce weed pressure and increase organic matter content while still providing year-round food and income.” By cropping between harvests and in continual rotation, SOM can be increased more rapidly resulting on increased soil moisture retention, reduced erosion, and a more robust microbial community. Wander et al. (1996) also report that despite higher biological activity, organically managed soils lost soil C if SOM losses were not offset by SOM inputs and that because of those C losses, net SOM, microbial biomass, and activity declined similar to what was measured in continuously mono-cropped soil under conventional tillage.

Despite the well-documented benefits of conservation agriculture on food production, Haitian farmers must perceive these benefits before adopting the practice. Therefore a great need exists to strengthen farmland productivity through research and experimentation including expanding work on cover crops. For many years, the dichotomy of landownership was thought to affect the ease of adoptability of conservation agriculture practices, because those who rent or sharecrop are less likely to invest in land improvement measures that do not offer immediate results. However, in a national survey of 1,540 peasant households, 25% were reported to be renters or sharecroppers, with survey results demonstrating no significance in renter or sharecropper’s willingness to adopt CA practices compared to farmers who own their land (Smucker et al., 2000; Himmelstein, 2013). The adoption of CA is particularly appealing for the intensive agricultural systems of Haiti where fallow periods are often non-existent due to food insecurity. Rather than fallow a field after a main crop is harvested, Hartman and Ammon

(2002) found: "the integration of cover crops into cropping systems may serve to provide and conserve nitrogen for grain crops, reduce soil erosion, reduce weed pressure and increase organic matter content while still providing year-round food and income."

Barriers to adoption of CA

Barriers to the adoption of CA principles in the Central Plateau are certainly prevalent. As the MARDNR (2010) states, "Haiti's farmers are willing to invest and adapt when they see the demonstrated economic benefits of such actions that outweigh the risks involved." The implementation of cover crops such as the proposed sunn hemp and sorghum sudangrass hybrids would save the farmer labor expenditures in tillage; however, the cost of seeds may be a deterrent.

As the poorest country in the Western Hemisphere, where daily income averages less than $2 US, many farmers may find the allocation of funds for seeding cover crops infeasible (Burgess et al., 2002). With the marginal size of the average familial plot less than one hectare, smallholder farmers may have a difficult time planting cover crops that do not offer immediate financial gain, or the provision of nutrition, despite their long-term conservation benefits. The accumulation of SOM is often associated with increased crop yields over time but this increase is not immediate and this delay may serve as an impediment to adoption. A conservation agriculture production system study conducted at three experimental sites in the Central Plateau validated this time lag. No-till practices and cover crops were employed over three years with no significant maize yield increase. However, increased weed suppression occurred in the no till treatments employing cover crops (Himmelstein, 2013).

USAID and other international aid organizations implemented three types of soil conservation structures in the earliest soil conservation projects: bench terraces, contour ditches, and rock walls. They are all very labor intensive to install, and bench terraces and contour ditches required a lot of soil movement that exposes the soil to erosion, and according to Smucker et al. (2000), terrace construction often results in the "most fertile soil being buried under the subsoil." In addition to contour ditches and terraces accumulating soil after every rainfall, hedgerows compete with crops and in times of insufficient rainfall have reduced yields (Isaac et al., 2004). Additionally, Smucker et al. (2000) reports that trees used in hedgerow contouring attempts were often used for fuel rather than conservation as "farmers tend to cut the largest trees having the best form leaving the least productive trees to provide seed for local plantings." To a large extent, international efforts to provide extension education and implement soil conservation have been ineffective even though these practices have been associated with improved farm income (N. Kennedy, personal communication, 2012).

The successful implementation of CA in Haiti via crop rotations, intercropping, and continuous soil cover as this proposal highlights, seem highly adaptable at little cost to the farmer. As previously noted, conservation and no till practices save the farmer labor, increase nutrient and moisture retention, and increase SOM and the health of microbial biomass. Continuously keeping agricultural plots growing in rotation has been proven to increase nutrient mineralization and SOM accumulation. By employing cover crops, research suggests farmers can reduce weed and pest infestation, without fallowing fields, so soils may be improved. In a small assessment on the economics and adoption of conservation agriculture in southern Haiti, innovations perceived by farmers as having: "greater relative advantage, compatibility with past experience and farmer's needs, observability, and less complexity" will be adopted more rapidly than other innovations (Bayard et al., 2007). Due to the year-long provision of food crops and the implementation of inter-cropping which is already widely practiced, cover crops meet the needs of farmers while offering observable benefits such as increased yield, and decreased erosion. Cover crops have the ability to increase nutrient mineralization, especially for N (Wang et al. 2007; Mulvaney 2010; Himmelstein, 2013). Because Haitian soils have repeatedly exhibited N and P deficiencies, and because of the importance of these macronutrients to crop growth and success, CA warrants consideration for implementation in Haitian smallholder farm systems for potential remediation of nutrient deficits.

To assess the effects of two promising cover crops on residue decomposition and short-term C and N mineralization, a litterbag experiment was conducted near the village of Corporant, in the Central Plateau of Haiti. Residues from two N-fixing species, sunn hemp, a cover crop, and common bean as well as two non-N fixing species, maize and sorghum sudangrass were utilized. Residues were collected locally, dried, and sealed into mesh litterbags with 50 µm openings. After assemblage, separate sealed mesh bags were placed either on the soil surface or were buried at a depth of 15 cm to simulate placement of residue either tilled after harvest or left on the soil surface to decompose in a no-till system. Over the course of 112 days, the bags were removed at predetermined intervals with residue mass and C and N content determined for each sampling date.

Because of the expense and complexity of conducting these types of studies in remote locations and the desire to compare more potential treatment combinations, a laboratory apparatus and technique to simulate field results is desirable. An inexpensive polyvinyl chloride (PVC) chamber was designed and calibration of this chamber took place utilizing domestic soil types of various textures, and residues of an N fixing and cereal grain crop were used for initial testing.

The litterbag study allowed information about staple crop and potential cover crop decomposition and nutrient mineralization to be collected in-situ. Determining the C and N content of these residues over time provides researchers and extensionists with baseline data on their decomposition and mineralization rates. Our laboratory investigations are based on the premise that developing a means to economically estimate CO_2 fluxes and N mineralization from incubated soils and residues can provide further insights on residue decomposition rate and impact on the cropping system.

OBJECTIVES

To assess C and N mineralization and the rate of decomposition of surface-placed and buried field and cover crop residues in a loam soil in the Central Plateau of Haiti.

To evaluate the ability of an inexpensive laboratory method to assess closed-system CO_2 evolution and inorganic N mineralization from surface and sub-surface-placed grass and legume crop residues in four soils of varying texture.

RESEARCH HYPOTHESES

Crop residues with a low C:N ratio decompose more rapidly and become net sources of N to the soil system, which is important when a cereal crop follows in the crop rotation. Surface-placed residues, representative of a no-tillage system, are expected to decompose more slowly than the same residues when buried in a tilled field due to less contact with decomposing organisms and inconsistency of residue moisture compared to incorporated residues (Nelson and

Sommers. 1982; Mulvaney, 2010; Zhao et al., 2010). Because of the tropical climatic conditions of Haiti, residue decomposition and mineralization rates are expected to be rapid.

The rate of both grass and legume residues can be accurately measured in an inexpensive laboratory apparatus. Legume residue will decompose more rapidly and have greater CO_2 evolution sooner than grass residues. Legume residues will also have greater N mineralization rates compared to grasses. These changes will be accurately measured over time with the developed laboratory apparatus for different soils, residues, and placements.

REFERENCES

Abera, G., E. Woldemeskel and L. Bakken. 2012. Carbon and nitrogen mineralization dynamics in different soils of the tropics amended with legume residues and contrasting soil moisture contents. Biol. Fertility Soils. 48:51-66.

Álvaro-Fuentes, J., M. López, C. Cantero-Martinez and J. Arrúe. 2008. Tillage effects on soil organic carbon fractions in Mediterranean dryland agroecosystems. Soil Sci. Soc. Am. J. 72:541-547.

Amundson, R. 2001. The carbon budget in soils. Ann. Rev. Earth Planet. Sci. 29:535-562.

Arias, D., E. Brearley and G. Damais. 2006. Restoring the competitiveness of the coffee sector in Haiti. In: Maximo, J. Regional Operations Department II Central American Isthmus, Mexico, Haiti and Dominican Republic. Washington, D.C.

Arshad, M. A., M. Schnitzer, D.A, Angers, and J.A. Ripmeester. 1990. Effects of till vs no-till on the quality of soil organic matter. Soil Biol. Biochem. 22:595-599.

Badrie, N. 2007. Proceedings of the 26th West Indies Agricultural Economic Conference, Puerto Rico. 23-26 Jul. 2006. Caribbean Agro-Economic Society. St. Augustine, West Indies

Bargout, R. N. and M. N. Raizada. 2013. Soil nutrient management in Haiti, pre-Columbus to the present day: lessons for future agricultural interventions. Agric. Food Secur. 2:11.

Baumann, D., T. L. Bastiaans and M.J. Kropff. 2001. Effects of intercropping on growth and reproductive capacity of late-emerging Senecio vulgaris L., with special reference to competition for light. Ann. Bot. 87:209-217.

Bayard, B., C. M. Jolly and D. A. Shannon. 2007. The economics of adoption and management of alley cropping in Haiti. J. Environ. Manage. 84:62-70.

Bending, G. D., M. K. Turner and J. E. Jones. 2002. Interactions between crop residue and soil organic matter quality and the functional diversity of soil microbial communities. Soil Biol. Biochem. 34:1073-1082.

Brady, N. C, and R. Weil. 2008. The nature and properties of soils. Pearson Prentice Hall, Upper Saddle River, N.J.

Brookes, P., D. Powlson and D. Jenkinson. 1982. Measurement of microbial biomass phosphorus in soil. Soil Biol. Biochem. 14:319-329.

Burgess, M. S., G. R. Mehuys and C. A. Madramootoo. 2002. Decomposition of grain-corn residues (Zea mays L.): A litterbag study under three tillage systems. Can. J. Soil Sci. 82:127-138

Clark, A. 2007. Managing cover crops profitably. Handbook Series Book 9 (3rd ed.) Sustainable

Agriculture Network, Beltsville, MD.

Clermont-Dauphin, C., J. Meynard and Y. Cabidoche. 2003. Devising fertilizer recommendations for diverse cropping systems in a region: the case of low-input bean/maize intercropping in a tropical highland of Haiti. Agronomie 23:673-681.

Dick, W. 1983. Organic carbon, nitrogen, and phosphorus concentrations and pH in soil profiles as affected by tillage intensity. Soil Sci. Soc. Am. J. 47:102-107.

Dupuy, A. 1989. Haiti in the world economy: class, race, and underdevelopment since 1700. Westview Press Boulder, Colorado.

Eichler, L. 2006. Community-based environmental management: A tool for natural disaster risk reduction in Haiti? MS Thesis. Duke University. Durham, NC.

FAO. 2011. What is conservation agriculture? [Online]. www.fao.org/ag/ca/6c.html. (accessed 8 Jan. 2015).

Freijer, J. I. and W. Bouten. 1991. A comparison of field methods for measuring soil carbon dioxide evolution: Experiments and simulation. Plant Soil 135:133-142.

Ghosh, P., M. Mohanty, K. Bandyopadhyay, D. Painuli and A. Misra. 2006. Growth, competition, yields advantage and economics in soybean/pigeonpea intercropping system in the semi-arid tropics of India: II. Effect of nutrient management. Field Crops Res. 96:90-97.

Gliessman, S. R. 1998. Agroecology: ecological processes in sustainable agriculture. CRC Press. London, UK.

Gregorich, E. and H. Janzen. 1996. Storage of soil carbon in the light fraction and macroorganic matter. p. 167-190. In: M.R. Carter and B.A. Stewart, editor, Structure and organic matter storage in agricultural soils. Lewis Publ., CRC press, Boca Raton, Fl.

Groarke, J. 2014. Haiti Remains US Government Priority. Embassy of the United States. London, UK.

Gupta, V. V. S. R. and J. J. Germida, 1988. Distribution of microbial biomass and its activity in different soil aggregate size classes as affected by cultivation. Soil Biol. Biochem. 20:777-786.

Haney, R., W. Brinton and E. Evans. 2008. Soil CO2 respiration: Comparison of chemical titration, CO2 IRGA analysis and the Solvita gel system. Renew. Agric. Food Syst. 23:171-176.

Hamdi, S., F. Moyano, S. Sall, M. Bernoux and T. Chevallier. 2013. Synthesis analysis of the temperature sensitivity of soil respiration from laboratory studies in relation to incubation methods and soil conditions. Soil Biol. and Biochem. 58:115–126.

Hartwig, N. L. and H.U. Ammon. 2002. Cover crops and living mulches. Weed Sci. 50:688-699.

Helgason, B. L., F.L. Walley, and J.J. Germida. 2010. No-till soil management increases microbial biomass and alters community profiles in soil aggregates. Appl. soil ecol.: a section of Agriculture, ecosystems & environment 46:390-397.

Himmelstein, J., A. Ares, and K. Moore. 2013. SANREM Innovation Lab. 2013 Annual Report. Virginia Polytechnic Institute and State University, Blacksburg, VA

Hylkema, A. 2011. Haiti soil fertility analysis and crop interpretations in the five winner watershed zone of intervention. M.S. Thesis. University of Florida. Gainesville, FL

Inal, A., A. Gunes, F. Zhang, and I. Cakmak. 2007. Peanut/maize intercropping induced changes in rhizosphere and nutrient concentrations in shoots. Plant Physiol. Biochem. 45:350-356.

Insam, H., C. Mitchell and J. Dormaar. 1991. Relationship of soil microbial biomass and activity with fertilization practice and crop yield of three ultisols. Soil Biol. Biochem. 23:459-464.

Isaac, L., C.W. Wood and D.A. Shannon. 2000. Decomposition and nitrogen release of prunings from hedgerow species assessed for alley cropping in Haiti. Agron. J. 92:501-511

Isaac, L., D.A. Shannon, and C.W. Wood. 2004. Hedgerow pruning management effects on maize yield and nitrogen uptake in an alley cropping system in Haiti. Agron J. 96:1632-1640.

Jeranyama, P., S.R. Waddington, O.B. Hesterman and R.R. Harwood. 2007. Nitrogen effects on maize yield following groundnut in rotation on smallholder farms in sub-humid Zimbabwe. Afri. J. of Biotechnol. 6:1503-1508

Kayombo, B., and R. Lal. 1986. Effects of soil compaction by rolling on soil structure and development of maize in no-till and disc ploughing systems on a tropical alfisol. Soil Tillage Res. 7:117-134.

Kirkby, C., J. Kirkegaard, A. Richardson, L. Wade, C. Blanchard and G. Batten. 2011. Stable soil organic matter: a comparison of C: N: P: S ratios in Australian and other world soils. Geoderma 163:197-208.

Ladd, J. N. and E.A. Paul. 1973. Changes in enzymic activity and distribution of acid-soluble, amino acid-nitrogen in soil during nitrogen immobilization and mineralization. Soil Biol. Biochem. 5:825-840.

Lal, R., 2004. Soil carbon sequestration impacts on global climate change and food security. Science 304:1623-1627.

Lauriault, L. and R. Kirksey. 2004. Yield and nutritive value of irrigated winter cereal forage grass–legume intercrops in the Southern High Plains, USA. Agron. J. 96:352-358.

Lithourgidis, A., C. Dordas, C. Damalas and D. Vlachostergios. 2011. Annual intercrops: an alternative pathway for sustainable agriculture. Aust. J. of Crop Sci. 5:396.

Lundahl, M. 2002. Politics or markets?: Essays on Haitian underdevelopment. Routledge Palgrave MacMillian, New York, NY.

McBride, M. B.1994: Environmental chemistry of soils. Oxford University Press. New York, NY.

McClintock, N. 2004. Regenerative Agriculture for Haiti's Central Plateau - A Sustainable Foundation for food and nutrition security. NGO Report. Zanmi Lasante, Paris, France.

MARNDR (Ministre de l´Agriculture des Ressources Naturelles et du Développement Rural). 2010. Agricultural Development Politics 2010-2025. Ministry of Agriculture, Natural Resources and Rural Development. Port-au-Prince. Haiti

Melillo, J.M., J.D. Aber, A.E. Linkins, A. Ricca, B. Fry and K.J. Nadelhoffer. 1989. Carbon and nitrogen dynamics along the decay continuum: plant litter to soil organic matter. Plant Soil 115:189-198.

Molatudi, R. and I. Mariga. 2012. Grain yield and biomass response of a maize/dry bean intercrop to maize density and dry bean variety. African J. of Agric. Res. 7:3139-3146.

Montgomery, D. R. 2007. Soil erosion and agricultural sustainability. Proc Nat. Acad. Sci. 104:13268-13272.

Mulvaney, M.J., C.W. Wood, K.S. Balkcom, D.A. Shannon, and J.M. Kemble. 2010. Carbon and nitrogen mineralization and persistence of organic residues under conservation and conventional tillage. Agron. J. 102:1425-1433.

Mubarak, A.R.; and A.B. Rosenani. 2003. Soil organic matter fractions in humid tropics as influenced by application of crop residues. Commun. Soil Sci. Plant Anal. 43:933-943

NRCS (Natural Resource Conservation Service- United States Department of Agriculture). 2010a. Entisols map. [Online] http://soils.usda.gov/technical/classification/orders/entisols.html (accessed 5 Jan. 2015).

NRCS (Natural Resource Conservation Service- United States Department of Agriculture). 2010b. Inceptisols Map. Nov, 2010 C. [Online] http://soils.usda.gov/technical/classification/orders/inceptisols.html (accessed 5 Jan. 2015

Nicolardot, B., S. Recous and B. Mary. 2001. Simulation of C and N mineralisation during crop residue decomposition: a simple dynamic model based on the C: N ratio of the residues. Plant Soil 228:83-103.

Nelson, D. W., and L.E. Sommers. 1982. Total carbon, organic carbon, and organic matter. p. 539-579. In A. L. Page, editor, Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties. Am. Soc. of Agron., Soil Sci. Soc. Am., Madison, WI.

Oades, J. M. 1984. Soil organic matter and structural stability: mechanisms and implications for management. Plant Soil 76:319-337.

Palm, C. A., M.J. Swift and P.L. Woomer. 1996. Soil biological dynamics in slash-and-burn agriculture. Agric. Ecosyst. Environ. 58:61-74.

Parton, W., J. Scurlock, D. Ojima, T. Gilmanov, R. Scholes, D.S. Schimel, T. Kirchner, T. Menaut, J.C. Seasted and E. Garcia-Moya. 1993. Observations and modeling of biomass and soil organic matter dynamics for the grassland biome worldwide. Global biogeochem. cycles 7:785-809.

Pimentel, D., C. Harvey, P. Resosudarmo, K. Sinclair, D. Kurz, M. McNair, S. Crist, L. Shpritz, L. L. Fitton and R. Saffouri. 1995. Environmental and economic costs of soil erosion and conservation benefits. Science 237:1117-1117.

Poirier, N., S. P. Sohi, J. L. Gaunt, N. Mahieu, E. W. Randall, D. S. Powlson and R. P. Evershed, 2005. The chemical composition of measurable soil organic matter pools. Org. Geochem. 36:1174-1189.

Powlson, D. S. 1993. Understanding the soil-nitrogen cycle. Soil Use Manage. 9:86-94.

Rochette, P., B. Ellert, E.G. Gregorich, R.L. Desjardins, E. Pattey, R. Lessard and B.G. Johnson. 1997. Description of a dynamic closed chamber for measuring soil respiration and its comparison with other techniques. Can. J. Soil Sci. 77:195-203.

Sainju, U., B. Singh and W. Whitehead. 2002. Long-term effects of tillage, cover crops, and nitrogen fertilization on organic carbon and nitrogen concentrations in sandy loam soils in Georgia, USA. Soil Tillage Res. 63:167-179.

Salinas-Garcia, J. R., J.E. Salinas-Garcia, D.E. Matocha, and F.M. Hons. 1997. Long-term tillage and nitrogen fertilization effects on soil properties of an Alfisol under dryland corn/cotton production. Soil Tillage Res. 42:79-93.

Schnitzer, M. 1991. Soil organic matter-the next 75 years. Soil Sci. 151:41-58.

Smucker, G. R., T.A. White and M.E. Bannister. 2000. Land tenure and the adoption of agricultural technology in Haiti. CGIAR Systemwide Program on Property Rights and Collective Action, International Food Policy Research Institute, Washington, D.C.

Stewart, R. E. 2012: Physical and Chemical Parameters of Common Soils in the Central Plateau Region of Haiti. M.S. Thesis. Virginia Polytechnic Institute and State University. Blacksburg, VA.

Strosser, E. 2010. Methods for determination of labile soil organic matter: an overview. J. Agrobio. 27:49-60.

Sullivan, P. G., D.J. Parrish, and J.M. Luna. 1991. Cover crop contributions to N supply and water conservation in corn production. Am. J. Alternative Agric. 6:106-113.

Taghipour, M. and M. Jalali. 2013. Effect of low-molecular-weight organic acids on kinetics release and fractionation of phosphorus in some calcareous soils of western Iran. Environ. Monit. Assess. 185:5471-5482.

Thierfelder, C. and P. Wall. 2010. Rotation in conservation agriculture systems of Zambia: effects on soil quality and water relations. Exp. Agric. 46:309-325.

Tian, G., B. Kang and L. Brussaard. 1992. Biological effects of plant residues with contrasting chemical compositions under humid tropical conditions—decomposition and nutrient release. Soil Biol. Biochem. 24:1051-1060.

Unger, P., B. Stewart, J. Parr, and R. Singh. 1991. Crop residue management and tillage methods for conserving soil and water in semi-arid regions. Soil Tillage Res. 20:219-240.

Verner, D. 2007. Social resilience and state fragility in Haiti. World Bank Publications. Washington, D.C.

Von Lützow, M., I. Kögel-Knabner, K. Ekschmitt, H. Flessa, G. Guggenberger, B. Matzner and E. Marschner. 2007. SOM fractionation methods: relevance to functional pools and to stabilization mechanisms. Soil Biol. Biochem. 39:2183-2207.

Von Lützow, M., J. Leifeld, M. Kainz, I. Kögel-Knabner and J. Munch. 2002. Indications for soil organic matter quality in soils under different management. Geoderma 105: 243-258.

Wahab, A., Lugo Lopez M., and G. Acevedo. 1987. Soil erosion in southeastern Haiti. J. Agric. Univ. Puerto Rico 71:239-240.

Wander, M. M., and S.J. Traina. 1996. Organic matter fractions from organically and conventionally managed soils: I. Carbon and nitrogen distribution. Soil Sci. Soc. Am. J. 60:1081-1087.

Wander, M. 2004. Soil organic matter fractions and their relevance to soil function. p. 67-102. In F. Magdoff and R. Weil, editors, Soil organic matter in sustainable agriculture. CRC Press, Boca Raton, FL.

Williams, V. J. 2011. A Case study of the desertification of Haiti. J. Agric. Sustainable Dev. 3:20-31

Wortman, S. E., C.A. Francis, M.A. Bernards, E.E. Blankenship and J.L. Lindquist. 2013. Mechanical termination of diverse cover crop mixtures for improved weed suppression in organic cropping systems. Weed Sci. 61:162-170.

Yang, Q., X. Wang, Y. Shen, J.N.M. Philp. 2013. Functional diversity of soil microbial communities in response to tillage and crop residue retention in an eroded Loess soil. Soil Plant Food (Tokyo). 59:311-321

Zhao, K., Z. Kun, L. Shi-Qing, X. Bing-Cheng and L. Hong-Ling. 2010. Comparative study on disturbed and undisturbed soil sample incubation for estimating soil nitrogen-supplying capacity. Commun. Soil Sci. Plant Anal. 41:2371-2382.

CHAPTER II- DECOMPOSITION, N AND C MINERALIZATION FROM FOOD AND COVER CROP RESIDUES IN THE CENTRAL PLATEAU OF HAITI

ABSTRACT

Cover crops are often a major focus of conservation agriculture (CA) efforts because of the ability to provide soil cover and increase nutrient mineralization in cropping systems. Smallholder farmers in Haiti are willing to consider adoption of CA practices, but only after the economic benefits of adoption are demonstrated. In order to evaluate the effect of plant residue type and placement on rate of decomposition and carbon (C) and nitrogen (N) mineralization residues from two food crops, maize (*Zea mays* L.) and common bean (*Phaseolus vulgaris* L.), and two promising cover crops, sunn hemp (*Crotalaria juncea* L.) and sorghum sudangrass (*Sorghum bicolor x S. bicolor* var. *Sudanese*) were used in a litterbag study conducted in the Central Plateau region of Haiti from May to September, 2013. Residues were placed in litterbags at a rate equivalent to 3.25 Mg residue ha^{-1} on a dry matter basis and installed either on the soil surface or buried at a depth of 15 cm to represent a tilled and no-tillage system, respectively. Initial C:N ratios of residues were: maize > common bean > sorghum sudangrass > sunn hemp. Highest residue mass loss rates and C and N mineralization generally occurred in the reverse order. Overall, surface-placed residues decomposed more slowly than buried residues with 40 and 17% of initial residue mass of surface and buried residues, respectively remaining at 112 days. Residues left on the soil surface, especially those with high C:N ratio (grass crops) will likely offer greater erosion protection over a longer period. Carbon and N mineralization was higher when residues were buried, potentially resulting in increased availability to a following crop. Net N mineralization of buried residues was 0.12, 0.07, 0.06, and 0.03 g N g $residue^{-1}$ for sunn hemp, sorghum sudangrass, maize, and common bean, respectively over the 112 days of the study. To achieve the goal of increasing nutrient supply

while maintaining year-round cover, a combination of grass and legume cover crops may be required with benefits increasing over multiple seasons.

INTRODUCTION

In Haiti, the poorest country in the Western Hemisphere, 60% of Haitian farmers have less than one hectare while less than 4% farm more than five ha (Cohen, 2010). The Haitian Ministry of Agriculture Resources and Department of Natural Resources (MARNDR, 2010) similarly reports the average farmer plot size to be 1.5 ha. This pressure on landholdings has resulted in an overall expansion of hillside agriculture production on steep slopes as the more fertile valleys have become crowded and over-exploited (McClintock, 2004; MARDNR, 2010). More than 50% of Haiti's agricultural regions have slopes over 40% and lack vegetative cover (MARDNR, 2010). Less than 1% of original forests remain in Haiti (White, 1995) and soil fertility is generally depleted. Nearly 85% of land in Haiti is classified as "greatly damaged or in the process of rapid destruction" (Voiget et al., 2011). Plowing and burning are the most prevalent land clearing practices (N. Kennedy, personal communication, 2012e; McClintock, 2004) and contribute to the estimated 36.5 million tons of soil lost annually (Badrie, 2007).

Soil fertility deficiencies and negative consequences for soil health result from erosion of topsoil from repeated cultivation on steep slopes. Due to external factors (erosion, slope, and deforestation) and unsustainable agricultural practices (plowing, burning, steeply sloped hillside production), efforts to conserve soil are of critical importance to Haiti. In order to combat erosion and maximize efficiency of limited land resources, the maintenance of soil structure and a favorable level of soil organic matter (SOM) content are vital to restoring productivity.

Conservation Agriculture (CA) is an umbrella term for resourceful agriculture systems attempting to reduce loss of inputs and counter challenges to soil productivity associated with SOM degradation. The Food and Agriculture Organization of the United Nations (FAO) defines CA as adhering to the following agricultural practices: "continuous minimum mechanical soil disturbance, permanent organic soil cover, and diversification of crop species grown in sequences and/or associations (FAO, 2011)."

The use of cover crops and reduced tillage has repeatedly demonstrated increased nutrient mineralization (Mulvaney, 2010; Perin et al., 2006), increased accumulation of SOM (Bessam and Mrabet, 2003; Ogle et al., 2013; Salinas-Garcia et al., 1997), and reduced erosion (Franzluebbers, 2002; Roth et al., 1998). Rotations of crop mixtures containing grasses residues with high C:N ratios and legumes with low C:N ratios can contribute N to the following crop via decomposition of residues left as soil cover after harvest (Abera et al., 2012; Karpenstein-Machan and Reinhold, 2000; Perin et al., 2006).

Despite the benefits of minimum and no-tillage practices on soil structure, nutrient retention, and nutrient mineralization, tillage remains a very common farming practice because it is a reliable form of weed control (Brady and Weil, 2008). However, studies have shown that increased soil cover and light interception by crop canopies can reduce the growth and fecundity of late-emerging weeds (Baumann, 2001). To achieve adequate weed suppression, a significant amount of plant residue is required. This amount of soil cover can often only be maintained when tillage is reduced (Uri, 1999).

Cover crops such as sunn hemp (*Crotalaria juncea* L.) can produce biomass of up to 13 Mg ha^{-1} of biomass, and 150 to 165 kg ha^{-1} of fixed N under favorable conditions in 60-90 days (Rotar and Joy, 1983; Clark, 2007). Mixtures of sunn hemp with sorghum sudangrass (*Sorghum bicolor x S. bicolor* var. *Sudanese)* have been successful as cover crops because sunn hemp has an upright habit that competes well for light when matched with sorghum sudangrass cultivars of similar height and has been shown to offer effective weed suppression (Clark, 2007). Moreover, sunn hemp decomposes quickly. Peak mineralization rates occurred at two weeks after burial in a litterbag study conducted on a sandy soil in Florida, and also within two weeks after initiation of a litterbag study in a sandy loam soil in Ghana (Wang et al., 2007; Fosu et al., 2007). Researchers in Alabama placed litterbags in both a sandy soil and a fine sandy loam to gauge the rate and effect of N release from sunn hemp on subsequent maize (*Zea mays* L.) yields. They found higher maize yields with sunn hemp and that sunn hemp generally provided more than adequate biomass coverage to achieve erosion control (Balkcom and Reeves, 2005).

Ibewiro et al. (2000) suggest that C:N ratio and mass loss rates of surface litter can be used as indicators of N release and synchronization of N release with crop demand. Two legume and one cereal cover crop were used to measure N fixation and release over two years in a sandy loam soil of a savanna in tropical Nigeria. Legume residues with lower C: N ratios resulted in increased dry matter yield and N uptake by the following crop while decomposing faster than the cereal residues (Ibewiro et al., 2000). Abera et al. (2014) conducted a litterbag study of legume residue decomposition in tropical Sub-Saharan Africa and also observed rapid decomposition rates for legumes. They found that 89% of the initial N in pigeon pea (*Cajanus cajan* L.) and 85% of N in haricot bean (*Phaseolus vulgaris* L.) were released after 150 days. Relative to the control, leaving legume residue in place resulted in two and threefold increases in following crop maize grain yield.

Murungu et al. (2011) measured N and P mineralization rates of two legume and two cereal crops and found that legume cover crop residues resulted in higher N contribution to following crops than the cereal residue. Nitrogen release from decomposing legume cover crops and their effect on maize yields were measured in the Bukoba District of Tanzania and adding legume cover crops resulted in a twofold maize grain yield increase in a high rainfall area and a threefold increase in an area of low rainfall (Baijukya et al., 2006). Cookson et al. (1998) installed a litterbag decomposition study on a silt loam soil in New Zealand comparing two cereal crops with a legume and report that mass loss from legume residue was nearly twice that of the cereal crop after 90 days of decomposition. Heal et al. (1997) report that N mineralization and litter decomposition is rapid when residue C:N ratio is < 20. Therefore litter with low C:N ratio is expected to decompose more rapidly than litter with a higher C:N ratio. This rapid decomposition and N release from legume residue can result in increased grain yield of the following crop when conditions favor good yields.

The MARDNR (2010) notes that Haitian farmers are willing to invest in new technologies when the demonstrated economic benefits of incorporation are observable and risks minimal. However, barriers to the adoption of CA principles and the incorporation of cover crops in the Central Plateau are certainly prevalent. The implementation of cover crops such as sunn hemp and sorghum sudangrass hybrids would save the farmer labor expenditures in tillage; however, the cost of seeds may be a deterrent and the overall value of N and other nutrient supply from residue is unknown. Also of concern is the need to dedicate limited arable land to the production of a non-edible cover crop that offers no nutritional or immediate economic value. Quantification of some of the potential benefits to the overall system is essential to increasing adoption of cover crops. Therefore this study set out to document decomposition and mineralization rates for potential cover crops, sunn hemp and sorghum sudangrass and common cash crops, common bean and maize grown in the Central Plateau.

MATERIALS AND METHODS

Site description

One field experiment was initiated at the Centre de Formation Fritz Lafontant near Corporant, Haiti (18° 55’ N, 72° 07’ W, 158.5 m elevation) in May, 2013. Initial soil physical and chemical parameters (0-15cm) for the site are presented in Table 1 and initial plant residue C and N content and C:N ratio are shown in Table 2. Soil pH was determined using a 1:1 (vol/vol) soil-water mix (Maguire and Heckendorn, 2011). Due to the calcareous nature of the soil, an Olsen extraction method utilizing sodium bicarbonate extractant for available phosphorous was utilized (Olsen et al., 1954) and analyzed using inductively coupled plasma atomic emission spectroscopy (ICP). For other nutrients, soil was extracted with Mehlich 1 at a 1:1 solution:soil ratio, (Mehlich, 1976) filtered (Whatman #2), and analyzed on an ICP. Soil organic matter was estimated using loss on ignition (LOI) (Blue M Ultra-Temp, Blue M, White Deer, PA) paired with ICP where a gravimetric, dry oxidation method was used to estimate the soil organic matter content for all samples (Davies, 1974; Pansu and Gautheyrou, 2007). Estimated sum of cations was determined using Mehlich 1 extractable bases, or non-acid generating cations (Ca, Mg and K), plus the acidity estimated from the Mehlich soil-buffer pH after conversion of all analytical results to meq/100 cm^3 or cmol(+)/kg (Maguire, and Heckendorn, 2011). Plant tissue C and N concentrations were determined by dry combustion (VarioMax CNS macro elemental analyzer, Elementar, Hanau, Germany).

Average annual climate for the Central Plateau, where Corporant is located is humid subtropical with large local variations due to the mountainous topography and reported annual precipitation is 1016 to 1524 mm (Erlich et al., 1987). Temperature and precipitation measured using an on-site weather station (Watchdog 2000, Spectrum Technologies, Aurora, IL) from the study period are included in Table 3.

Treatments

Plant residues from the study were collected in February, 2013, from fields near the Centre de Formation Fritz Lafontant near Corporant. Maize and common bean residues were collected after the most recent harvest while sunn hemp and sorghum sudangrass were collected at full bloom/heading. After field collection, all residues were individually placed in a solar drier until a constant weight was reached and stored on site prior to further preparation.

In May, 2013, residues were placed in litterbags and installed either on the soil surface or buried at a depth of 15 cm within a field. Prior to installation residues were cut into approximately 2 cm pieces and inserted into 10 x 20 cm litterbags with 50μm openings (Ankom Scientific, Macedon, NY), at a rate of 6.5 g bag^{-1}, which is equivalent to 3.25 Mg residue ha^{-1} on a dry matter basis, a rate higher than found on many smallholder farms but consistent with previously measured amounts of crop residue under intensive management (Agenor, 1977). Care was exercised to include representative amounts of stem and leaf in each sample.

Litterbags were consecutively numbered, both inside and out, individually weighed, then placed in the field in a 0.5 m^2 grid where both surface and subsurface placement of the appropriate residue occurred at each point. Surface-placed litterbags were affixed with ground staples. Litterbags from each residue and placement combination were collected from the field: 3, 7, 14, 28, 56 and 112 days after study initiation.

As the litterbags were collected, their contents were dried and sent back to Virginia Tech for analysis. Once dry, samples were weighed and mass loss determined as the difference of initial and final weight. Total C and N content in residues were determined by dry combustion (VarioMax CNS macro elemental analyzer, Elementar, Hanau, Germany).

Statistical analysis

The experimental design was a split plot with a full factorial of four residue types and two placements. Main plot was placement and sub-plots were residue type. Regression was used to evaluate the effect of experimental factors on residue decomposition and C and N mineralization. Depending on the significance of the model, linear or nonlinear regression models available in SAS JMP Pro 11 (JMP, 2013) were applied to least squares estimates for residue mass loss, and N, C, and C:N ratio measurements over time. The most appropriate regression model was chosen based on the significance of the model, lowest root mean square error (RMSE), highest R^2, and reflects the higher-order model when these parameters were similar. Slopes of regressions or regression components for each residue and placement combination were compared to assess potential differences among treatments.

RESULTS AND DISCUSSION

Residue mass loss over time

Mass of both maize and sorghum sudangrass, either surface-placed or buried, decreased with time (Figure 1). However decomposition of buried residues was faster (Table 4). Initially, the rate of mass loss was similar for both residue types when left on the surface. Both lost mass at a rate of approximately 2.2% day^{-1} during the initial seven days, and after that, both surface-placed grass residues continued to lose mass at a similar rate (Table 3). At 56 days, 73 and 71% of the initial mass of surface-placed maize and sorghum sudangrass remained, respectively (Figure 1). Buried residues, by comparison, decomposed more rapidly (Figure 1, Table 4). At 112 days, < 12% of the original mass of maize residue remained and only 5% of initial sorghum sudangrass mass. The difference in mass loss rate between the two residues is likely due to the lower initial C:N ratio in sorghum sudangrass compared to that of maize (Table 2). The initial (seven day) rate of decomposition was faster for buried maize residue than sorghum sudangrass but was similar afterwards (Table 4). Mass loss from day 0 to day 3 in buried residue was >40% for both grass residues. High initial mass loss rates within the first three days of the study may be partially due to favorable climatic factors. Rainfall occurred the day before litterbag installation and each of the first three days after installation. Daily average temperature (26.5 C) was also favorable for decomposition. Although the surface-placed litterbags absorbed rainfall, it is likely that high daily temperatures resulted in more evaporation of water from these litterbags compared to below-ground litterbags. Higher moisture content and retention is often associated with increased rates of decomposition of residues in laboratory incubation and litterbag field studies (Douglas and Rickman, 1992; Blagodatsky et al., 1998; Abera et al., 2014).

Surface-placed sunn hemp lost mass at a faster rate than common bean over the first 28 days of the study (Figure 2) but buried sunn hemp decomposition was similar to buried common bean. This is likely a result of the relatively high C:N ration in the common bean residue (Table 2). The rate of buried sunn hemp residue decomposition was higher than common bean during the initial 56 days of the study, also likely due to the difference in C:N ratio of the two residues. Overall, decomposition rates were lower than those measured in similar work in Sub-Saharan Africa where haricot bean and pigeon pea residues lost 24-73% of initial mass within the first 30 days of the study and common bean and sunn hemp lost 20-53% (Abera et al., 2014). Ibewiro et al. (2000) compared mucuna [*Mucuna pruriens* (L.) *DC.* var. *utilis* (Wright) Bruck)] and lablab (*Lablab purpureus* L.) in a dryland savanna in Nigeria and also observed higher rates of mass loss (approximately 60%) within the study's first 30 days for both legumes regardless of placement. Likely due to advanced maturity and aging of the field crop residues, common bean C:N values were similar to those of the grass crops in our study (Table 2). Njunie et al. (2004) observed slower release of nutrients and decomposition of *Clitoria ternatea* (L.) and lablab in mature tissues when compared with younger cuttings of the same residues. The similar rates of decomposition of common bean and grassy crop residues likely stems from the relatively high C:N ratio of our common bean residues. However, since whole common bean plants are commonly removed from fields to facilitate dry-down and harvest and then piled or returned to fields, it is likely that our values are representative of what would occur with bean residue under current management.

The overall rates of surface vs. buried residue decomposition in our study (Table 4) coincide with the findings from numerous others who also report that surface mass loss occurred at slower rates (Holland and Coleman, 1987; Thomas and Asakawa, 1993; Ibewiro et al., 2000; Thippayarugs et al., 2006; Abera et al., 2014). Greater contact with the microbial community in buried residues is theorized to be responsible for higher rates of decay in comparison to surface-placed residue. Additionally, the 50µm mesh openings in the litterbags used in this work excluded surface meso- and macro-fauna from the decomposition process which contributed to the slower decomposition rates observed with surface-placed residues.

Nitrogen mineralization

Nitrogen concentration decreased for all residues over 112 days, implying net mineralization of N (Figures 3 and 4). As expected, the highest amount of N mineralization occurred from the buried residues with the lowest C:N ratios (Table 2). Eighty-five percent of buried sunn hemp residue N was mineralized by 112 days, compared to 54% of initial N of buried common bean (Figure 4). Nitrogen mineralization from buried sorghum sudangrass and maize residues was >90% of the initial amount, though the absolute amount of N mineralized was less that from the leguminous species (Figures 3 and 4). Overall, surface-placed residues with the lowest initial C:N ratios mineralized N at faster rates than those with higher initial ratios (Table 5). For instance, surface-placed sunn hemp residue N declined much more rapidly than common bean over the initial 14 days (Figure 4). Previous research under similar conditions has reported residue N loss of > 54% within 28 days (Ibewiro et al. 2000). These studies also documented a rapid initial N release over the first 60 days followed by a slower and curvilinear trend in N release from legumes. Net N mineralization in our study ranged from 10-60% with an average of 43% for buried residues and 35-60% for surface- placed residue within the first 28 days. Buried sunn hemp N decreased by 78% over 56 days (Figure 4). Fosu et al. (2007) reported a 50% decrease in N concentration of sunn hemp over a 70 days in a field study in Ghana. This rapid N release from sunn hemp under these conditions indicates promising decomposition kinetics for N from sunn hemp as a potential green manure in the Central Plateau.

Carbon mineralization

Retention of crop residue on or near the soil surface has been shown to reduce residue C loss and increase SOC over time (Lal, 2004). We observed average residue C loss rates of 68% for surface-placed residue and 86% for buried residue (Figures 5 and 6). This decrease in C concentration for buried residues is similar to what was observed for mass loss because soil C mineralizes faster when in greater contact with soil microbial biomass (Figures 5 and 6). Similar trends have been demonstrated throughout tropical and temperate systems worldwide (e.g. Ono et al., 2009).

The N limited soil system where the litterbags were deployed may serve as explanation for the minimal release of C from surface-placed residue in comparison to buried residues. Sunn hemp exhibited higher C loss rates than common bean during the first 14 days regardless of placement. However, maize C mineralization exceeded that from sorghum sudangrass regardless of placement (Table 6). The C loss of maize was similar to sunn hemp and sorghum sudangrass throughout the study (Figures 4 and 5) despite the higher C:N ratio of maize (Table 2). Thomas and Asakawa (1993) tested decomposition rates of six legumes and four cereals in Columbia and also reported similar C losses for grasses and three of the legumes studied (*Centrosema acutifolium*, *Pueraria phaseoloides* and *Stylosantes guianensis*). They concluded that mineralization potential was highly species-dependent and this, along with residue maturity and aging, may help explain our results as well.

Carbon:nitrogen ratio

Maize C:N ratio was initially near 54:1 and decreased at the same rate for both buried and surface-placed residue through the first 28 days, after which the C:N ratio of the buried maize decreased at a faster rate than at the surface (Table 7). Sorghum sudangrass C:N ratio was initially 31:1 (Table 2) and so the rate of decrease was lower than for maize (Table 7). At 56 days, sorghum sudangrass C:N ratio was near 20:1 for both surface and sub-surface-placed residue.

Initial common bean C:N ratio was similar to that of maize (Figures 7 and 8) and the change in C:N ratio was similar as well. Burying bean residue resulted in a more rapid and overall greater decrease in C:N ratio compared to placing it on the surface (Table 7). Sunn hemp, the residue with the lowest C:N in our litterbag decomposition study exhibited the fastest decomposition rates when buried (Table 7) Abera et al. (2014) reported similar outcomes for pigeon pea and haricot bean, as pigeon pea had a lower C:N ratio and was also found to release N more rapidly. However, when sunn hemp residue remained on the soil surface, C:N ratio remained near 20:1 from day 14 through the duration of the study (Figure 8). More rapid decrease in C:N ratio over time for residues with low C:N ratios has been substantiated by numerous other researchers in laboratory and litterbag field analysis (Blagodatsky et al., 1998;

Fosu et al., 2007; Zhang et al., 2008; Abera, 2014). Similar to what was observed for mass loss and N mineralization of these residue samples, C:N ratio of most residues decreased over 112 days regardless of placement or residue quality.

CONCLUSIONS

Initial residue C:N affected C and N mineralization rates and mass loss for the residues we tested, with higher N concentration and narrower C:N ratio resulting in more rapid mass loss. This was expected based on previous research, and indicates that a legume with high N concentration is the ideal candidate cover crop for supplying N to a following crop. In our work, sunn hemp contained the highest N concentrations and released the most N to the system in the least time. Overall, burying residue resulted in much faster decomposition and N mineralization over the course of our study. In N-poor systems such as those in the Central Plateau, if the goal of a legume cover crop is to supply N to the succeeding crop, incorporating that cover crop into the soil with tillage will hasten decomposition and nutrient release. However, using tillage will likely increase soil erosion and nutrient depletion compared to no-tillage. We observed much slower overall mass loss when any of the residue types was left on the soil surface. This indicates that all would be somewhat effective in protecting soil from erosive effects of rainfall. However, those residues with high C:N ratio (grasses and weathered legume residue) will likely offer protection for a longer time. The continued utilization of legumes and beans in relay and intercrops along with the introduction of short-season cover crops could help to rebuild soil structure and increase SOM. In order to achieve both goals of keeping soil covered and increasing nutrient supply to other crops in the rotation it may be necessary to employ a combination of cover crops at different times in the rotations and to utilize cover crops over an extended period of time to improve the overall N status of the system.

REFERENCES

Abera, G., E. Wolde-Meskel and L. Bakken. 2014. Unexpected high decomposition of legume residues in dry season soils from tropical coffee plantations and crop lands. Agron. Sustain. Dev. 34: 667-676.

Abera, G., E. Wolde-Meskel and L. Bakken. 2012. Carbon and nitrogen mineralization dynamics in different soils of the tropics amended with legume residues and contrasting soil moisture contents. Biol. Fertility Soils 48:51-66.

Agenor, L. 1977. Note on maize research in Haiti. Nouvelles Agronomiques des Antilles et de la Guyane 3:525-534.

Badrie, N. 2007. Proceedings of the 26th West Indies Agricultural Economic Conference, Puerto Rico. 23-26 Jul. 2006. Caribbean Agro-Economic Society. St. Augustine, West Indies.

Baijukya, F. P., N. de Ridder and K. E. Giller. 2006. Nitrogen release from decomposing residues of leguminous cover crops and their effect on maize yield on depleted soils of Bukoba District, Tanzania. Plant Soil 279:77-93.

Balkcom, K. S., and D.W. Reeves. 2005. Sunn-hemp utilized as a legume cover crop for corn production. Agron J. 97: 26-31.

Baumann, D., T. L. Bastiaans and M.J. Kropff. 2001. Effects of intercropping on growth and reproductive capacity of late-emerging Senecio vulgaris L. with special reference to competition for light. Ann. Bot. 87:209-217.

Bessam, F. and R. Mrabet. 2003. Long-term changes in soil organic matter under conventional tillage and no-tillage systems in semiarid Morocco. Soil Use Manage. 19:139-143.

Blagodatsky, S. A., I.V. Yevdokimov, A.A Larionova, and J. Richter. 1998. Microbial growth in soil and nitrogen turnover: Model calibration with laboratory data. Soil Biol. Biochem. 30:1757-1764.

Brady, N. C, and R. Weil. 2008. The nature and properties of soils. Pearson Prentice Hall, Upper Saddle River, N.J.

Clark, A. 2007. Managing cover crops profitably. Handbook Series Book 9 (3rd ed.) Sustainable Agriculture Network, Beltsville, MD.

Cohen, M. 2010. Planting Now: Agricultural challenges and opportunities for Haiti's reconstruction. Oxfam, London, England

Cookson, W. R., M. H. Beare and P. E. Wilson. 1998: Effects of prior crop residue management on microbial properties and crop residue decomposition. Applied Soil Ecology 7:179-188.

Davies, B. E. 1974: Loss-on-ignition as an estimate of soil organic matter. Soil Sci. Soc. Am. J.

38:150-151.

Douglas, C.L. and R.W. Rickman. 1992. Estimating crop residue decomposition from air temperature, initial nitrogen content, and residue placement. Soil Sci. Soc. Am. J. 56:272-278.

Erlich, M., F. Conway, N. Adrien, F. LeBeau, L. Lewis and H. Lauwerysen. 1987. Haiti country environmental profile: a field study. USAID, Port-au-Prince, Haiti.

FAO. 2011. What is conservation agriculture? [Online]. http://www.fao.org/ag/ca/1a.html. (accessed 8 Jan. 2015).

Fosu, M., R. F. Kühne and P. L. Vlek. 2007. Mineralization and microbial biomass dynamics during decomposition of four leguminous residues. Am. J. Agric. Biol. Sci. 7: 632-637.

Franzluebbers, A. J. 2002. Water infiltration and soil structure related to organic matter and its stratification with depth. Soil Tillage Res. 66: 197-205.

Heal, O.W., J.M. Anderson and M.J. Swift. 1997. Plant litter quality and decomposition: a historical overview. p. 3–30, In: Cadish, G. & K.E. Giller, editors, Driven by Nature Plant Litter Quality and Decomposition. CAB International, New York, NY.

Holland, E. A., and D. C. Coleman. 1987. Litter placement effects on microbial and organic-matter dynamics in an agroecosystem. Ecology 68:425-433.

Hylkema, A. 2011. Haiti soil fertility analysis and crop interpretations in the five winner watershed zone of intervention. M.S. Thesis. University of Florida. Gainesville, FL

Ibewiro, B., N. Sanginga, B. Vanlauwe and R. Merckx. 2000. Nitrogen contributions from decomposing cover crop residues to maize in a tropical derived savanna. Nutr. Cycling Agroecosyst. 57, 131-140.

JMP® Pro, Version 11. 2013. SAS Institute, Cary, NC, 1989-2007.

Karpenstein-Machan, M., and R. Stuelpnagel. 2000. Biomass yield and nitrogen fixation of legumes monocropped and intercropped with rye and rotation effects on a subsequent maize crop. Plant Soil 218:215-232.

Lal, R., 2004. Soil carbon sequestration impacts on global climate change and food security. Science 304:1623-1627.

Maguire, R. and S. Heckendorn. 2011. Laboratory procedures: Virginia Tech Soil Testing Laboratory. VA Cooperative Extension Publication #452-881. Virginia Cooperative Extension, Blacksburg, VA.

MARNDR (Ministre de l´Agriculture des Ressources Naturelles et du Développement Rural). 2010. Agricultural Development Politics 2010-2025. Ministry of Agriculture, Natural Resources and Rural Development. Port-au-Prince. Haiti

Mehlich, A. 1976. New buffer pH method for rapid estimation of exchangeable acidity and lime requirement of soils. Commun. Soil Sci. Plant Anal. 7:637-653

McClintock N. 2004. Regenerative agriculture for Haiti's Central Plateau - A sustainable foundation for food and nutrition security, Zanmi Lasante, Paris.

Mulvaney, M.J., C.W. Wood, K.S. Balkcom, D.A. Shannon, and J.M. Kemble. 2010. Carbon and nitrogen mineralization and persistence of organic residues under conservation and conventional tillage. Agron. J. 102:1425-1433.

Murungu, F. S., C. Chiduza, P. Muchaonyerwa and P. N. S. Mnkeni. 2011. Decomposition, nitrogen and phosphorus mineralization from winter-grown cover crop residues and suitability for a smallholder farming system in South Africa. Nutr. Cycling in Agroecosyst. 89:115-123.

Njunie, M. N., M. G. Wagger, and P. Luna-Orea. 2004. Residue decomposition and nutrient release dynamics from two tropical forage legumes in a Kenyan environment. Agron. J. 96:1073-1081.

Ogle, S. M., A. Swan and K. Paustian. 2012. No-till management impacts on crop productivity, carbon input and soil carbon sequestration. Agric. Ecosyst. Environ. 149:37-49.

Olsen, S.R., C.V. Cole, F.S. Watanabe and L.A. Dean. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circular 939. U.S. Government Printing Office, Washington D.C.

Ono, K., K. Hirai, S. Morita, K. Ohse and S. Hiradate. 2009. Organic carbon accumulation processes on a forest floor during an early humification stage in a temperate deciduous forest in Japan: Evaluations of chemical compositional changes by13C NMR and their decomposition rates from litterbag experiment. Geoderma 151: 351-356.

Pansu, M. and J. Gautheyrou. 2007. Handbook of soil analysis: mineralogical, organic and inorganic methods. Springer Science and Business Media, New York, NY. p.926-927.

Perin, A., R.H.S. Santos, S.S. Urguiagal, P.R. Cecon, J.G.M Guerra and G.B. de Freitas. 2006. Sunnhemp and millet as green manure for tropical maize production. Scientia Agricola 63:453-459

Karpenstein-Machan, M., and R. Stuelpnagel. 2000. Biomass yield and nitrogen fixation of legumes monocropped and intercropped with rye and rotation effects on a subsequent maize crop. Plant Soil 218:215-232.

Rotar, P.P., and R.J. Joy. 1983. 'Tropic Sun' sunn hemp, Crotalaria juncea L. research. Extension Series 036 University of Hawaii, Honolulu, HI.

Roth, C. H., B. Meyer, H. G. Frede and R. Derpsch. 1988: Effect of mulch rates and tillage systems on infiltrability and other soil physical properties of an Oxisol in Paraná, Brazil. Soil Tillage Res. 11:81-91.

Salinas-Garcia, J. R., J. R. Salinas-Garcia, J. E. Matocha and F. M. Hons. 1997. Long-term tillage and nitrogen fertilization effects on soil properties of an Alfisol under dryland corn/cotton production. Soil Till Res. 42:79-93.

Stewart, R. E. 2012: Physical and Chemical Parameters of Common Soils in the Central Plateau Region of Haiti. M.S. Thesis. Virginia Polytechnic Institute and State University. Blacksburg, VA.

Thippayarugs, S., T. Banyong, V. Patma, L. Viriya, P. Aran, and C. Georg. 2008. Interactions in decomposition and N mineralization between tropical legume residue components. Agroforest Syst. 72:137-148.

Thomas, R.J., and N.M. Asakawa. 1993. Decomposition of leaf litter from tropical forage grasses and legumes. Soil Biol. Biochem. 25:1351-1361.

Uri, N.D. 1999. Factors affecting the use of conservation tillage in the United States. Water Air Soil Pollut. 116:621–638.

Voigt, S., T. Schneiderhan, A. Twele, M. Gahler, E. Stein, and H. Mehl. 2011. Rapid damage assessment and situation mapping: learning from the 2010 Haiti earthquake. Photogramm. Eng. Remote Sens. 77: 923-931.

Walters, K. R., A.G. Korick and M.J.Vojtesak. 1989. The Caribbean basin: a climatological study. Air Force Environmental Technical Applications Center. Scott AFB, IL.

Wang, Q., L. Yuncong, K. Waldermar and H. Zafar. 2007. Influence of cover crops and soil amendments on okra (Abelmoschus esculentus L.) production and soil nematodes. Renew. Agric. Food Syst. 22:41-53.

White, T. A. and J. L. Jickling. 1995. Peasants, experts, and land use in Haiti: Lessons from indigenous and project technology. J. Soil Water Conserv. 50:7-14.

Zhang, D., H. Dafeng, L. Yigi, and Z. Guoyi. 2008. Rates of litter decomposition in terrestrial ecosystems: global patterns and controlling factor. J. Plant Ecol. 1:85-93.

TABLES

Table 1. Initial physical and chemical parameters for soil (0-15cm) at the Corporant experimental site, 2013.

pH[†]	NO_3-N[‡]	NH_4-N[‡]	Total N	Phosphorus[¶]	Potassium[#]	Magnesium	Calcium	Cation Exchange[#]	Organic Matter[§]	Sand	Silt	Clay
		----------------------------mg kg^{-1} ---------------------------						meq $100g^{-1}$	%	-------------%-------------		
7.4	2.1	1.8	1412	12	87	328	5438	30	1.6	41	38	21

[†] 1:1 soil water

[‡] NH4-N and NO3-N: 2 M KCL; automated flow injection analysis.

[¶] $NaHCO_3$ extraction

[#] Mehlich 1 extraction

[§] Loss on ignition

Table 2. Initial nitrogen (N) and carbon (C) content and C:N ratio for plant residues used in the litterbag decomposition study.

Residue	N	C	C:N
	------%------		
Maize	0.65	36.69	56.5
Sorghum sudangrass	1.09	34.26	31.3
Common bean[†]	0.64	34.83	54.2
Sunn hemp	1.23	36.92	30.1

[†] Common bean residue was weathered post-harvest.

Table 3. Mean temperature and cumulative monthly rainfall, Corporant, Haiti, May to September, 2013.

Month	Rainfall	Mean Temperature
	----mm----	----C----
May	632	26.1
June	435	26.5
July	233	26.9
August	416	27.1
September	308	26.8

Table 4. Regression equations and statistics for residue mass loss, on a percent dry weight basis, over 112d, where X = time in days after application.

Residue species and placement	Equation	RMSE[†]	R^2
Maize, buried	$y = 66.65e^{-0.0123x} + 33.35e^{-17.3890x}$	6.214	0.974
Maize, surface	$y = 100e^{-0.006x}$	5.152	0.939
Sorghum sudangrass, buried	$y = 100e^{-0.026x}$	6.806	0.940
Sorghum sudangrass, surface	$y = 100e^{-0.007x}$	9.476	0.665
Common bean, buried	$y = 100e^{-0.012x}$	7.873	0.915
Common bean, surface	$y = 100e^{-0.004x}$	6.777	0.609
Sunn hemp, buried	$y = 52.30e^{-0.0079x} + 47.70e^{-0.3136x}$	3.742	0.990
Sunn hemp, surface	$y = 63.44e^{-0.0001x} + 37.76e^{-0.0306x}$	7.932	0.863

[†] Root mean square error

Table 5. Regression equations and statistics for change in mass of residue N remaining over 112d, where X = time in days after application.

Residue species and placement	Equation	RMSE[†]	R^2
Maize, buried	$y = 0.03e^{-0.0010x} + 0.03e^{-1.0601x}$	0.007	0.910
Maize, surface	$y = 0.36e^{-0.0069x} + 0.02e^{-22.3816x}$	0.003	0.976
Sorghum sudangrass, buried	$y = -0.20 + 0.28e^{-0.0022x}$	0.012	0.829
Sorghum sudangrass, surface	$y = 0.05e^{-0.0055x} + 0.02e^{-0.6272x}$	0.003	0.978
Common bean, buried	$y =0.02 + 0.02e^{-0.0210x}$	0.005	0.799
Common bean, surface	$y =0.03 + 0.02e^{-0.0236x}$	0.004	0.793
Sunn hemp, buried	$y = 0.05e^{-0.0087x} + 0.07e^{-0.3640x}$	0.015	0.916
Sunn hemp, surface	$y =0.04 + 0.09e^{-0.0561x}$	0.007	0.972

[†] Root mean square error

Table 6. Regression equations and statistics for change in mass of residue C remaining over 112d, where X = time in days after application.

Residue species and placement	Equation	RMSE[†]	R^2
Maize, buried	$y = 0.03e^{-0.0010x} + 0.03e^{-1.0601x}$	0.007	0.910
Maize, surface	$y = 0.36e^{-0.0069x} + 0.02e^{-22.3816x}$	0.003	0.976
Sorghum sudangrass, buried	$y = -0.20 + 0.28e^{-0.0022x}$	0.012	0.829
Sorghum sudangrass, surface	$y = 0.05e^{-0.0055x} + 0.02e^{-0.6272x}$	0.003	0.978
Common bean, buried	$y =0.02 + 0.02e^{-0.0210x}$	0.005	0.799
Common bean, surface	$y =0.03 + 0.02e^{-0.0236x}$	0.004	0.793
Sunn hemp, buried	$y = 0.05e^{-0.0087x} + 0.07e^{-0.3640x}$	0.015	0.916
Sunn hemp, surface	$y =0.04 + 0.09e^{-0.0561x}$	0.007	0.972

[†] Root mean square error

Table 7. Regression equations and statistics for change in residue C:N ratio over 112d, where X = time in days after application.

Residue species and placement	Equation	RMSE[†]	R^2
Maize, buried	$y = 35.04e^{-0.0040x} + 20.94e^{-0.0579x}$	2.184	0.985
Maize, surface	$y = 40.56e^{-0.0020x} + 14.66e^{-0.0586x}$	2.335	0.961
Sorghum sudangrass, buried	$y = 21.44e^{-0.0021x} + 10.03e^{-0.3034x}$	1.209	0.969
Sorghum sudangrass, surface	$y = 31.27 - 0.2126x$	1.411	0.944
Common bean, buried	$y = 21.88 + 32.50e^{-0.0283x}$	8.769	0.734
Common bean, surface	$y = 17.26 + 41.10e^{-0.0093x}$	2.235	0.966
Sunn hemp, buried	$y = 11.04e^{-0.0623x} + 21.85e^{-0.0048x}$	7.306	0.670
Sunn hemp, surface	$y = 20.26e^{-0.0006x} + 9.98e^{-0.3873x}$	1.418	0.939

[†] Root mean square error

FIGURES

Figure 1. Buried and surface-placed maize and sorghum sudangrass residue mass loss (dry weight basis) over 112d.

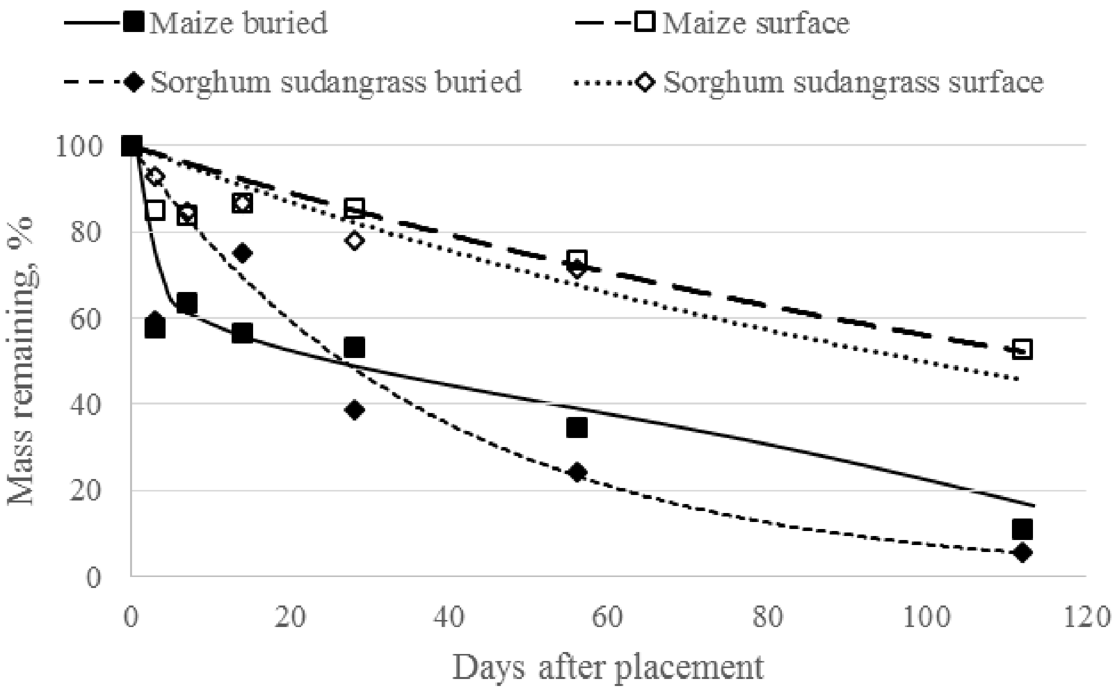


Figure 2. Buried and surface-placed common bean and sunn hemp residue mass loss (dry weight basis) over 112d.

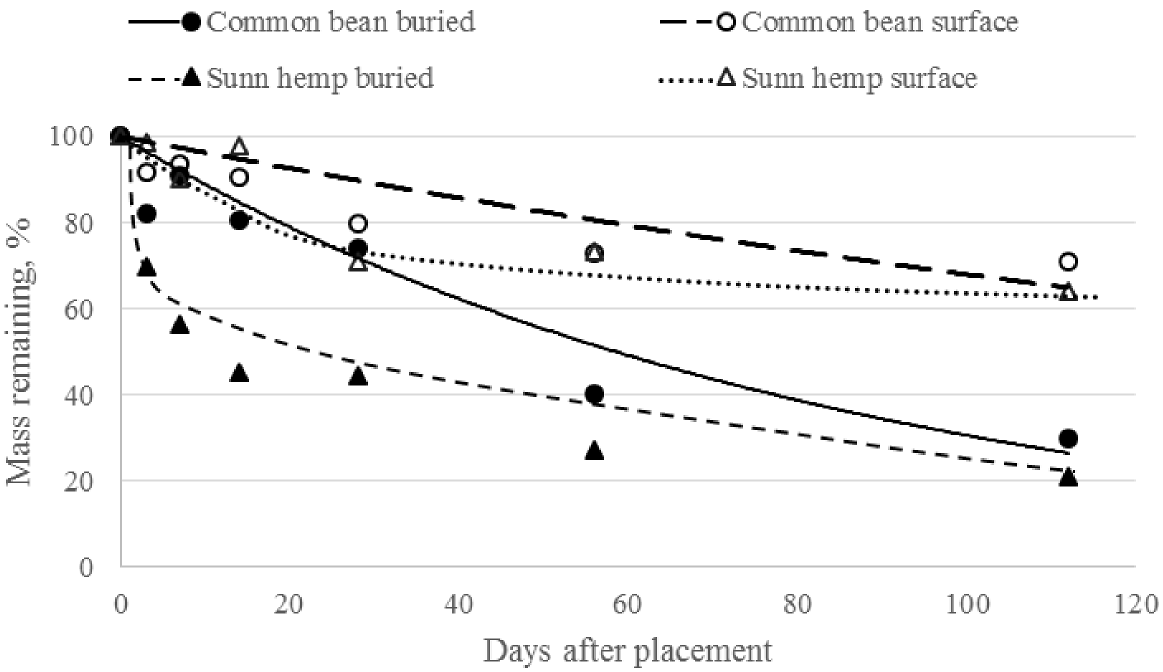


Figure 3. Net N mineralization from buried and surface-placed maize and sorghum sudangrass residue over 112d.

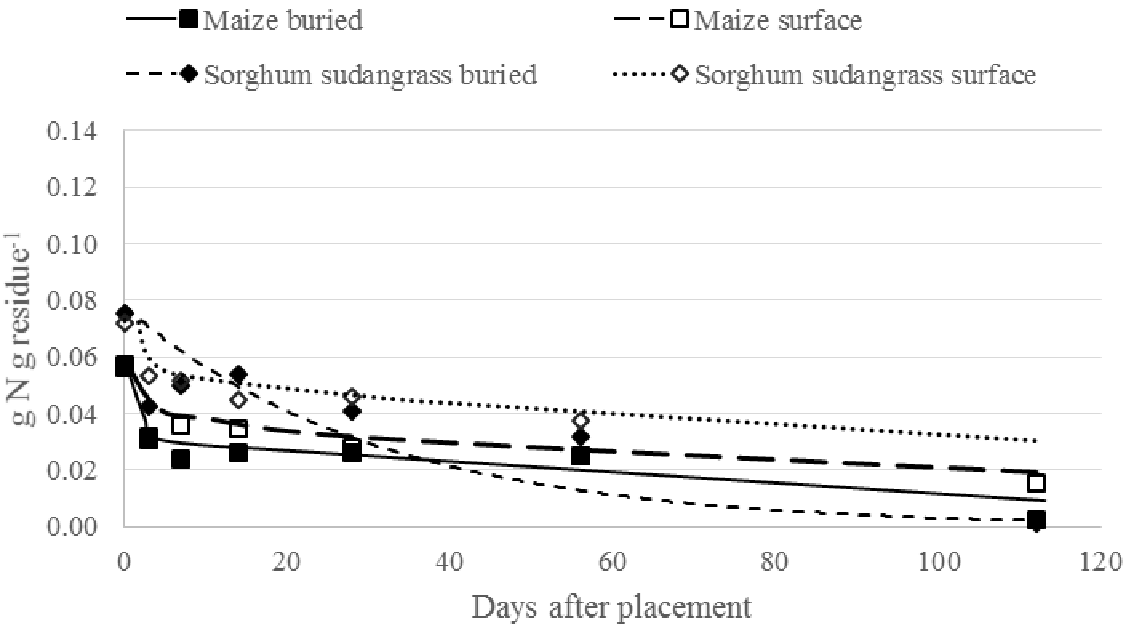


Figure 4. Net N mineralization from buried and surface-placed common bean and sunn hemp residue over 112d.

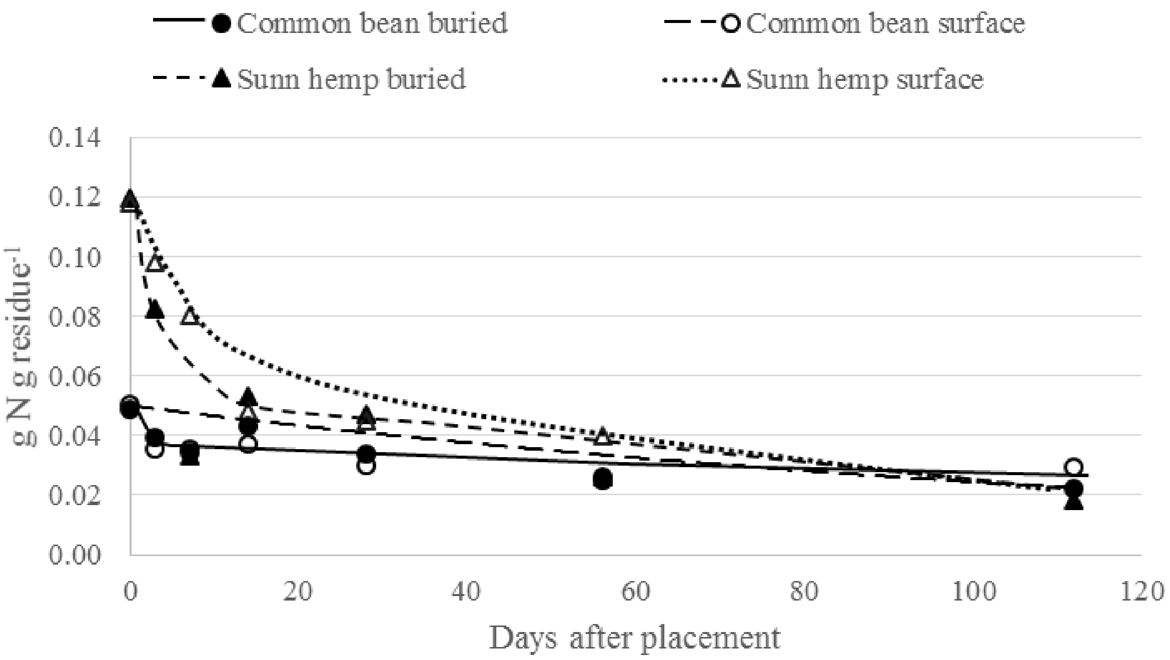


Figure 5. Net C mineralization from buried and surface-placed maize and sorghum sudangrass residue over 112d.

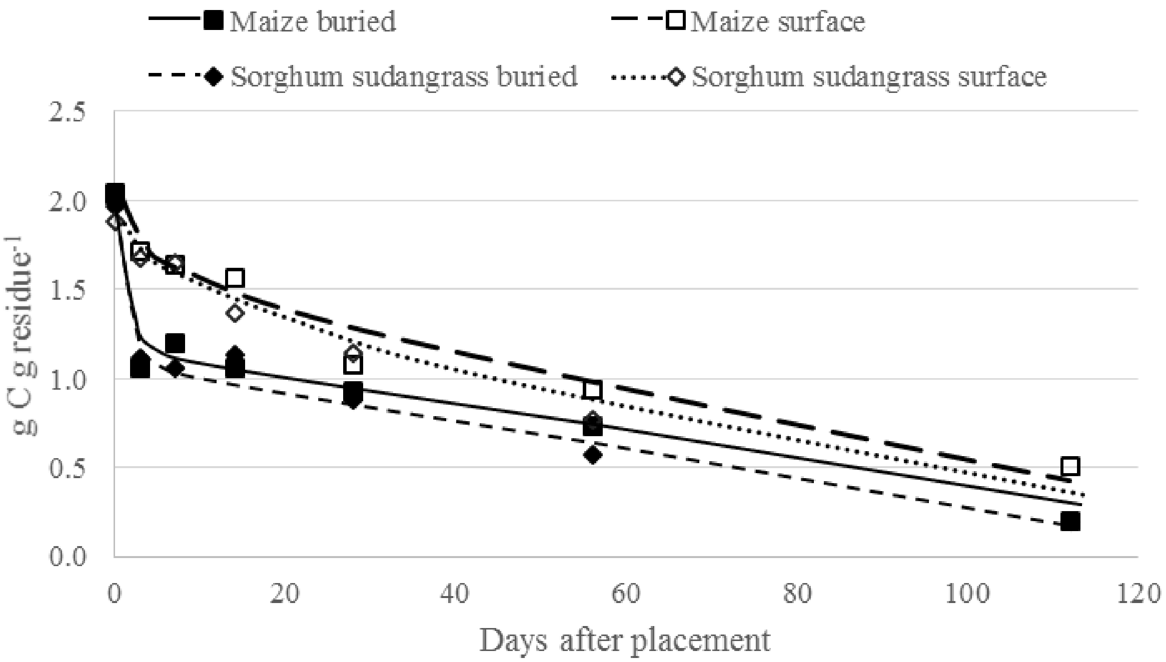


Figure 6. Net C mineralization from buried and surface-placed common bean and sunn hemp residue over 112d.

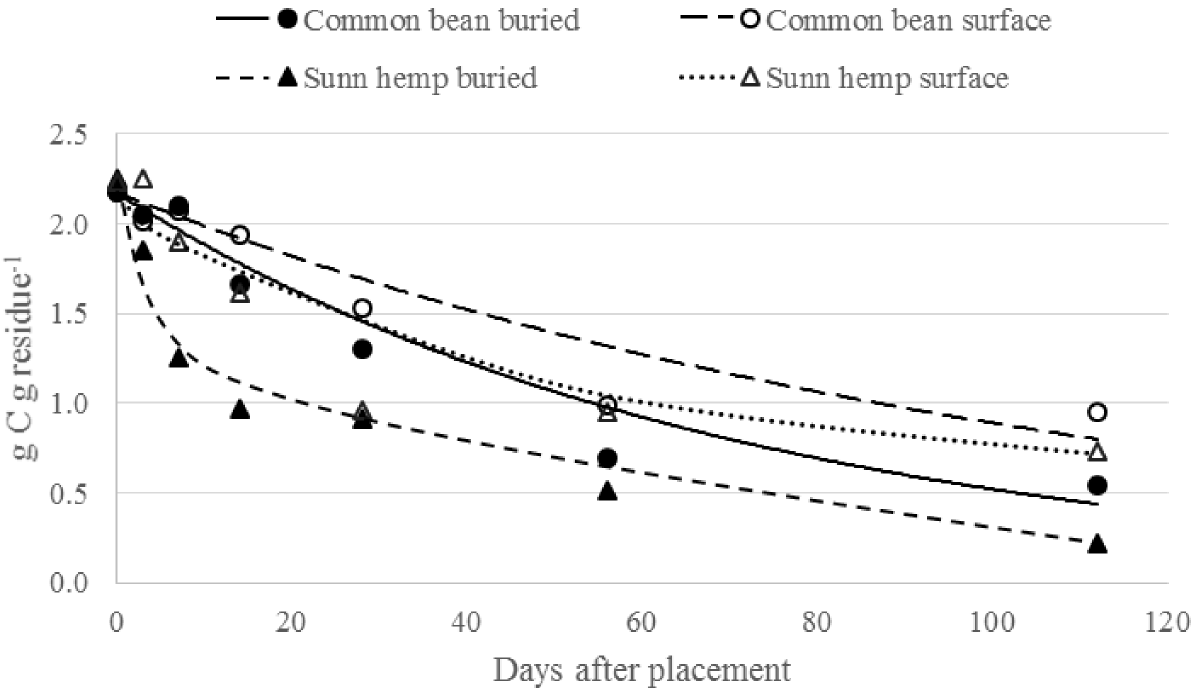


Figure 7. Buried and surface-placed maize and sorghum sudangrass residue C:N ratio over 112d.

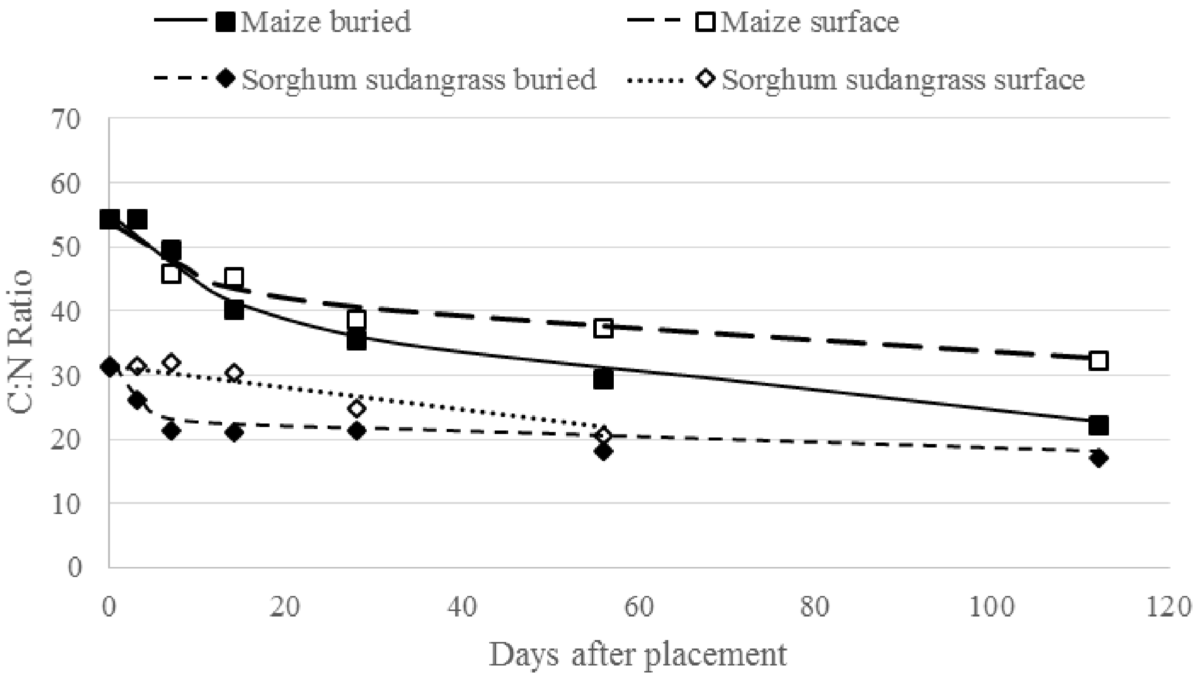
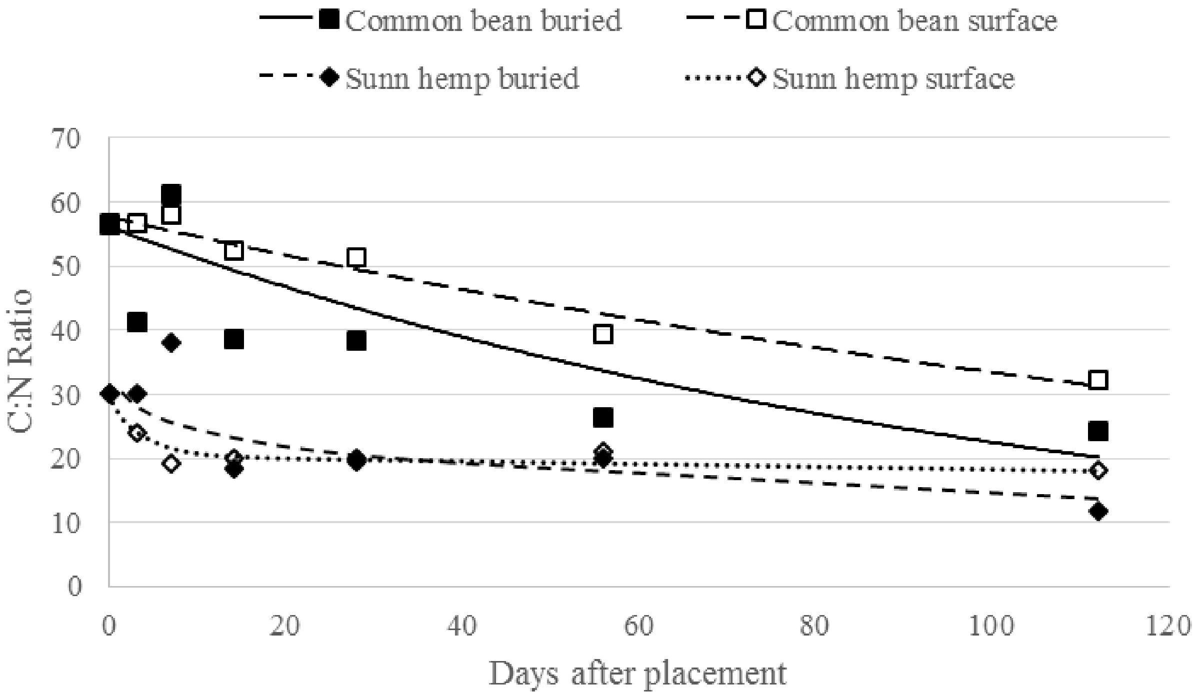


Figure 8. Buried and surface common bean and sunn hemp residue C:N ratio over 112d.



CHAPTER III-.DEVELOPMENT AND VALIDATION OF A MICROLYSIMETER INCUBATION CHAMBER FOR IN-VITRO ESTIMATES OF PLANT RESIDUE CARBON AND NITROGEN MINERALIZATION RATES

ABSTRACT

Accurate and inexpensive in-vitro techniques to estimate plant residue decomposition and nutrient mineralization could allow researchers to make more rapid and accurate estimates of these parameters under highly controlled conditions, but no commercially-available system currently exists. To that end, four common agricultural soils in Virginia of varying texture were aerobically incubated in Zenpure PureFlo® filter cups with a charged 0.45 micron nylon filter base in a full factorial structure with either surface-placed or buried maize (*Zea mays* L.) or alfalfa (*Medicago sativa* L.) residues. To assess treatment effects over time, samples were removed and analyzed on days: 0, 3, 7, 14, 28, 56, 84 and 112. The precision of detection of carbon (C) evolution collected from headspace within the microlysimeter chambers was insufficient to reliably detect differences at the C levels measured among the treatments evaluated in this study. While the relative amounts of NO_3^- and NH_4^+ in leachate did increase over the initial 28 days of sampling, no trends due to treatment were evident. Nor were there consistent differences in nitrogen (N) mineralization due to the type of residue used, though the difference in C:N ratio between the alfalfa and maize suggests that greater N immobilization with maize should have likely occurred. These inconsistencies and the relative lack of precision experienced with these units indicates that prior to adoption, further experimentation and development is needed.

INTRODUCTION

Since all heterotrophs degrade organic matter to satisfy their energy requirements, measurement of CO_2 evolution is considered a good indicator of overall biological activity of soil and this respiration can be quantified (Mondini et al., 2010). Upon organic matter addition to a soil, "heterotrophic zymogeneous microorganisms become active, multiply rapidly, and yield carbon dioxide in large quantities" (Brady and Weil, 2008). Because of this relationship, upon substrate addition, CO_2 levels will increase during the initial stages of mineralization, decrease during prolonged immobilization, and eventually increase again in response to N re-mineralization (Abera et al., 2012; Isaac and Nair, 2005; Rochette et al., 1997). These patterns of respiration and nutrient mineralization have been demonstrated in numerous studies involving different substrate supply, soil moisture, soil texture, and temperature (Blagodatsky et al., 1998; Chen and Stark, 2000; Ding et al., 2007; Isaac and Nair, 2005).

Controlled soil incubation studies conducted in vitro most commonly utilize closed chamber systems with an alkali trap (Rochette et al., 1997) because this is generally the most cost effective means of obtaining respiration measurements. Upon removal of the alkali trap, a titration with $BaCl_2$ is conducted. The trap is then back-titrated with HCl to a phenolphthalein endpoint that is relative to the amount of CO_2 evolved over the duration of incubation (Haney et al., 2008). However, Rochette et al. (1997) note the following factors which may compromise the accuracy of flux estimations by alkaline traps: "inadequate absorption efficiency of the alkali solution, oxygen depletion of the chamber and soil atmosphere, lack of air turbulence and modification of soil temperature and moisture regimes during exposure." Bekku et al. (1997) conducted a comparison of three primary types of respiration measurement methods including an infrared gas analyzer (IRGA), a closed chamber method (CCM), and a closed dynamic chamber method (CDCM), with an alkali trap control where amounts of estimated glucose oxidized and respired over 10 days were measured. The alkali adsorption method estimates were 1.3 times greater than the other three methods. Freijer and Bouton (1991) compared closed chamber methods with dynamic CO_2 adsorption and alkali adsorption methods also reported alkali adsorption as least accurate, with underestimation in their case. Better results have been found with a system that circulates air through the chamber after scrubbing with a caustic alkaline solution (Bekku et al., 1997; Freijer and Bouton, 1991; Haney et al., 2008).

Norman et al. (1997) compared the following four apparatus types for measuring soil surface CO_2 fluxes: (1) a closed dynamic chamber; (2) a closed static chamber; (3) an open chamber; and (4) eddy correlation flux. Magnitude of variability over all sites and apparatuses were compared to values from a reference system, a CDCM utilizing IRGA. The standard deviation used to calculate the CV was contrived from 8-16 observations from the reference system at each site with standard error averaging 8%. Critical values were found to range from 10-20% with overall uncertainty in results estimated between 10-15%. In the development of a simplified method for measuring microbial respiration of incubated soils, Cheng and Coleman (1989) used a dynamic air flow technique with alkali traps. Results were calibrated against values determined by IRGA and with the detection level of the proposed apparatus (40 µg) significantly higher than that of the IRGA (0.31 µg). However, after incorporating larger incubation flasks the method was deemed adequate for routine soil respiration measurements.

While evaluations of tools that enable the measurement of soil C respiration exist, there is a dearth of material describing systems that can measure both C and N mineralization in a soil ecosystem. Therefore, the intent of the devised apparatus was to create a CDMC to measure C mineralization in conjunction with concurrent measurements of N mineralization rates in incubated soil and residues. Along with the need for continual respiration measurement there coexists a lack of cost-effective and commercially available units for sampling. The Nadelhoffer (1990) procedure details a dual chamber microlysimeter system that enables incubated soil to be both leached for soil N, and receives closed system alkali scrubbed airflow for a CO_2-free chamber before extraction. However the component parts detailed in that method are no longer commercially available, leading to our development of a new unit to simultaneously estimate C and N mineralization.

Despite the limitations of procedures designed to estimate soil respiration rates, there is still value in respiration measurements for estimating the decomposition rates of plant residues in soil. For instance, Stanford and Smith (1971) first used soil incubation to compare soil N mineralization to N mineralizable substrate and demonstrated that the forms of organic N contributing to mineralizable N were similar for most of the 39 soils compared in the study. Blagodatsky et al. (1998) developed a model of microbial respiration from incubation data that agreed well with experimental data on microbial growth in seven different pools of C and N. The fraction of total variation explained by the model was in the range 0.92–0.985 (R^2) for the different variants of the experiment. The overall most beneficial use of soil incubation studies is the ability to examine isolated effects and interactions of soil nutrient mineralization, while eliminating many of the extraneous factors of a natural system.

Inexpensive, custom microlysimeter units constructed so that CO_2 evolution and N mineralization could be measured from in-vitro soil:residue samples over time. The proposed microlysimeter apparatus comprised primarily of inexpensive PVC piping does not have to be transported to the field for sample collection like the IRGA chambers and employs dynamic chamber circulation, which has improved accuracy compared to traditional alkaline trap methods.

MATERIALS AND METHODS

Microlysimeter units

The microlysimeter units were composed of 10.2 cm diameter PVC piping cut to a height of 15.2 cm to allow ample headspace for air mixing. The base of the cut PVC was next inserted into a 10.2 cm PVC flat cap and sealed with PVC glue and primer. Two 2.54 cm plastic spigots were then inserted into the front and back of the unit. Screw caps for 10.2 cm PVC were drilled and a 9mm septa installed and sealed with silicon glue before being screwed tightly in place after the cup of soil was placed within. A manifold provided regulated air flow from the manifold nipple into each chamber via 45.7 cm of 0.95 cm^3 plastic tubing affixed to the plastic spigot (Figure 1). Carbon dioxide-free air was passed through a 0.1 M NaOH solution and was distributed via the manifold into the headspace above the soil in each closed PVC microlysimeter unit. The second plastic spigot was left open to expel ambient air from the container, and after a minimum of three minutes of continual flow with carbon dioxide-free air, both spigots were closed, forming an airtight seal. After construction and soil additions, approximately 177 cm^3 of headspace remained for gas sampling and air mixing.

Soil

Four common agricultural soils in Virginia of varying texture, a Groseclose clay loam (GCL), Braddock and Unison silt loam (BUSL), a Bojac sandy loam (BSL), and a Davidson clay soil (DC) were used to assess repeatability and accuracy of CO_2 and inorganic N estimates over time. Both the GCL and BUSL soils were collected from Virginia Polytechnic Institute and State University's Kentland Farm near Blacksburg, VA from no-till continuous maize (Zea mays L.) cropping systems. The BSL soil was collected from agricultural land in the Coastal Plain of

Virginia under a no-till maize, soybean (*Glycine max* L.), vetch (*Vicia villosa* Roth) cover crop cropping system. The DC was collected from the Virginia Tech Northern Piedmont Center near Orange, VA that had been in a no-till maize and soybean rotation. Physical and chemical parameters for each soil are presented in Table 1. Soil pH was determined using a 1:1 (vol/vol) soil-water mix. Soil organic matter was estimated using the loss on ignition method (LOI) (Blue M Ultra-Temp, Blue M, White Deer, PA) paired with inductively coupled plasma atomic emission spectroscopy (ICP) where a gravimetric, dry oxidation method is used to estimate the soil organic matter content for all samples (Davies, 1974; Pansu and Gautheyrou, 2007). Estimated sum of cations was determined using Mehlich 1 extractable bases, or non-acid generating cations (Ca, Mg and K), plus the acidity estimated from the Mehlich soil-buffer pH after conversion of all analytical results to meq/100 cm3 or cmol(+)/kg (Maguire, and Heckendorn, 2011; Mehlich, 1976). After collection, all soils were air dried, passed through a 2mm sieve, and wetted to 70% water holding capacity prior to initiation of the incubations.

Residue

Residue, as either maize or alfalfa was added at a rate of 0.0336 g residue 50g soil^{-1}, which is equivalent to 1 Mg ha^{-1} with residue either placed on the soil surface or mixed with soil in order to represent a tilled or no-tilled system, respectively. Alfalfa residue was collected in May, 2013 from a vegetatively growing production field. Maize residue was also collected in May and had overwintered in the field from the fall, 2012 harvest. Initial carbon and nitrogen values of the maize and alfalfa residues are presented in Table 2 and C:N ratios were 17:1 and 71:1 for alfalfa and maize, respectively.

Wetted soils and residue were weighed and placed into 175 ml Zenpure PureFlo® filter cups with a charged 0.45 micron nylon filter base in a completely random design with treatments of soil, residue type and residue placement, by date, and incubated at 30 °C in a temperature-controlled growth chamber at 80% relative humidity. Initial unit weights with wetted residue and soil were recorded so that samples could be maintained at 70% WHC for the duration of the incubation. At days 0, 3, 7, 14, 28, 56, 84, and 112 after initiation, appropriate units were removed from the controlled environment chambers and analyzed. Each soil and residue combination was replicated five times on each sample date for a total of 640 CIM units.

Sampling

Soil and residue leaching

At the indicated sampling intervals, filter cup units were removed from the controlled environment chamber, and individually attached to a PureFlo® filter cup base with stopper size five affixed to a 125 mL Erlenmeyer flask, and the hose barb attached to a vacuum calibrated to 0.6 Mpa. Each cup was leached using 100 mL of 0.1 M CaCl2 to simulate natural rainfall and left 30 minutes to leach by gravity before vacuum pressure was applied to complete extraction of ammonium and nitrate (Nadelhoffer, 1990). Extracted leachate was next analyzed by modification of Quick Chem Methods 12-107-04-1G for soil nitrate, and Method 12-107-06-3A for soil ammonium on the Lachat QuickChem 8500 (Lachat Instruments, Loveland, CO).

Carbon dioxide sampling

After leaching, cups were placed within the specifically constructed CIM units. After one hour, 25 mL of air was extracted from the sealed chambers' headspace and injected into a 20 mL evacuated vial (Nadelhoffer, 1990). Air sample CO_2 concentration was then determined using gas chromatography (Shimadzu Gas Chromatography GC-201 Greenhouse Gas Analyzer) modified with a CO_2 splitter (Shimazdu Scientific Instruments, Mandel, CA). The instrument has a CO_2 detection limit of 0.07 g C kg soil hr^{-1}. At the initiation of each run, three randomized blank samples were drawn from evacuated, empty CIM units to ensure that samples were truly free of CO_2 prior to beginning the sampling period.

Experimental design and statistical analysis

The experiment used a completely random design with a full factorial of soil by residue by placement treatments with five replications and eight removal dates. Simple statistics including sample mean, standard deviation, and coefficient of variation (CV) were used to compare the precision of the microlysimeter units over soils, residues, and residue placement.

The GLMMIX procedure available from SAS was used to conduct analysis of variance with soil, residue, date, and placement considered fixed effects and replication considered a random effect. A protected Least Significant Difference (LSD) procedure ($p<0.05$) was used to determine significant differences in leachate NO_3^- and NH_4^+ and CO_2 concentration among soils, residues, and placements at each sampling date. Regression was used to evaluate the rate of change in CO_2 evolution over sampling periods.

RESULTS AND DISCUSSION

Carbon evolution

Initial evaluation of precision of measurement of C evolution measured in the CIM units is presented in Table 3. Coefficient of variation ranged from six to 52% over sampling dates and treatments with a mean of 24%. There did appear to be a strong relationship between the relative magnitude of the measured values and error. As a percentage of the confidence interval range, the mean represented between 200 and 17% of that value with an average of 90%. Nadelhoffer (1990) reported a range in CV of one to 19% for CO_2 in that work and concluded that the precision of the system was adequate. Our values are higher than those reported to be acceptable in most instances in the literature.

The measured amount of C evolved was impacted by a three-way interaction of soil series, residue and placement on days 3, 28, 56, and 112 after initiation while only soil by residue and soil by placement interactions were significant on days 0, 7, and 84. The latter results will be discussed first. On day 0, C evolution was lower for the Groseclose soil with buried residue and Davidson soils regardless of placement, compared to other treatments (Table 4). The trend reversed on days 7 and 84 with the greatest C evolution from the Davidson soil with surface-placed residue (Table 4). A similar lack of a consistent trend for C evolution was observed by residue type and soil (Table 5). On day 0, the greatest C evolution was measured with surface-placed residue on both the Braddock and Bojac soils. On day 7, C evolution was lowest for the Braddock soil regardless of placement and surface-placed residue on the Groseclose soil (Table 5). By day 84, the greatest C evolution was measured from the Davidson soil regardless of placement, though surface-placed residue C evolution was similar to several other treatment combinations (Table 5).

Very few differences in C evolution were on day 3 (Table 6) which was not unexpected. Other researchers have also reported an initial delay in C evolution in laboratory studies with previously dried samples (Haney et al., 2008) though Blagodatsky et al. (1998) indicate that microbial activity is often restored with a few days of rewetting. Greater treatment differences were observed in later dates, but no consistent trends of soil by residue by placement treatments were observed as time progressed (Tables 6 and 7). This is in contrast to the reports of Abera et al. (2012) who found that legume residues with smaller C:N ratio produced more rapid and greater overall release of CO_2.

Nitrate in leachate

Similar to what was observed with C evolution, the ability to separate effects of soil, residue, and placement treatments on leachate nitrate concentration was inconsistent (Table 8). The overall trend for mean nitrate concentration in leachate did increase from day 0 to 28, then decrease (Table 8). This trend is to be expected as microbial activity is initially slow, followed by more rapid residue decomposition, then a period of maintenance or decline as the C source is exhausted (Blagodatsky et al., 2008). Initial leachate nitrate concentration for alfalfa was approximately 3.2 kg ha^{-1} when averaged over all treatments and values for alfalfa buried in Davidson soil was lower than surface-placed alfalfa on Groseclose, Braddock, and Bojac soils and buried residue in the Braddock soil (Figure 2). On day three, nitrate values in leachate were lowest for the Bojac soil, compared to all other treatments. This may be due to the coarser texture of the Bojac resulting in lower mineralization rates, similar to the results predicted by Blagodatsky et al. (1998). Due to equipment malfunction, values for four treatments were unavailable on day seven. Overall nitrate in leachate on days 14 and 28 was loweest for alfalfa placed on the surface of Davidson soil on day 14 (3.3 kg ha^{-1}) and for alfalfa buried in the Davidson soil on day 28, though this value was similar to the Bojac soil regardless of placement (Figure 2). By the end of the study period, no differences in nitrate concentration were detected among treatments. Overall leachate nitrate values averaged 5.4 and 5.2 kg nitrate ha^{-1} for maize and alfalfa over the course of the study (Figure 3). Similar to the trends with alfalfa, nitrate from soil plus maize residue increased up to 28 days after study initiation, then declined. Overall, there were differences in nitrate in leachate from maize residue among treatments, especially on days 14, 28, and 84, though no consistent influence of treatment on nitrate concentration was observed (Figure 3). This is contrary to the findings of Groffman et al. (1987) who reported greater leaching with legume residue incorporation with tillage, however their work represents a broader timeframe and range in temperature, moisture, etc.

Ammonium in leachate

Coefficient of variation for ammonium concentration ranged from four to 169% over soils, residue and placement (Table 9). In the case of ammonium, there did appear to be a relationship between the magnitude of measured values and error. At very low levels the relative error was typically greater than when mean ammonium values were higher (Table 9). This in not unexpected as smaller discrepancies or errors are often magnified with very low mean values.

There were no differences in ammonium concentration in leachate from alfalfa residue for any soil or placement on day zero, but levels for Braddock and Groseclose soils were greater than Bojac or Davidson soils on day three (Figure 4). Ammonium concentration was higher on day 7 for the Bojac soil, regardless of alfalfa residue placement and then declined thereafter (Figure 4). On day 14, alfalfa residue resulted in greater leachate ammonium when placed on the surface of the Davidson soil but this declined by the next sampling period. There were no differences among treatments on the sampling periods for 84 and 112 days after study initiation (Figure 4). For maize residue, the highest ammonium concentration on day zero was measured from maize residue placed on the surface of the Bojac soil (Figure 5). By day 3, the amount of ammonium was similar between the Braddock and Groseclose soils, with no effect of maize residue placement, and both were higher than the other two soils tested. On day 28, maize residue placed on the surface of Braddock soil resulted in greater ammonium in leachate than the other treatments followed by maize buried in the Braddock soil (Figure 5). Higher ammonium concentration in leachate for these two treatment was also observed on day 56, though no differences were detected thereafter (Figure 5). This is in contrast to the results of Abera et al.

(2012) and the general trends reported for decomposition of crop residues with relatively low N concentration (Beaton and Nelson, 2005) where once trends among treatments were established, those differences continued.

CONCLUSIONS

Overall, we observed few, and mostly inconsistent, treatment effects on C evolution and NO_3 and NH_4 in leachate with the prototype microlysimeters. While there as a trend toward increasing, then decreasing C evolution with time, we detected very few consistent differences due to the treatments we imposed. This likely indicates that these units will be unable to reliably estimate small relative changes in C evolution from varying residue C sources.

Based on the relative initial C:N ratio of the maize and alfalfa, faster decomposition with less N immobilization was expected for alfalfa. This was not observed as similar trends in N mineralization were found for both residue types. The expected initial decline in available N in these soils in response to microbial immobilization, followed by increased availability of NO_3 for maize residue was not observed either. It is likely that either there were unmeasured N losses from the system or that the soil extraction with weak salt solution was ineffective.

Further work to refine the prototype microlysimeter and the techniques for use is necessary before adoption is recommended.

REFERENCES

Abera, G., E. Wolde-Meskel and L. Bakken. 2012. Carbon and nitrogen mineralization dynamics in different soils of the tropics amended with legume residues and contrasting soil moisture contents. Biol. Fertility Soils 48:51-66.

Beaton, J.D. and W.L. Nelson. 2005. Soil fertility and fertilizers: An introduction to nutrient management. Vol. 515. Pearson Prentice Hall. Upper Saddle River, NJ.

Bekku, Y., H. Koizumi, T. Oikawa and H. Iwaki. 1997. Examination of four methods for measuring soil respiration. Applied Soil Ecology 5:247-254.

Blagodatsky, S. A., I.V. Yevdokimov, A.A Larionova, and J. Richter. 1998. Microbial growth in soil and nitrogen turnover: Model calibration with laboratory data. Soil Biol. Biochem. 30:1757-1764.

Brady, N. C., and R. Weil. 2008. The nature and properties of soils. Pearson Prentice Hall, Upper Saddle River, N.J.

Chen, J. and J.M Stark. 2000. Plant species effects and carbon and nitrogen cycling in a sagebrush–crested wheatgrass soil. Soil Biol. Biochem. 32:47-57.

Cheng, W. and D.C. Coleman. 1989. A simple method for measuring CO_2 in a continuous air-flow system: Modifications to the substrate-induced respiration technique. Soil Biol. Biochem. 21:385-388.

Davies, B. E. 1974. Loss-on-ignition as an estimate of soil organic matter. Soil Sci. Soc. Am. J. 38:150-151.

Ding, W., Y. Cai, Z. Cai, K. Yagi and X. Zheng. 2007. Soil respiration under maize crops: effects of water, temperature, and nitrogen fertilization. Soil Science Society of America Journal, 71:944-951.

Freijer, J. I., and W. Bouten. 1991. A comparison of field methods for measuring soil carbon dioxide evolution: Experiments and simulation. Plant Soil 135:133-142.

Groffman, P. M., P.F. Hendrix and D.A. Crossley Jr. 1987. Nitrogen dynamics in conventional and no-tillage agroecosystems with inorganic fertilizer or legume nitrogen inputs. Plant Soil 97:315-332.

Haney, R., W. Brinton and E. Evans. 2008. Soil CO_2 respiration: Comparison of chemical titration, CO_2 IRGA analysis and the Solvita gel system. Renew. Agric. Food Syst. 23:171-176.

Isaac, S. R. and A.M. Nair. 2005. Biodegradation of leaf litter in the warm humid tropics of Kerala, India. Soil Biol. Biochem. 37:1656-1664.

Maguire, R. and S. Heckendorn. 2011. Laboratory procedures: Virginia Tech Soil Testing Laboratory. VA Cooperative Extension Publication #452-881. Blacksburg, VA.

Mehlich, A. 1976. New buffer pH method for rapid estimation of exchangeable acidity and lime requirement of soils. Comm. Soil Sci. Plant Anal. 7:637-653.

Mondini, C., T. Sinicco, M.L. Cayuela, and M. Sanchez-Monedero. 2010. A simple automated system for measuring soil respiration by gas chromatography. Talanta 81:849-855.

Nadelhoffer, K. J. 1990. Microlysimeter for measuring nitrogen mineralization and microbial respiration in aerobic soil incubations. Soil Sci. Soc. Am. J. 54:411-415.

Norman, J.M., C. Kucharik, S.T. Gower, and D.D. Baldocchi. 1997. A comparison of six methods for measuring soil-surface carbon dioxide fluxes. J. Geophys. Res. Atmos. 102:28771-28777.

Pansu, M. and J. Gautheyrou. 2007. Handbook of soil analysis: mineralogical, organic and inorganic methods. Springer Science and Business Media, New York, NY. p.926-927.

Rochette, P., B. Ellert, E.G. Gregorich, R.L. Desjardins, E. Pattey, R. Lessard and B.G Johnson. 1997. Description of a dynamic closed chamber for measuring soil respiration and its comparison with other techniques. Can. J. Soil Sci. 77:195-203.

Stanford, G. and S.J. Smith. 1971. Nitrogen mineralization potentials of soils. Soil Sci. Soc. Am. J. 36:465-472.

TABLES

Table 1. Select chemical and physical parameters for soils used in microlysimeter validation studies.

Soil series and texture	pH[†]	P[‡]	K[‡]	CEC[§]	Organic Matter[¶]
		------kg ha^{-1}------		meq $100g^{-1}$	%
Groseclose clay loam	7.0	45	186	9.8	3.8
Bojac sandy loam	5.6	96	54	3.4	0.8
Braddock & Unison silt loam	7.2	160	155	15	2.5
Davidson clay	5.6	14	178	7.9	4.1

[†] 1:1 soil water

[‡] Mehlich 1 extraction, plant available estimate

[§] Estimated, sum of cations

[¶] Loss on ignition

Table 2. Maize and alfalfa residue initial carbon and nitrogen content.

Residue type	N	C	C:N ratio
	------%------		
Alfalfa	2.16	37.1	17:1
Maize	0.54	38.3	71:1

Table 3. Simple statistics for C mineralization on indicated sampling intervals over soil, residue and placement treatments.

	Day							
	0	3	7	14	28	56	112	224
	------------------------------mg C kg soil^{-1} hr^{-1}------------------------------							
Mean	2.92	8.15	26.30	25.66	25.82	96.32	27.81	34.70
sd[†]	0.23	4.23	4.30	4.89	7.24	25.32	1.55	12.35
CV[‡]	7.9	51.9	16.3	19.1	28.0	26.3	5.6	35.6
95% Confidence Interval, Lower	2.62	1.14	19.39	17.72	11.42	44.15	25.51	10.62
95% Confidence Interval, Upper	3.26	18.12	33.21	33.59	40.21	148.49	30.11	58.79

[†] standard deviation

[‡] coefficient of variation

Table 4. Carbon mineralization as affected by soil and residue placement, days 0, 7, and 84.

Soil series	Placement	Day 0		Day 7		Day 84	
		-----------mg C kg soil^{-1} hr^{-1}-----------					
Braddock	Buried	2.86	a[†]	26.20	c	27.34	ab
Braddock	Surface	3.06	a	18.41	d	26.88	b
Bojac	Buried	3.16	a	24.69	c	28.16	a
Bojac	Surface	3.00	a	29.11	b	27.76	ab
Davidson	Buried	2.75	b	29.16	b	30.43	a
Davidson	Surface	2.79	b	32.33	a	29.07	a
Groseclose	Buried	2.78	b	25.39	c	26.86	b
Groseclose	Surface	3.11	a	25.61	c	26.30	b

[†] Means within a column designated with the same lowercase letter are not significantly different, P<0.05.

Table 5. Carbon mineralization as affected by soil and residue type, days 0, 7, and 84.

Soil series	Placement	Day 0		Day 7		Day 84	
		------------mg C kg soil^{-1} hr^{-1}------------					
Braddock	Buried	3.12	a[†]	22.32	b	28.22	b
Braddock	Surface	2.81	bc	21.81	b	25.67	d
Bojac	Buried	2.93	b	29.55	a	27.69	bc
Bojac	Surface	3.23	a	24.74	a	28.22	b
Davidson	Buried	2.80	bc	30.38	a	30.16	a
Davidson	Surface	2.73	c	31.24	a	29.16	ab
Groseclose	Buried	2.92	bc	28.42	a	27.15	c
Groseclose	Surface	2.98	b	22.22	b	26.05	d

[†] Means within a column designated with the same lowercase letter are not significantly different, $P<0.05$.

Table 6. Carbon mineralization as affected by soil, placement and residue, days 3, 28, 56 and 112 after initiation.

Soil series	Placement	Residue	Day 3		Day 28		Day 56		Day 112	
			-------------------mg C kg soil^{-1} hr^{-1}-------------------							
Braddock	Buried	Alfalfa	6.26	b[†]	18.52	c	138.68	ab	23.81	b
Braddock	Buried	Maize	12.00	ab	20.37	bc	151.83	a	31.12	b
Braddock	Surface	Alfalfa	8.95	b	16.89	c	77.28	bc	38.43	ab
Braddock	Surface	Maize	5.27	b	28.95	bc	49.64	c	28.62	b
Bojac	Buried	Alfalfa	9.90	ab	28.90	bc	100.60	b	44.21	ab
Bojac	Buried	Maize	8.87	b	23.41	bc	91.59	bc	26.11	b
Bojac	Surface	Alfalfa	4.68	b	25.98	bc	83.83	bc	24.99	b
Bojac	Surface	Maize	9.81	ab	54.12	a	82.02	bc	44.75	ab
Davidson	Buried	Alfalfa	5.19	b	26.97	bc	109.15	b	30.46	b
Davidson	Buried	Maize	5.16	b	22.28	bc	57.65	c	29.62	b
Davidson	Surface	Alfalfa	6.16	b	18.92	c	104.49	b	50.52	a
Davidson	Surface	Maize	11.41	ab	26.51	bc	76.46	bc	44.98	ab
Groseclose	Buried	Alfalfa	6.72	b	22.13	bc	95.11	b	22.90	b
Groseclose	Buried	Maize	17.82	a	23.66	bc	84.92	bc	45.81	ab
Groseclose	Surface	Alfalfa	5.34	b	25.20	bc	94.30	bc	34.82	ab
Groseclose	Surface	Maize	6.88	b	30.24	b	143.53	ab	34.13	ab

[†] Means within a column designated with the same lowercase letter are not significantly different, $P<0.05$.

Table 7. Regression equations of carbon mineralization as affected by soil series, placement, and residue over 112 days.

			Contrast Model		
			Linear	Quadratic	
Soil Series	Placement	Residue	Pr>F		Equation
Braddock	Buried	Alfalfa	<0.0001	<0.0001	$y = -0.0029x^2 + 0.0332x - 0.0414$
Braddock	Buried	Maize	<0.0001	<0.0001	$y = -0.003x^2 + 0.0348x - 0.042$
Braddock	Surface	Alfalfa	<0.0001	0.0206	$y = -0.001x^2 + 0.0154x - 0.0158$
Braddock	Surface	Maize	<0.0001	0.0001	$y = -0.0014x^2 + 0.0171x - 0.0177$
Bojac	Buried	Alfalfa	<0.0001	0.0090	$y = -0.0017x^2 + 0.0225x - 0.0244$
Bojac	Buried	Maize	<0.0001	0.0001	$y = -0.002x^2 + 0.0239x - 0.0268$
Bojac	Surface	Alfalfa	<0.0001	<0.0001	$y = -0.0023x^2 + 0.0258x - 0.0287$
Bojac	Surface	Maize	<0.0001	0.0007	$y = -0.0021x^2 + 0.0259x - 0.0282$
Davidson	Buried	Alfalfa	<0.0001	0.0003	$y = -0.0021x^2 + 0.0261x - 0.0319$
Davidson	Buried	Maize	<0.0001	<0.0001	$y = -0.0014x^2 + 0.0175x - 0.0169$
Davidson	Surface	Alfalfa	<0.0001	0.0005	$y = -0.0014x^2 + 0.0206x - 0.0221$
Davidson	Surface	Maize	<0.0001	0.0274	$y = -0.0011x^2 + 0.0164x - 0.0145$
Groseclose	Buried	Alfalfa	<0.0001	<0.0001	$y = -0.0023x^2 + 0.0257x - 0.0294$
Groseclose	Buried	Maize	<0.0001	0.0056	$y = -0.0012x^2 + 0.0171x - 0.0145$
Groseclose	Surface	Alfalfa	<0.0001	<0.0001	$y = -0.0021x^2 + 0.0247x - 0.0278$
Groseclose	Surface	Maize	<0.0001	<0.0001	$y = -0.0028x^2 + 0.0337x - 0.043$

Table 8. Simple statistics for leachate nitrate on indicated sampling day over soil, residue and placement treatments.

	Day							
	0	3	7	14	28	56	84	112
	---------------------------kg ha^{-1}---------------------------							
Mean	2.90	3.41	2.97	9.26	12.23	1.44	5.75	0.54
sd[†]	1.29	0.33	0.09	1.40	3.45	0.29	1.44	1.11
CV[‡]	67.20	14.55	4.35	22.50	42.30	29.40	37.80	310.50
95% Confidence Interval, Lower	1.41	3.03	2.88	7.65	8.27	1.11	4.29	-0.74
95% Confidence Interval, Upper	4.38	3.80	3.08	10.86	16.19	1.76	7.62	1.80

[†] standard deviation

[‡] coefficient of variation

Table 9. Simple statistics for leachate ammonium on indicated sampling day over soil, residue and placement treatments.

	Day							
	0	3	7	14	28	56	84	112
	---------------------kg ha^{-1}---------------------							
Mean	5.30	4.62	13.89	7.82	8.67	3.57	0.72	2.64
sd[†]	1.52	0.45	0.39	1.41	5.55	0.60	0.83	2.52
CV[‡]	43.05	14.70	4.20	27.15	96.00	25.35	169.35	143.55
95% Confidence Interval, Lower	3.56	4.10	13.44	6.18	2.30	2.88	-0.17	-0.27
95% Confidence Interval, Upper	7.05	5.15	14.34	9.44	15.06	4.28	1.71	5.55

[†] standard deviation

[‡] coefficient of variation

FIGURES

Figure 1. Schematic drawing and measurements for microlysimeter design.

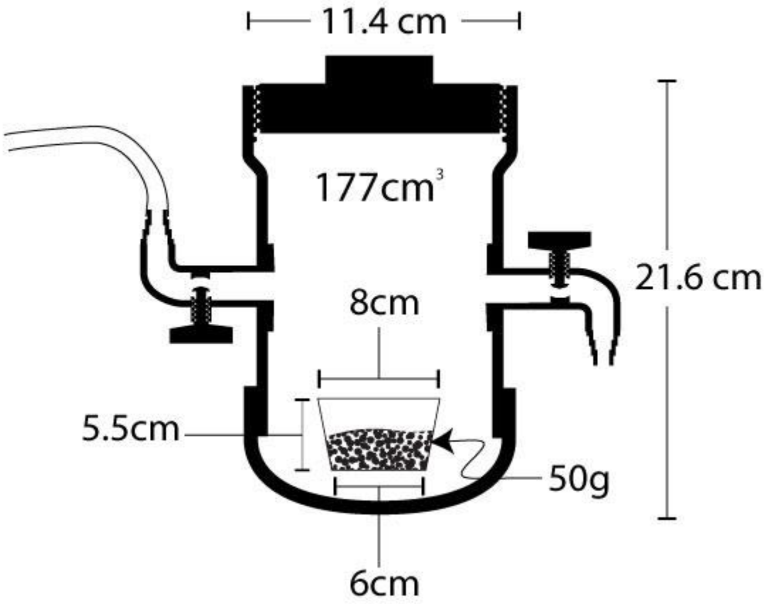


Figure 2. Leachate nitrate concentration for alfalfa residue on indicated sampling day by soil and placement.

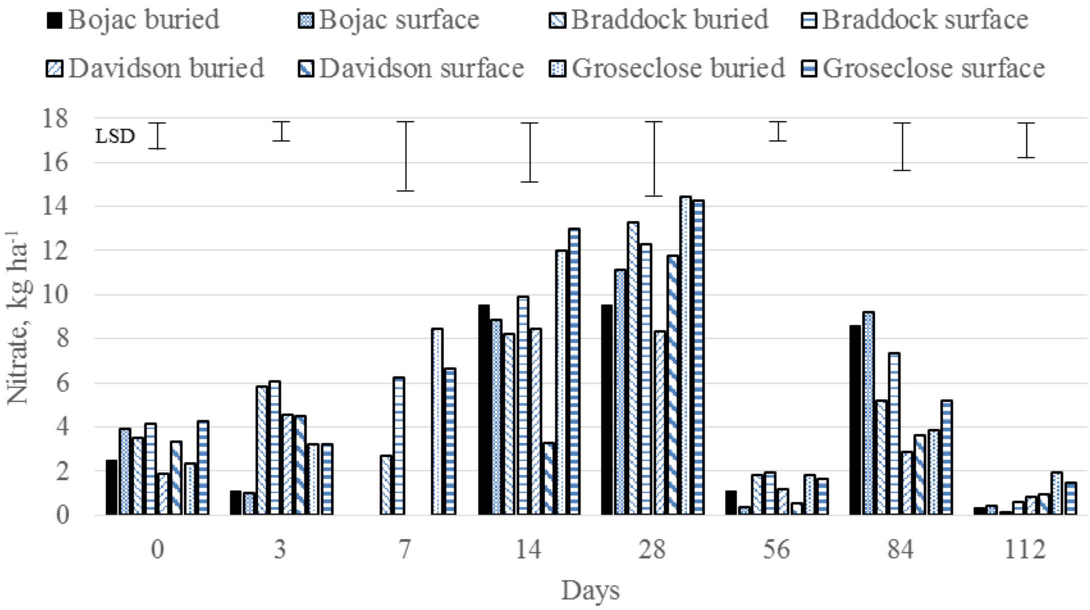


Figure 3. Leachate nitrate concentration for maize residue on indicated sampling day by soil and placement.

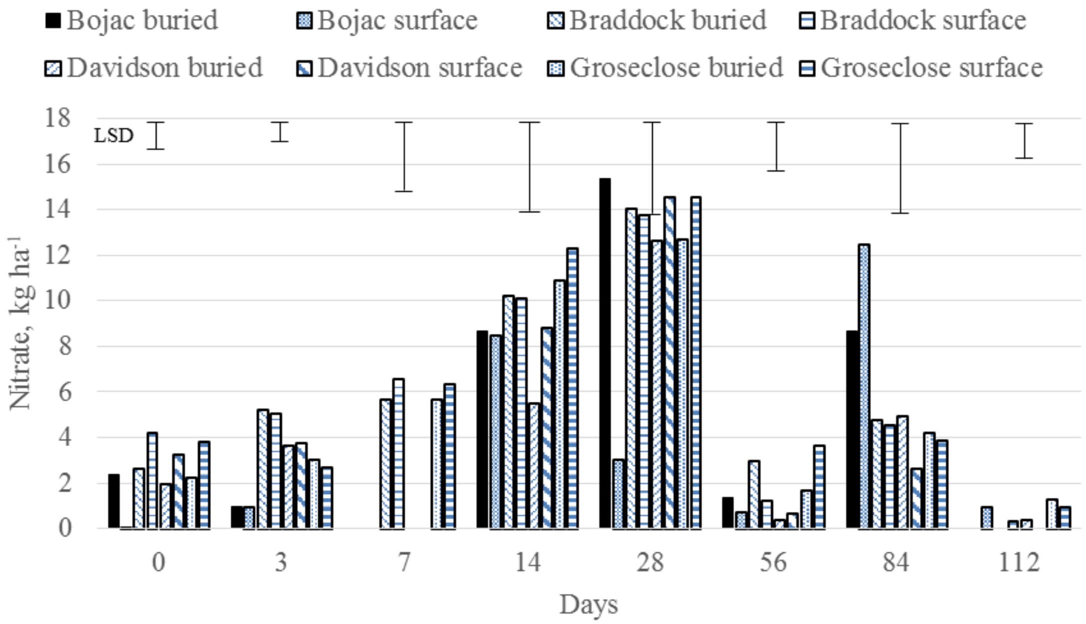


Figure 4. Leachate ammonium concentration for alfalfa residue on indicated sampling day by soil and placement.

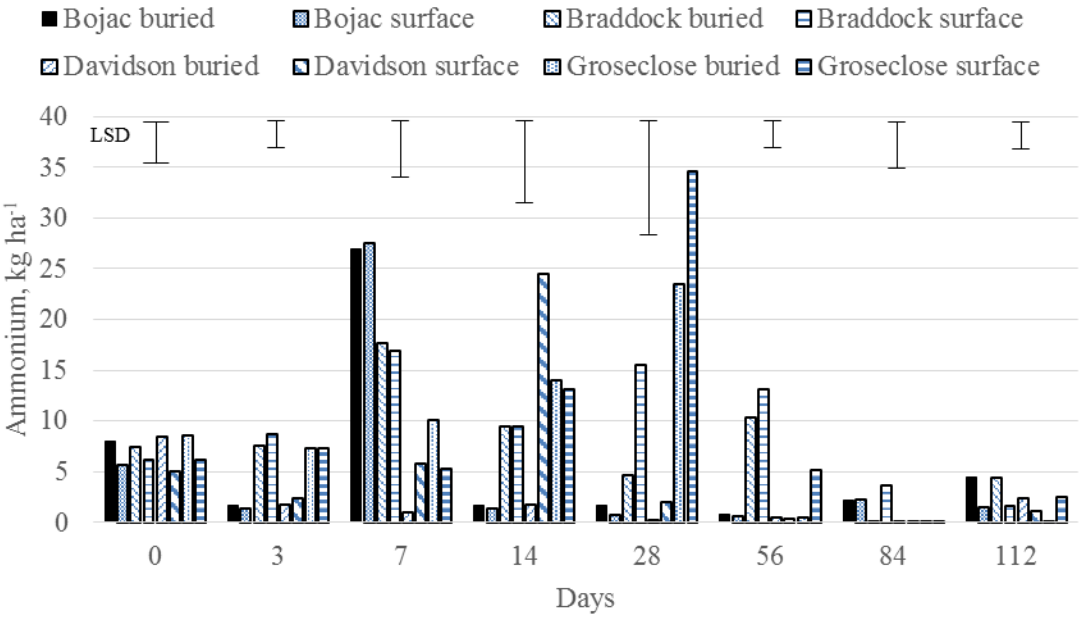


Figure 5. Leachate ammonium concentration for maize residue on indicated sampling day by soil and placement.