IMPROVED USE OF GREEN MANURE AS A NITROGEN SOURCE FOR SWEET CORN

By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL
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To my new family and my old, may you help me to find balance in my life and make me a better person than I could ever be alone.

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A green manure (GM) is a crop used primarily as a soil amendment and a nutrient source for future crops. Leguminous GMs may represent a substantial source of on-farm nitrogen (N) also capable of increasing soil organic matter and suppressing weeds and parasitic nematodes. In temperate and tropical environments, GMs such as hairy vetch (*Vicia villosa*) and sunn hemp (*Crotalaria juncea*) have been found to accumulate 150-250 kg N ha^{-1} while fully satisfying N-requirements of subsequent crops. However, spring crop production with GMs in Florida remains particularly challenging because N accumulation and subsequent GM benefits of temperate winter legumes are reduced while tropical summer legumes cannot survive freezes and may experience unacceptable levels of N-loss during winter fallow. Establishing a winter GM after the summer GM may significantly reduce N leaching losses during winter and retain N benefits for spring crops, but this has not been studied.

We conducted a 2-year field study to evaluate yield response of sweet corn (*Zea mays* var. Rugosa) to GMs of sunn hemp and/or lupin (*Lupinus angustifolius*; winter 2001-02) and cahaba white vetch (*Vicia sativa*; winter 2002-03) and supplementation with 0, 67, or 133 kg inorganic N ha^{-1}. Unamended (non-GM) treatments receiving 0, 67, 133, 200 or 267 kg inorganic N ha^{-1} were used for comparison. Growth and N analyses were conducted for all crops and decomposition monitored for overwintering sunn hemp. These analyses revealed substantial growth and N-accumulation for sunn hemp (up to 12.2 Mt ha^{-1} and 135 kg N ha^{-1}), but rapid N-loss (60-66% 2-4 weeks after death) occurred when senesced leaves and upright stems decomposed separately in our reduced tillage and reduced mowing system. Winter GM growth (2-4 Mt ha^{-1} and 35-40 kg N ha^{-1}) was and not enhanced by following sunn hemp. Green manures resulted in N benefit for sweet corn of ~50-70 kg N ha^{-1}, and ear yields for corn with sunn hemp plus winter GM and 133 kg N ha^{-1} only were similar to unamended corn with recommended N-rate (200 kg N ha^{-1}) in either year. Amendment with GMs significantly increased corn root length density, but did so in the upper 15 cm soil layer and close to the plant, possibly interfering with late-season ear-fill by exposure to water and N-stress. Apparent N-recovery was not affected by use of GMs in this system. Green manure approaches significantly increased particulate organic C and N pools over two years, though it remains unclear if these changes can create effective differences in soil organic matter. Living sunn hemp reduced end-of-season weed biomass up to 80% and suppressed lesion and stubby-root nematodes while winter legumes had mixed affects.

CHAPTER 1
INTRODUCTION

Overview

This chapter serves as a brief overview tying together the individual components of this study. Detailed introductions, literature reviews, materials and methods, results, discussions and conclusions are provided in relevant chapters. Green manure (GM) growth, nitrogen (N) accumulation, decomposition and N-release are treated in Chapter 2. Chapter 3 evaluates effects of GMs on sweet corn growth, N-accumulation, N-status indicators, and ear yields. A sweet corn root study, conducted to complement information from growth and yield analysis, is described in Chapter 4. Effects of GM approaches on soil carbon (C) and N pools are treated in Chapter 5, with effects on weeds and plant parasitic nematodes assessed in Chapter 6. Chapter 7 provides a review and synthesis of findings, followed by Appendices (of selected tables) and References.

Introduction

Rationale

The last century of American agriculture has been characterized by a shift from highly diversified low-input systems to highly specialized operations greatly depending on external non-renewable resources. Dramatic increases in farm size, along with an erosion of farm and crop diversity, have resulted in agroecosystems more vulnerable to pressures of urbanization, climate change, and volatile global markets. Need exists to provide farmers with economically viable alternatives that harness ecological processes,

farm and biological diversity, and on-farm resources (see Gold 1999, Dinnes et al. 2002 for discussions).

With a production area of 2.3 million acres and a crop value of 3.8 billion dollars, vegetable, fruit and field crop production comprise major agricultural activities in Florida (Florida Agricultural Statistics Service 2004). Many soils in this region possess little organic matter (<1%) and exhibit poor water and nutrient retention (for examples, see Appendix A or Carlisle et al. 1988), especially those experiencing regular disturbance (through tillage) and low input rates for organic matter. Conventional cropping systems on such soils therefore require continuous application of large amounts of external nutrients and irrigation water, yet remain vulnerable to large losses of these inputs. Producers, consumers, government agencies, and researchers have therefore expressed increasing interest in alternative and/or organic production systems (Gold 1999, Dinnes et al. 2002).

A green manure (GM) is a crop used primarily as a soil amendment and a nutrient source for subsequent crops. In most production environments, lack of N limits plant growth more than any other nutrient. Crop plants effectively satisfy their N requirement only by acquisition of mineralized N (NH_4^+ and NO_3^-). Atmospheric N (N_2), though abundant, cannot be utilized by plants. Legumes, however, possess a symbiotic relationship with rhizobial bacteria capable of transforming atmospheric N_2 into plant-usable form and may accumulate large amounts of N via this pathway. Legumes utilized as GMs therefore represent a potentially renewable source of on-farm, biologically fixed N. Unlike chemical N fertilizers, legumes may also fix and add large amounts of C to a cropping system (Hargrove 1986, Sharma and Mittra 1988, Goyal et al. 1992). Legumes

can also correct phosphorus (P) imbalances typically associated with excess applications of animal waste products because legume P levels are similar to those of other plants. The slow release of N from decomposing GM residues may be better timed with plant uptake, possibly increasing N-uptake efficiency and crop yield while reducing N leaching losses (Bath 2000, Wivstad 1997). Green manure approaches may also drive long-term increases of soil organic matter and microbial biomass, further improving nutrient retention and N-uptake efficiency (for example, see Agustin et al. 1999). When used in place of fallow, well-chosen GMs may reduce erosion and suppress weeds and specific crop pests (Ross et al. 2001, McSorley 1999). Green manures may also offer habitat or resources for beneficial organisms (Altieri and Letourneau 1982, Yeates et al. 1999, Bugg et al. 1991a,b).

Presently, GM management is difficult relative to chemical fertilizer approaches. Nitrogen release from plant residues depends on a large number of interactive factors including chemical composition and N concentration, temperature, and water availability (Schomberg et al. 1994, Andren 1992). Practical information about the composition and N concentration of GMs as they change over a growing season is often lacking. Most existing information on GM performance comes from studies conducted in temperate or tropical environments on fine-textured soils, the results of which may not hold in north Florida with its sub-tropical/sub-temperate climate and sandy soil. Especially for high N-demanding crops, GMs may not supply adequate N if amount and timing of N-release do not match crop demand. At times, GM-amended crops may require supplementary inorganic N fertilizer to prevent yield reductions, but little or no information exists on optimal supplementation levels. It also remains unclear if long-term improvements in soil

fertility can be achieved under Florida conditions. Current guidelines to GM use and previous GM research have not yet developed management techniques necessary to produce economic yields comparable to chemically fertilized, high-N demanding crops in north Florida. Improved integration of GMs in such cropping systems will require more precise and detailed information about GM growth and decomposition, subsequent crop yield responses, and effects on soil and pests over time in specific production environments.

Green Manure Management

Performance of GMs varies by species, growth environment (climate, soil, weather, pests,etc.), and management (e.g., planting date, length of growing season,etc.). Table 1.1 summarizes the dry matter and N accumulation of about 50 GM species from 40 studies and includes reported information about study location, soil type, and length of growing season. Green manures generally fall into two categories: tropical ("warm weather") and temperate ("cool weather"). Few, if any, tropical legumes can survive hard freezes (when temperature drops below –2 C for several hours), though they can usually tolerate temperatures in excess of 40 C. Temperate legumes, on the other hand, often decline at temperatures over 25 C but may persist without injury at –10 C or lower. The most widely used tropical GM legumes probably include those in genera *Crotalaria* (sunn hemp), *Glycine* (soybean), *Indigofera* (indigos), *Mucuna* (velvetbean), *Vigna* (cowpea), *Cajanus* (pigeonpea), and *Sesbania*, while the temperate GM legumes often include *Trifolium* (clovers), *Vicia* (vetches), *Medicago* (alfalfa, trefoils, and other medics), and *Lupinus* (lupins). Typical non-legume temperate GMs consist of cereal rye (*Secale cereale*), mustards (*Brassica* spp), radishes (*Raphanus* spp), buckwheat (*Fagopyrum esculentum*), millet (*Echinocloa* spp), oats (*Avena* spp), and wheat (*Triticum* spp).

Legume GMs are often preferable to non-legumes because they supply their own N, but in production scenarios where N is less limiting, where a specific GM service other than high N supply (such as allelopathy) is sought, and/or where legumes do not perform well, non-legumes or mixtures of legumes and non-legumes may be more desirable (for example, see Karpenstein-Machan and Stuelpnagel 2000). Because they do not derive direct sales profit, GMs are often chosen that require some acceptably low level of nutrients, irrigation, and pest control and fit into otherwise unplanted fallow periods.

When biological N-fixation is not water or temperature limited, legumes are often selected as GMs due to their N-fixation capacity. Probably because they are adapted to and grown in warmer climates with higher light levels, tropical legumes often accumulate biomass and N faster than winter legumes. Genetic differences (species and variety) also may dictate that some legumes grow larger and accumulate more N than others. Environment (temperature, soil type, nutrient and water availability) and management (planting density and timing, mowing, pest control,etc.) may further alter performance of individual GM species. For example, sunn hemp (*Crotalaria juncea*; a tropical legume) generally grows more rapidly than temperate legumes, accumulates greater biomass and N than most tropical legumes (likely because it is capable of growing upright and becoming quite stemmy), with reduced performance on low-fertility soils and under water stress (Seneratne and Ratnasinghe 1995, Ladha et al. 1996, Mansoer et al. 1997, Jeranyama et al. 2000, Ramos et al. 2001, Steinmaier and Ngoliya 2001)

Climate probably limits GM selection more than any other single factor. In very cold climates, temperate legumes survive during the spring, summer, and fall. As one moves to warmer climates, increasing winter temperatures permit temperate legumes to

persist during winter months while tropical legumes become better suited during warmer months. Where lowest “winter” temperatures remain above freezing, tropical legumes may survive year-round, and high temperatures may begin to exclude use of temperate legumes. However, precipitation, soil type, and pest pressures also interact with temperature to determine how specific GMs will perform in a given location. Potential N accumulation and growing season of a GM must fit a particular crop rotation. Desirability of GMs may also include or exclude ability to reseed, growth habit (upright, prostrate, viney,etc.), aggressiveness, and presence of toxic or allelopathic chemicals affecting livestock, crops, and/or plant pests. For example, sunn hemp may be desirable preceding a fall vegetable crop because it accumulates much N, thrives in high summer temperatures, is killed easily by stem breakage, does not become weedy by reseeding itself (at least in Florida), and may suppress parasitic nematodes. However, sunn hemp may be ill-suited to grow near trees because its height and mass make it competitive for light, water, and nutrients and it would require replanting on an annual basis.

Both tropical and temperate GMs may be used in north Florida, but their production level and/or growing time is often restricted by variable temperatures and low-fertility soils. Compared to temperate environments, effective N-accumulation from temperate GM legumes in Florida may occur slowly and/or have limited potential due to high temperatures and poor adaptation to sandy soils. More productive summer legumes do not survive winter freezes in north Florida, and decomposition during this period can result in heavy losses of residue N. If GMs do not supply adequate N to meet requirements of subsequent crops, then supplementary inorganic N may be required to

prevent yield reductions. Crops with high N-demand planted just after winter therefore pose a particularly acute challenge for GM use in north Florida.

During the winter, a temperate GM may take up significant amounts of N from a decomposing tropical legume, possibly boosting the growth and N accumulation of the temperate legume and reducing N leaching losses. Overwintering residue with low N content and/or high C:N ratio may also reduce N leaching losses (Stopes et al. 1996, Wyland et al. 1996). In some systems, it may therefore be advantageous to follow a stemmy, vigorous summer GM with a well-adapted winter GM, and to preserve as much recalcitrant litter as possible by reducing tillage. However, excessive build-up of crop residues may interfere with growth of a number of crops; selection of less sensitive crops and/or periodic tillage may become important.

Approach

This project focused on a GM approach to production of a spring planted, high-N demanding vegetable crop – sweet corn (*Zea mays* var Rugosa) – in north Florida. Based on information from the University of Florida-Institute of Food and Agricultural Science (UF-IFAS) Electronic Data Information Source (EDIS), extension recommendations for sweet corn on sandy Florida soils include at least 180-200 kg N ha^{-1} (Hochmuth and Cordasco 2000). Florida farmers generally use chemical fertilizers to satisfy the N requirements of sweet corn. We conducted our study at the Plant Science Research and Education Unit in Citra, Florida, primarily on Candler and Lake sands (see Appendix A for soil characterization data).

To help develop improved GM management techniques appropriate for spring crops in north Florida, a novel approach to a GM/sweet corn cropping system was investigated. Sunn hemp was planted in late summer, grown for 12-14 weeks to optimize

N content, biomass and overall recalcitrance. Afterwards, blue lupin (*Lupinus angustifolius*; winter 2001-02) or cahaba white vetch (*Vicia sativa*; winter 2002-03) was planted into the standing sunn hemp residues to capture mineralized N and/or fix additional N. Sunn hemp and lupin/vetch were also evaluated alone. After mowing of all residues, sweet corn was then planted in the spring. All crops were planted using reduced or zero-tillage. Several rates of supplementary inorganic N were applied to both GM-amended and unamended (conventional) sweet corn. We believed the combined GM approach would supply significant amounts of N to sweet corn while also providing long-term benefits by increasing soil organic matter and microbial biomass and suppressing parasitic nematodes and weed production. The overall project is therefore planned to continue for at least 5 years, depending on availability of external funding.

Hypotheses

1. Sunn hemp stem residues would immobilize a significant amount of N during winter decomposition (Chapter 2).
2. Growth of winter legumes following sunn hemp would be enhanced, reaching levels similar to those reported for temperate environments (Chapter 2).
3. The double-GM approach would significantly reduce chemical N required by sweet corn to achieve ear yields similar to an optimal level identified in the conventional approach (Chapter 3).
4. Green manures would increase N recovery rates of sweet corn (Chapter 3).
5. Amendment with GMs would increase sweet corn root length density and redistribute it nearer to the GM residue (Chapter 4).
6. GMs would increase total soil C and N as well as specific soil C and N pools often indicative of recent organic additions including microbial biomass C and particulate organic C and N (Chapter 5).
7. Green Manures would significantly suppress weed biomass and plant parasitic nematode population (Chapter 6).

Objectives

The objectives of this research were as follows:

1. To generate detailed information about GM biomass and N accumulation by tissue fraction during growth, and subsequent decomposition and N-release by the summer GM during winter months (Chapter 2).

2. To gauge impacts of GMs on sweet corn growth, N-status indicators, and root distribution patterns throughout the season (Chapters 3 and 4).

3. To estimate chemical N-supplementation needed to achieve acceptable sweet corn ear yields for GM approaches (Chapter 3).

4. To determine if any GM approach can produce corn ear yields equivalent to the conventional approach (Chapter 3).

5. To estimate N recoveries and losses for GM and conventional approaches (Chapter 3).

6. To evaluate effects of GMs on soil properties, weeds, and parasitic nematodes having long-term implications for the efficacy of the system (Chapters 5 and 6).

General Set-Up and Design

Table 1.2 lists the 15 overall treatments of the study, which began in August 2001 and was conducted at the Plant Science Research and Education Unit near Citra, FL. Candler fine sand (Typic Quarzipsamments, hyperthermic, uncoated; 98% sand in the upper 15 cm) and Lake fine sand (Typic Quarzipsamments, hyperthermic, coated; 97% sand in the upper 15 cm) were the dominant soil types (see Appendix A for detailed characterization). Study design consisted of four randomized complete blocks with plots 7.6 m x 8.8 m (25 ft x 30 ft). Treatments were composed of two main effects: GM level and chemical N-rate level (chemical N applied to sweet corn only). Green manure level consisted of: a summer leguminous GM (sunn hemp) followed by a winter legume (blue lupin, winter 2001-02; cahaba white vetch, year 2002-03) denoted as SH+L; summer legume only (SH); winter legume only (L); and a conventional level with no GM (Conv). Following summer and winter, a spring crop of sweet corn was planted in all plots and

supplemented with 0, 67, and 133 kg NH_4NO_3-N ha^{-1} for each GM level (denoted as 0N, 67N, and 133N). Conventional GM level also possessed fertilization rates of 200 and 267 kg NH_4NO_3-N ha^{-1} (Conv 200N and Conv 267N) representing 3/3 and 4/3 the chemical N-rate recommended for sweet corn in Florida by UF-IFAS extension. A final treatment of complete fallow (Fal) receiving chemical weed control (identical to other treatments) but no GM, sweet corn, chemical-N, or tillage was included for comparison purposes. More detailed materials and methods are found in relevant chapters (see Overview, above).

Measurements

- Measurements taken for all crops were: plant numbers at beginning of season; leaf area and leaf, stem, root, and reproductive (flowers/pods/ears) fresh and dry weights taken every 2-4 weeks and at final samplings, as well as N concentration and content of all tissues.
- Measurements taken for sweet corn were: leaf chlorophyll readings every 2 weeks and at final samplings, ear number and ear grade at final samplings, and root length density for selected plots at selected dates in 2003.
- Measurements taken for soil (0-25 cm) were: Total Soil C and N, Particulate Organic C and N, Microbial Biomass C, and pH at selected dates.
- Continuously taken measurements were: Precipitation, air temperature at 1m, soil temperature at a depth of 5 cm, and relative humidity using Watchdog Dataloggers (Spectrum Technologies; Plainfield, IL; see Appendix B).
- Measurements of nematodes were: soil counts for selected plots at selected dates.
- Measurements taken for weeds were: total dry weight, N concentration and N content in all plots at end of sunn hemp and vetch.

Table 1.1. Review of green manure studies.

Green Manure	**Study**	**Dry Weight (Mt ha^{-1})** **N Content (kg ha^{-1})**	**Environment** **Growth Time; Management Notes**
Oats *Avena sativa*	Dyck & Liebman 1995	3.3-4.3 80-82	Sandy loam, Maine 3 months
Azolla *Azolla microphylla*	Ladha et al. 2000	2.1-2.3 61-75	Silty Clay, Philippines 6-9 weeks; flooded
Colza *Brassica campestris*	N'Dayegamiye & Tran 2001	2.1-4.6 59-99	Silt loam, Canada 4 months; 30 kg N ha^{-1} applied
Mustard *Brassica hirta*	N'Dayegamiye & Tran 2001	2.3-3.8 62-72	Silt loam, Canada 4 months; 30 kg N ha^{-1} applied
Pigeonpea *Cajanus cajan*	Ladha et al. 1996	6.5-9.0 154-235	Clay or loam?, Philippines ~6 months; clipped to 20-30 cm 5 times
Canavalia *Canavalia ensiformis*	Ramos et al. 2001	4.4 58	Sandy loam, Cuba 8-9 weeks
Centro *Centrosema pubescens*	Steinmaier & Ngoliya 2001	1.2 27	Sandy loam, Zambia 14 weeks (?)
Rhodes Grass *Chloris gayana*	Steinmaier & Ngoliya 2001	14 167	Sandy loam, Zambia 14 weeks (?)
Clitoria *Clitoria ternatea*	Ladha et al. 1996	6.9-7.7 256-306	Clay or loam?, Philippines ~6 months; clipped to 20-30 cm 2-3 times
Sunn Hemp *Crotalaria juncea*	Jeranyama et al. 2000	0.9-2.9 23-82	Loamy sand, Zimbabwe 6-7 weeks
	Ladha et al. 1996	7.6-7.8 277-279	Clay or loam?, Philippines ~6 months; clipped to 20-30 cm 2-3 times
	Mansoer et al. 1997	4.8-7.3 120-138	Sandy loam, Alabama 9-12 weeks
	Ramos et al. 2001	11.1 195	Sandy loam, Cuba 8-9 weeks
	Seneratne & Ratnasinghe 1995	6.1-9.6 161-252	NR, Sri Lanka 8-9 weeks
	Steinmaier & Ngoliya 2001	12.1 227	Sandy loam, Zambia 14 weeks (?)
Crotalaria *Crotalaria ochroleuca*	Carsky et al. 1999	5.0 (13 wks), 8.0 (19 wks) 114 (13 wks), 137 (19 wks)	Loamy sand, Nigeria 13 and 19 weeks; AAR = 1350 mm
	Carsky et al. 1999	2.0 (13 wks), 3.3 (19 wks) 52 (13 wks), 63 (19 wks)	Clay loam, Nigeria 13 and 19 weeks; AAR = 900 mm

AAR = average annual rainfall.

Table 1.1. Continued.

Green Manure	Study	Dry Weight (Mt ha^{-1}) N Content (kg ha^{-1})	Environment Growth Time; Management Notes
Sunn Hemp Marejea *Crotalaria zanzibarica* cv Marejea	Steinmaier & Ngoliya 2001	14.6 328	Sandy loam, Zambia 14 weeks (?)
Desmanthus *Desmanthus virgatus*	Ladha et al. 1996	8.0-9.1 251-283	Clay or loam?, Philippines ~6 months
Millet *Echinochloa crus* galli	N'Dayegamiye & Tran 2001	2.3-11.2 65-139	Silt loam, Canada 4 months; 30 kg N ha^{-1} applied
Buckwheat *Fagopyrum esculentum*	N'Dayegamiye & Tran 2001	2.1-3.7 52-65	Silt loam, Canada 4 months; 30 kg N ha^{-1} applied
Soybean *Glycine max*	Thonnissen et al. 2000a	2.8-5.8 106-141	NR, Taiwan & Philippines 2-2.5 months
Indigo *Indigofera tinctoria*	Agustin et al. 1999	2.3-2.9 56-57	Clay loam, Philippines 5-6 months after death of other intercrops
	Thonnissen et al. 2000a	0.2-2.0 5-44	NR, Taiwan & Philippines 2-2.5 months
Lablab *Lablab purpureus*/ *Dolichos lablab*	Carsky et al. 1999	1.9 (13 wks), 2.0 (19 wks) 71 (13wks), 47 (19wks)	Loamy sand, Nigeria 13 and 19 weeks; AAR = 1350 mm
	Carsky et al. 1999	0.6 (13 wks), 1.8 (19 wks) 23 (13 wks), 49 (19wks)	Clay loam, Nigeria 13 and 19 weeks; AAR = 900 mm
	Kouyate et al. 2000	0.7-1.7 NR	Loamy sand, Mali NR; AAR = 619 mm
	Kouyate et al. 2000	0.6-2.0 NR	Loam, Mali NR; AAR = 619 mm
	Steinmaier & Ngoliya 2001	5.8 115	Sandy loam, Zambia 14 weeks (?)
Black Lentil *Lens culinaris*	Brandt 1999	2.3-2.7 53-64	Loam, Saskatchewan NR; AAR = 359 mm
	Guldan et al. 1996	1.0-2.2 34-58	Sandy loam, New Mexico ~22 weeks; interseeded in sweet corn after 2 weeks
	Guldan et al. 1996	0.9-1.1 34-35	Sandy loam, New Mexico ~17 weels; interseeded in sweet corn after 7 weeks
Rye Grass *Lolium multiflorum*	Dapaah & Vyn 1998	1.3-2.5 NR	Loam, Ontario 7 months; intercropped with barley
	Stopes et al. 1996	0.7-17.5* 15-346*	Clay loam, England *6-25 months of growth; periodic mowing

AAR = average annual rainfall; NR = not reported.

Table 1.1. Continued.

Green Manure	**Study**	**Dry Weight (Mt ha^{-1})** **N Content (kg ha^{-1})**	**Environment** **Growth Time; Management Notes**
Blue Lupin *Lupinus angustifolius*	Forbes 1970	5.3-6.7 NR	NR (Sandy loam?), Tifton, GA NR
	Gallaher 1991	~1.0 ~20	Sand, Gainesville 24 weeks; 25 plants m^{-2}
	Gallaher 1991	~1.8 ~30-35	Sand, Gainesville 24 weeks; 50 plants m^{-2}
	Gallaher 1991	2.1 36	Sand, Gainesville 24 weeks; 100 plants m^{-2}
	Suman (in Forbes 1970)	2.8-3.1 NR	NR, South Carolina NR
Siratro *Macroptilium atropurpureum*	Ladha et al. 1996	4.9-5.5 132-178	Clay or loam(?), Philippines ~6 months
	Steinmaier & Ngoliya 2001	2.4 62	Sandy loam, Zambia 14 weeks (?)
Trefoil *Medicago lupulina*	Stopes et al. 1996	0.6-20.4* 15-459*	Clay loam, England *6-25 months of growth; periodic mowing
Burr Medic *Medicago polymorpha*	Shresthra et al. 1999	1.1 (C), 1.6 (N) NR	Loam, Michigan 90 days; cut for forage at 60 days (C) or not (N)
Burr&Snail Medics *Medicago polymorpha*, *M. scutellata*	Jeranyama et al. 1998	0.6-3.1 17-75	Loam, Michigan 9-11 weeks; 5 planting dates
	Jeranyama et al. 1998	0.1-1.3 2-32	Loam, Michigan 9-11 weeks; 5 planting dates, intercropped with corn
Gamma Medic *Medicago rugosa*	Shresthra et al. 1999	1.4 NR	Loam, Michigan 13 weeks
Alfalfa *Medicago sativa*	Griffin, et al. 2000	3.7-5.7 105-174	Silt loam, Maine 1 year
	Guldan et al. 1996	1.1-1.5 41-53	Sandy loam, New Mexico ~22 weeks; interseeded in sweet corn after 2 weeks
	Guldan et al. 1996	0.5-1.2 21-43	Sandy loam, New Mexico ~17 weeks; interseeded in sweet corn after 7 weeks
	Shresthra et al. 1999	1.6 NR	Loam, Michigan 13 weeks
	Singogo et al. 1996	2.8-5.7 107-138	Sandy loam, Kansas 7-8 months

NR = not reported.

Table 1.1. Continued.

Green Manure	**Study**	**Dry Weight (Mt ha^{-1})** **N Content (kg ha^{-1})**	**Environment** **Growth Time; Management Notes**
Barrel Medic *Medicago truncatula*	Guldan et al. 1996	2.4-4.5 72-131	Sandy loam, New Mexico ~22 weeks; interseeded in sweet corn after 2 weeks
	Guldan et al. 1996	1.0-2.3 37-69	Sandy loam, New Mexico ~17 weeks; interseeded in sweet corn after 7 weeks
	Shresthra et al. 1999	1.4 (C), 3.2 (N) NR	Loam, Michigan 13 weeks; cut for forage at 60 days (C) or not (N)
Yellow Sweet Clover *Melilotus officianalis*	Blackshaw et al. 2001b	3.1-5.4 NR	Sandy clay loam, Alberta NR; AAR = 387 mm; multiple intercrops
Mucuna *Mucuna aterrima*	Ramos et al. 2001	2.1 64	Sandy loam, Cuba 8-9 weeks
Velvet Bean *Mucuna pruriens* / *M. atropurpuriem* / *M. deeringiana*	Carsky et al. 1999	4.0 (13 wks), 6.2 (19 wks) 131(13 wks), 154 (19 wks)	Loamy sand, Nigeria 13 and 19 weeks; AAR = 1350 mm
	Carsky et al. 1999	1.7 (13 wks), 3.4 (19 wks) 53 (13 wks), 85 (19 wks)	Clay loam, Nigeria 13 and 19 weeks; AAR = 900 mm
	Steinmaier & Ngoliya 2001	9.3 183	Sandy loam, Zambia 14 weeks (?)
Glycine *Neonotonia wightii*	Steinmaier & Ngoliya 2001	0.9 21	Sandy loam, Zambia 14 weeks (?)
Winter/Field Pea *Pisum sativum*	Karpenstein-Machan and Stuelpnagel 2000	~4.8 ~200	Silty clay, Germany ~ 4 months
	Soon et al. 2001	1.1-3.5 (stover) 8.2-28.3 (stover)	Sandy loam, Alberta NR; pea-wheat-canola-wheat rotation
Winter Pea + Rye *Pisum sativum* + *Secale cereale*	Karpenstein-Machan and Stuelpnagel 2000	~6-12 ~200	Silty clay, Germany ~ 4 months; 3 different seeding mixtures
Winter Pea (Austrian) *Pisum sativum* subsp arvense	Singogo et al. 1996	3.2-7.6 107-230	Sandy loam, Kansas 7-8 months
Oilseed radish *Raphanus sativus*	Dapaah & Vyn 1998	2.5-3.5 NR	Loam, Ontario 3 months; intercropped with barley
Rye *Secale cereale*	Cline & Silvernail 2001, 2002	3.5-4.0 (0N), 4.0-9.0 (140N) 28-43 (0N), 43-64 (140N)	Silt loam, Kentucky 8 months; 0 or 140 kg N ha^{-1} for preceeding corn crop
	Griffin, et al. 2000	4.1-6.6 52-66	Silt loam, Maine 9 months

AAR = average annual rainfall; NR = not reported.

Table 1.1. Continued.

Green Manure	Study	Dry Weight (Mt ha^{-1}) N Content (kg ha^{-1})	Environment Growth Time; Management Notes
Rye *Secale cereale*	Karpenstein-Machan and Stuelpnagel 2000	~9-13.5 NR	Silty clay, Germany ~4 months
	Ranells and Wagger 1996	1.5-5.7 17-64	Loamy sand, Georgia 6 months
	Ross et al. 2001	2.7-3.4 (n), 6.4 (m) NR	Silty clay loam, Alberta 14-16 weeks; mowed at 7-8 wks (m) and non-mowed (n)
	Ross et al. 2001	0.5-0.6 (n) NR	Loam, Alberta 14-16 weeks; mowed at 7-8 wks (m) and non-mowed (n)
	Tollenaar et al. 1993	1.0-6.1 NR	Loam, Ontario 8 months; 4 rye cultivars
Sesbania *Sesbania macrantha*	Steinmaier & Ngoliya 2001	7.1 124	Sandy loam, Zambia 14 weeks (?)
Sesbania *Sesbania rostrata*	Kouyate et al. 2000	0.7-1.4 NR	Loamy sand, Mali NR; AAR = 619 mm
	Kouyate et al. 2000	2.3-4.6 NR	Loam, Mali NR; AAR = 619 mm
Sesbania *Sesbania rostrata*	Ladha et al. 2000	3.2-4.6 71-88	Silty clay, Philippines 6-9 weeks; flooded
Stylo *Stylosanthes guianensis*	Steinmaier & Ngoliya 2001	4.3 88	Sandy loam, Zambia 14 weeks (?)
Teramnus *Teramnus uncinatus*	Steinmaier & Ngoliya 2001	3.8 80	Sandy loam, Zambia 14 weeks (?)
Berseem Clover *Trifolium alexandrinum*	Ross et al. 2001	6.7-10.2 (n), 9.2 (m) NR	Silty clay loam, Alberta 14-16 weeks; mowed at 7-8 wks (m) and non-mowed (n)
	Ross et al. 2001	4.0-6.0 (n) NR	Loam, Alberta 14-16 weeks; mowed at 7-8 wks (m) and non-mowed (n)
	Shresthra et al. 1999	1.9 (C), 4.1 (N) NR	Loam, Michigan 13 weeks; cut for forage at 60 days (C) or not (N)
Kura Clover *Trifolium ambiguum*	Zemenchik et al. 2000	6.2-10.7 NR	Silt loam, Wisconsin NR; intercropped with corn, then grown alone
Alsike Clover *Trifolium hybridum*	Ross et al. 2001	3.0-4.6 (n), 6.1 (m) NR	Silty clay loam, Alberta 14-16 weeks; mowed at 7-8 wks (m) and non-mowed (n)
	Ross et al. 2001	2.5-2.7 (n) NR	Loam, Alberta 14-16 weeks; mowed at 7-8 wks (m) and non-mowed (n)

AAR = average annual rainfall; NR = not reported.

Table 1.1. Continued.

Green Manure	Study	Dry Weight (Mt ha^{-1}) N Content (kg ha^{-1})	Environment Growth Time; Management Notes
Crimson Clover *Trifolium incarnatum*	Abdul-Baki et al. 1996	4.2-5.7 151	Sandy Loam, Maryland 8 months
	Dyck & Liebman 1995	5.8-7.3 130-143	Sandy loam, Maine 3.5 months
	Dyck et al. 1995	4.8-5.1 117-123	Sandy loam and silt loam, Maine 2-2.5 months
	Karpenstein-Machan and Stuelpnagel 2000	~4-10.5 ~200	Silty clay, Germany ~4 months
	Ranells and Wagger 1996	1.4-5.0 35-134	Loamy sand, Georgia 6 months
Crimson Clover *Trifolium incarnatum*	Ross et al. 2001	2.1-4.0 (n), 5.7 (m) NR	Silty clay loam, Alberta 14-16 weeks; mowed at 7-8 wks (m) and non-mowed (n)
	Ross et al. 2001	3.7-5.1 (n) NR	Loam, Alberta 14-16 weeks; mowed at 7-8 wks (m) and non-mowed (n)
Crimson Clover + Rye *Trifolium incarnatum* + *S. cereale*	Karpenstein-Machan and Stuelpnagel 2000	~6-12 ~200	Silty clay, Germany ~4 months; 3 different seeding mixtures
	Ranells and Wagger 1996	2.3-5.2 42-111	Loamy sand, Georgia 6 months
Balansa Clover *Trifolium michelianum* var balansae	Ross et al. 2001	2.5-4.5 (n), 7.2 (m) NR	Silty clay loam, Alberta 14-16 weeks; mowed at 7-8 wks (m) and non-mowed (n)
	Ross et al. 2001	2.3-3.5 (n) NR	Loam, Alberta 14-16 weeks; mowed at 7-8 wks (m) and non-mowed (n)
Red Clover *Trifolium pratense*	Dapaah & Vyn 1998	2.4-3.7 NR	Loam, Ontario 10 months; intercropped with barley
	Davis & Liebman 2001	1.5-3.0 72-115	Sandy loam, Maine NR; intercropped with wheat
	Guldan et al. 1996	0.8-1.9 29-49	Sandy loam, New Mexico 22 weeks; interseeded in sweet corn after 2 weeks
	Guldan et al. 1996	0.3-0.6 13-16	Sandy loam, New Mexico 17 weeks; interseeded in sweet corn after 7 weeks
	N'Dayegamiye & Tran 2001	0.6-0.7 13	Silt loam, Canada 4 months; 30 kg N ha^{-1} applied
	Ross et al. 2001	1.7-2.9 (n), 5.2 (m) NR	Silty clay loam, Alberta 14-16 weeks; mowed at 7-8 wks (m) and non-mowed (n)

NR = not reported.

Table 1.1. Continued.

Green Manure	Study	Dry Weight (Mt ha^{-1}) N Content (kg ha^{-1})	Environment Growth Time; Management Notes
	Ross et al. 2001	2.1-2.2 (n) NR	Loam, Alberta 14-16 weeks; mowed at 7-8 wks (m) and non-mowed (n)
	Soon et al. 2001	1.7-3.6 51-94	Sandy loam, Alberta NR; red clover-wheat-canola-wheat rotation
	Stopes et al. 1996	0.8-25.4* 21-741*	Clay loam, England *6-25 months of growth; periodic mowing
White Clover *Trifolium repens*	Ross et al. 2001	0.8-2.1 (n), 4.0 (m) NR	Silty clay loam, Alberta 14-16 weeks; mowed at 7-8 wks (m) and non-mowed (n)
	Ross et al. 2001	2.7-3.0(n) NR	Loam, Alberta 14-16 weeks; mowed at 7-8 wks (m) and non-mowed (n)
	Stopes et al. 1996	0.6-25.0* 17-592*	Clay loam, England *6-25 months of growth; periodic mowing
Persian Clover *Trifolium resupinatum*	Ross et al. 2001	1.7-3.4 (n), 7.2 (m) NR	Silty clay loam, Alberta 14-16 weeks; mowed at 7-8 wks (m) and non-mowed (n)
	Ross et al. 2001	3.7-4.6 (n) NR	Loam, Alberta 14-16 weeks; mowed at 7-8 wks (m) and non-mowed (n)
Wheat *Triticum aestivum*	Singogo et al. 1996	4.9-9.8 81-87	Sandy loam, Kansas 7-8 months;
Hairy Vetch *Vicia villosa*	Abdul-Baki et al. 1996	4.4-5.2 167-197	Sandy Loam, Maryland 8 months
	Cline & Silvernail 2001, 2002	3.5-4.0 (0N ≈ 140N) 115-164 (0N ≈ 140N)	Silt loam, Kentucky 8 months; 0 or 140 kg N ha^{-1} for preceeding corn crop
	Guldan et al. 1996	1.8-3.8 70-124	Sandy loam, New Mexico 22 weeks; interseeded in sweet corn after 2 weeks
	Guldan et al. 1996	1.5-2.8 58-88	Sandy loam, New Mexico 17 weeks; interseeded in sweet corn after 7 weeks
	Puget & Drinkwater 2001	4.4 NR	Silt loam, Pennsylvania ~ 8 months
	Ranells and Wagger 1996	2.9-4.8 125-182	Loamy sand, Georgia 6 months
	Sainju & Singh 2001	3.0-6.7 104-257	Sandy loam, Georgia ~ 6 months; 3 tillage types, 2 kill dates
	Singogo et al. 1996	5.6-8.9 233-247	Sandy loam, Kansas 7-8 months

NR = not reported.

Table 1.1. Continued.

Green Manure	**Study**	**Dry Weight (Mt ha^{-1})** **N Content (kg ha^{-1})**	**Environment** **Growth Time; Management Notes**
Hairy Vetch + Rye *Vicia villosa* + *Secale cereale*	Abdul-Baki et al. 1996	5.9 120-162	Sandy Loam, Maryland 8 months
	Cline & Silvernail 2001,2002	4.0 (0N), 4.0-10.0 (0N) 104-152 (0N), 141-149 (140N)	Silt loam, Kentucky 8 months; 0 or 140 kg N ha^{-1} for preceeding corn crop
	Griffin, et al. 2000	3.6-6.9 57-209	Silt loam, Maine 9 months
	Ranells and Wagger 1996	3.0-5.4 82-200	Loamy sand, Georgia 6 months
Black Gram *Vigna mungo*	Seneratne & Ratnasinghe 1995	7.1-8.8 (stover) 104-155 (stover)	NR, Sri Lanka 11-12 weeks
Mung bean *Vigna radiata*	Seneratne & Ratnasinghe 1995	3.1-5.5 (stover) 30-88 (stover)	NR, Sri Lanka 11-12 weeks; 2 cultivars
	Thonnissen et al. 2000a	1.1 26	NR, Taiwan & Philippines 9-11 weeks
Cowpea *Vigna unguiculata*	Carsky et al. 1999	0.6 (13 and 19 wks) 16 (13 wks), 21 (19 wks)	Loamy sand, Nigeria 13 and 19 weeks; AAR = 1350 mm
	Carsky et al. 1999	1.4 (13 wks), 2.3 (19 wks) 45 (13 wks), 58 (19wks)	Clay loam, Nigeria 13 and 19 weeks; AAR = 900 mm
	Jeranyama et al. 2000	0.6-4.6 15-154	Loamy sand, Zimbabwe 11 weeks
	Kouyate et al. 2000	1.5-2.5 NR	Loamy sand, Mali NR; AAR = 619 mm
	Kouyate et al. 2000	1.1-2.4 NR	Loam, Mali NR; AAR = 619 mm
	Seneratne & Ratnasinghe 1995	3.7-8.5 42-155	NR, Sri Lanka 11-12 weeks; 3 cultivars

AAR = average annual rainfall; NR = not reported.

Table 1.2. Overview of experimental treatments.

Treatment	Crop 1 July-November	Crop 2 November-April	Crop 3 April-July
(1) SH+L 0N	Sunn hemp	Lupin(Year1) or Vetch(Year2)	Sweet Corn + 0 N
(2) SH+L 67N	Sunn hemp	Lupin(Year1) or Vetch(Year2)	Sweet Corn + 67 N
(3) SH+L 133N	Sunn hemp	Lupin(Year1) or Vetch(Year2)	Sweet Corn + 133 N
(4) SH 0N	Sunn hemp	Fallow	Sweet Corn + 0 N
(5) SH 67N	Sunn hemp	Fallow	Sweet Corn + 67 N
(6) SH 133N	Sunn hemp	Fallow	Sweet Corn + 133 N
(7) L 0N	Fallow	Lupin(Year1) or Vetch(Year2)	Sweet Corn + 0 N
(8) L 67N	Fallow	Lupin(Year1) or Vetch(Year2)	Sweet Corn + 67 N
(9) L 133N	Fallow	Lupin(Year1) or Vetch(Year2)	Sweet Corn + 133 N
(10) Conv 0N	Fallow	Fallow	Sweet Corn + 0 N
(11) Conv 67N	Fallow	Fallow	Sweet Corn + 67 N
(12) Conv 133N	Fallow	Fallow	Sweet Corn + 133 N
(13) Conv 200N	Fallow	Fallow	Sweet Corn + 200 N
(14) Conv 267N	Fallow	Fallow	Sweet Corn + 267 N
(15) Fal	Fallow	Fallow	Fallow

SH = sunn hemp; L = winter legume; Conv = conventional; Fal = Complete fallow;
N = kg NH_4NO_3-N ha^{-1}.

CHAPTER 2
GREEN MANURE GROWTH AND DECOMPOSITION

Introduction and Literature Review

Due to coarse texture, high temperatures and high rainfall, many Florida soils contain little organic matter (less than 1-2%) and possess poor water and nutrient retention. This is especially true for agricultural soils that experience regular tillage and low carbon (C) input rates. Legumes utilized as green manures may be useful as a component of sustainability in such production environments. A green manure (GM) is a crop used primarily as a soil amendment and a nutrient source for future crops. Legumes may add nitrogen (N) to the system through biological fixation and can correct phosphorus (P) imbalances typically associated with excess applications of animal manures. The slow release of N from decomposing GM residues may be better timed with plant uptake (Bath 2000, Wivstad 1997). Unlike chemical fertilizers, legumes may fix and add large amounts of C to a cropping system (Hargrove 1986, Sharma and Mittra 1988, Goyal et al. 1992) and may drive long-term increases of soil organic matter and microbial biomas (Goyal et al. 1992, 1999). Green manures may provide other benefits such as reduction of soil erosion, conservation of soil water, improved retention of other crop nutrients, and control of plant pests, pathogens and weeds with less reliance on off-farm chemical inputs (Bugg et al. 1991a McSorley 1999, Ross et al. 2001).

Effective use of GMs is often hampered by lack of precise information about N availability for future crops. Nitrogen accumulation and subsequent release from decomposing GMs depends largely on residue composition and N concentration,

temperature, water availability, and residue management (Schomberg et al. 1994, Andren 1992), which in turn depend on GM species, site environment (climate, soil, weather, etc.), and cropping system. Table 1.1 outlines the dry matter and N accumulation of about 50 GM species from 40 studies. While not exhaustive, this review probably represents a major cross section of recent GM studies, most of which took place in temperate (and high latitude) or tropical (equatorial) regions on relatively fine-textured soils. Results of such studies may not extend to intermediate regions such as Florida. In temperate regions, the cooler and often less variable temperature regimes with longer daylight hours may be more conducive to temperate legumes. Compared to tropical regions, much of Florida experiences winter freezes that kill warm weather annuals used as both GMs and many of the crops that follow them. Sandy soils and unique pest problems also make establishment more challenging, especially for temperate GMs such as clovers and medics.

Additionally, pertinent information about composition and N concentration of GMs as they change over a growing season is often lacking. Almost all studies report end-of-season GM biomass and N content/concentration only. For example, of the peer-reviewed literature sampled in Table 1.1, only Karpenstein-Machan and Stuelpnagel (2000) provide growth analysis of investigated GMs. This poses an obstacle to GM adoption because growing time in an on-farm production system differs from that studied in research, creating yet another way GM biomass and composition in an on-farm setting may differ from reported findings.

Biological N-fixation and overall N-accumulation rates are primary factors governing the adequacy of a GM as an N-source. Estimates of N accumulation for

leguminous GMs and the relative contribution of biological N fixation in this process ranges broadly depending on soil fertility, water availability, and GM species. Generally speaking, legumes will take up what N is available from the soil, but thereafter will accumulate N from biological fixation to meet demand. For example, sunn hemp (*Crotalaria juncea*) has been estimated to fix 27-39% (Ramos et al. 2001), 72-81% (Ladha et al. 1996), and 91% (Senaratne and Ratnasinghe 1995) of its total N in different study locations and conditions. Water stress and deficiency of nutrients other than N may significantly reduce fixation, either directly or through reduced availability of assimilates from photosynthesis. Although they did not report rainfall or temperature conditions, Ladha et al. (1996) attributed a 9% differential in relative contribution of fixed N in sunn hemp over two years to differences in weather patterns that directly affected plant growth. Reduction of soil N through competition may increase rates of biological N-fixation. Karpenstein-Machan and Stuelpnagel (2000) found that relative contribution of N-fixation to hairy vetch (*Vicia villosa*) and crimson clover (*Trifolium incarnatum*) N increased when intercropped with an increasingly larger proportion of cereal rye (*Secale cereale*).

Nitrogen contributions from below-ground tissues of GMs (roots, root nodules) is difficult to determine due to rapid turnover of these tissues and possible root exudation of N. For example, Ramos et al. (2001) determined that 39-49% of all N accumulated by *Canavalia ensiformis* and *Mucuna aterrima* GMs was belowground, and 10-12% of all accumulated N transferred to the soil by root and nodule turnover and root exudation. In a 3-year study, Griffin et al. (2000) reported 56%, 46%, and 38% of biomass and 32%, 28%, and 19% of total N in roots at final sampling for alfalfa (*Medicago sativa*), cereal

rye, and hairy vetch plus rye intercrop. However, both of these studies occurred on fine textured and/or high fertility soils.

Soil-based residue decomposition and N-release generally occur faster for residues with lower C:N ratios and lignin and polyphenol contents, with optimum temperature and water availability usually around 35 C and field capacity, respectively (Andren et al. 1992, Lomander et al. 1998, Vigil and Kissel 1995). Mathematically, these investigators often characterize decomposition as a negative exponential decline in residue biomass or C over time, with the rate affected by a "decay rate constant" that may depend on temperature, water availability, N availability, and chemical quality of the residue. Investigators may gain greater accuracy by statistically resolving decomposition into two "pools" with faster and slower decay rate constants. For example, Somda et al. (date unknown) used a litterbag study of a number of legumes and non-legumes; C:N and lignin:N ratios were generally lower for legumes (8:1-27:1, and 2:1-9:1, respectively) than for non-legumes (27:1-186:1, and 4:1-44:1, respectively) as were decay rate constants of both fast and slow pools. Kuo and Sainju (1997) showed mixing hairy vetch residue with increasingly large proportions of cereal rye and rye grass (*Lolium multiflorum*) residues slowed the relative rate of N release. Working in Georgia, Ranells and Wagger (1996) also found faster decomposition and N-release for hairy vetch and crimson clover grown alone than when grown with cereal rye, but still found no net N-immobilization in any treatment (including rye alone).

For materials with low lignin:N, C:N may control decomposition, while lignin:N ratio may become more important as it becomes higher. Decomposition of mixed materials over time may therefore involve control by C:N initially, then lignin:N as

recalcitrant material makes up more of the remainder (Mueller et al. 1998). Palm and Sanchez (1991) also found that polyphenol concentration may exert more control over breakdown rates than lignin and N concentrations for residues high in polyphenols. In a review of previously published data from 11 studies, Seneviratne (2000) found that: when N availability is limiting (typically, plant residues with N concentrations less than 2%) a positive linear relationship existed between N-release and N concentration ($r^2 = 0.63$); when N concentration was non-limiting (typically, residues with N concentration greater than 2%) N concentration does not affect N-release; C:N ratio was a good predictor of N release over a wide range of N contents; and polyphenol content better predicted N-mineralization than lignin:N in low N residues in tropical environments.

Leaf C:N ratio and lignin content is generally much lower than stems or roots of the same plant, and in most studies leaf decomposition and N release occurs significantly faster than for other tissues. Prolonged periods of N-immobilization (when decomposition results in a net accumulation of N) are often recorded for recalcitrant stems and roots (Collins et al. 1990, Cobo et al. 2002). Cobo et al. (2002) characterized decomposition, N, P, K, Ca, and Mg release, as well as C, lignin, polyphenol, and cell wall contents of leaves and stems of about one dozen different tropical legumes. On average leaves decomposed five times faster than stems, decomposition was closely related to cell wall content, and N release most dependent on lignin:N ratio. Cobo et al. (2002) found that decomposition and N-release was faster for stems mixed with leaves than for stems alone, and slower for leaves mixed with stems than leaves alone. Both Cobo et al. (2002) and Collins et al. (1990) showed the decomposition rate of different tissue types decomposing together was faster than predicted by summing individual

decomposition rates. These studies suggest fungal decomposers may redistribute N from leaves to more recalcitrant tissues during decomposition.

Puget and Drinkwater (2001) used ^{13}C to compare the decomposition of root and shoot derived C in hairy vetch residues on a silt loam in Pennsylvania. In their study, shoot and root biomass for vetch was 3.71 and 0.89 Mt ha^{-1} respectively, lignin:N six times higher in roots, and non-structural carbohydrates (eg, sugars and starches) was four times higher in shoots. Twenty-two weeks after soil-incorporation, 13% of shoot C and 49% of root C remained in the soil, making the overall mass of shoot and root contributions to soil organic C relatively equal at this time.

Soil incorporation of plant residues may speed decomposition and N release by buffering temperature and water regimes relative to the surface. Hargrove et al. (date unkown), Schomberg et al. (1994), and Thonissen et al. (2000) showed more rapid decomposition of soil incorporated residues vs surface residues in no-till systems. Schomberg et al. (1994) also found greater N-immobilization potential for surface sorghum (*Sorghum bicolor*) and wheat (*Triticum aestivum*) residue, although initial N-immobilization was more rapid when the residues were buried. At peak immobilization (5 months to 1 year or more), highly recalcitrant (sorghum and wheat) residues tied up 150-170% of their initial N content. For these low-N residues net N immobilization lasted longer than one year on soil surface (study ended after 1 year) and only 1/3 year for buried residues. Nitrogen immobilization ended and release began only when 45-55% of the residue mass had decomposed. Bowen et al. (1993) found that 60-80% of N applied within 10 legume GMs was released as inorganic-N within 120-150 days after soil incorporation, while Thonnissen et al. (2000b) found similar levels of N-release to take

place faster (within 2-6 weeks) for soybean (*Glycine max*) and vetch. In Alabama, however, Mansoer et al. (1997) found less than 50% of N remaining in surface and soil-incorporated sunn hemp, respectively, at 16 weeks after plant death..

Most studies reviewed here found best correlation with two-pool exponential models for decomposition and N-release (see Katterer et al. 1998 for a review). More complex decomposition/N-release models exist that make use of residue quality, soil, and weather data to predict decomposition, including the CERES and CENTURY models used by DSSAT (Decision Support System for Agrotechnology Transfer, see Jones et al. 2003). These and similar models can often be adjusted to more accurately reflect actual decomposition and N-release data obtained in field experiments (Bowen et al. 1993, Hadas et al. 1993, Quemada et al. 1997).

As part of a larger study on improved use of GMs in vegetable cropping systems in Florida, we investigated a GM sequence of sunn hemp (SH) followed by a winter legume (L) of blue lupin (*Lupinus angustifolius*, winter 2001-02) and cahaba white vetch (*Vicia sativa*, winter 2002-03) as an N-source for sweet corn (*Zea mays* var Rugosa). We hypothesized that sunn hemp stem residues would immobilize a significant amount of N during winter decomposition, and that growth of winter legumes following sunn hemp would be enhanced, reaching levels more typically seen in temperate environments. The objectives of this particular study component were to generate detailed information about GM biomass and N accumulation by tissue fraction during growth, and subsequent decomposition and N-release by the summer GM over the winter.

Materials and Methods

Set-up and Design

This study consisted of nine of the 15 overall treatments related in Chapter 1 (Table 1.2). Only treatments with GM components in the rotation were investigated here: sunn hemp followed by lupin (winter 2001-02) or vetch (winter 2002-03; treatment denoted as SH+L), sunn hemp followed by fallow (SH), fallow followed by lupin or vetch (L). Only methods relevant to GM growth, N-accumulation, decomposition and N-release are presented in this chapter. Methods regarding GM effects on sweet corn growth analysis, root dynamics, and yield, and effects on soil properties and plant pests are discussed in relevant chapters.

Timeline of Operations

2001-02

On 7 August 2001, sunn hemp was planted following complete disking and plowing of the field. Seed was inoculated with cowpea-type rhizobium and planted at 2-4 cm depth. In-row spacing was 3.12 cm (1.25 in), between-row spacing was 76 cm (30 in). Sunn hemp emerged 11 August 2001 and grew until 31 October 2001 when it was killed with an application of Gramoxone (Syngenta; Basel, Switzerland). Lupin was inoculated with lupin-type rhizobium and planted on 19 November 2001 using a rip-strip planter and with spacing identical to sunn hemp. Lupin emerged 22 November 2001 and grew until 12 April 2002. All plots were then mown and field treated with RoundUp (RoundUp; Columbus, OH). Sweet corn (variety GS 0966, Syngenta) was planted 26 April 2002 using a rip-strip planter, with in-row spacing of 18 cm and between-row spacing of 75 cm.

2002-03

On 19 July 2002, inoculated sunn hemp was planted with a rip-strip planter at the same spacing and depth as year 1, emerging 21 July 2002 and growing until 30 October 2002 when it was killed with Diuron/Touchstone. Cahaba white vetch was inoculated with vetch-type rhizobium and planted 15 November 2002 with a zero-till grain-drill at a rate of ~35 kg ha^{-1} (30 lbs $acre^{-1}$). Sweet corn (variety GS 0966, Syngenta) was directly planted into vetch on 7 April 2003.

Measurements

2001-02

Sunn hemp was sampled from 8 of the 24 plots every two weeks after emergence (WAE), and at final sampling all plots were sampled. Sunn hemp was also sampled at 4, 6, 10, 12, and 16 weeks after death (WAD). Decomposition was therefore quantified for undisturbed material (not dried). Due to poor stand establishment, lupin was sampled from 6 of 24 plots at 4, 8, 12, and 16 WAE, and at final sampling (20 WAE) all plots were sampled. In each sampled plot, 61 cm (2 ft) of row length representative of the entire plot and with uniform emergence was removed at each sampling, brought to the UF Environmental Agronomy Lab (University of Florida, Gainesville, FL), refrigerated before processing (no longer than one week). Entire plants were removed including roots. In Gainesville, heights for all sampled plants were recorded, with plants subsequently separated into leaves, stems, roots, and reproductive tissues (flowers and pods, where existing). Roots were washed clean of soil and debris. Total sample leaf number and area and leaf, stem, root, and reproductive (flowers/pods) fresh weights were taken for each sample. Leaf area was determined with an LI-3000 (Li-cor; Lincoln, NE). Dry weights were recorded for subsamples after oven-drying at 65 C for 72 hours. Afterwards, all

subsamples were ground in a Wiley mill to pass through a 2 mm screen, and a thoroughly mixed 5 g portion of each grinding was subsequently stored. Grindings were then subjected to a wet-acid Kjeldahl digestion, diluted, filtered, and analyzed for total Kjeldahl N at the UF-IFAS Analytical Research Lab (University of Florida, Gainesville, FL; EPA Method 351.2; Jones and Case 1991).

For each sample, shoot to root ratio of biomass (S:R-B) was calculated as the sum of above ground dry matter divided by root dry matter (kg kg^{-1}), and shoot to root ratio of N (S:R-N) was calculated as shoot N content divided by root N content (kg kg^{-1}). Specific leaf area (SLA) was calculated as cm^2 leaf g^{-1} leaf dry weight, and specific leaf N (SLN) was calculated as μg N cm^{-2} leaf. Leaf area index (LAI) was determined by sample leaf area divided by sampled area (sampled row length x between row space; m^2 leaf m^{-2} ground).

2002-03

Sunn hemp was sampled from all 24 plots at 2, 6, 10, and 14 WAE, and also from treatments SH 0N and SH 133N at 4, 8, and 12 WAE. Sunn hemp residue was sampled at 2, 4, 6, 8, 11, 14, and 18 weeks after death WAD. Vetch was sampled from all 24 plots every 3 weeks after emergence. Row length sampled remained 61 cm. When plants became large, all but 1-3 plants were clipped at ground level, weighed, and returned to the plot. The subsample of 1-3 representative plants was excavated and taken to the Environmental Agronomy Lab for measurement of the same growth parameters as described for the previous year, with identical grinding and N analysis. Throughout both years, continuous measurements of solar radiation, air temperature and relative humidity at 1 m, rainfall/irrigation, and soil temperature at 12.5 cm were made using a Watchdog datalogger (Spectrum Technologies; Plainfield, IL).

Analysis

Numerical trends and figures were developed using MS Excel. Using SAS statistical software package (Statistical Analysis Systems; Cary, NC), a general linear model was developed for final sampling data to assess the possibility of significant differences due to GM combinations, sweet corn chemical N-fertilization rate, interaction between GM type and N-rate, and replication effects for all measurements. Green manure type, chemical N-rate, and the interaction of the two were insignificant at the $\alpha = 0.05$ level of significance in either year. Results are therefore presented as averages of all sampled treatments.

Results

Sunn Hemp 2001

Growth

As the initial crop of the experiment, all plots had identical histories (same previous crops, same fertilization levels), and throughout the season no significant differences existed for any factor of sunn hemp growth due to main or sub-effects. Figure 2.1(a) illustrates the accumulation and subsequent decomposition of sunn hemp biomass by tissue type for 2001. Figure 2.1(b) shows accumulation and subsequent loss of sunn hemp N by tissue type. Sunn hemp produced a total of 8.00 ± 0.40 Mt ha^{-1} and 76 ± 4 kg N ha^{-1} by final sampling at 12 WAE. Of this, 6.95 ± 0.37 Mt ha^{-1} (87%) and 72 ± 4 kg N ha^{-1} (94%) was above ground. Maximum LAI of 3.59 ± 0.25 occurring 10 weeks after emergence (WAE) (Figure 2.2a). Average daily maximum temperatures remained around 36 C during August and September of 2001 and around 33 C during October of 2001.

In terms of biomass, leaves accounted for the largest tissue fraction in samplings during the first 4 WAE (58% and 51% of total biomass at 2 and 4 WAE). By 6 WAE

stems became the largest single tissue fraction, accounting for over half of total dry weight by 8 WAE. Stem and root dry weight increased throughout the entire growth season reaching final values of 4.76 ± 0.26 and 1.05 ± 0.06 Mt ha^{-1} respectively; leaf biomass increased for 10 weeks to a maximum value of 1.50 ± 0.07 Mt ha^{-1}. Flowers did not appear until 8 WAE and increased to 0.76 ± 0.05 Mt ha^{-1} by 12 WAE (Figure 2.1a).

Leaves and flowers possessed relatively high N concentrations that changed little throughout the season (20.1-21.8 g N kg^{-1} and 24.1-29.0 g N kg^{-1} respectively). Stems and roots had much lower N concentrations that tended to decrease as a negative exponential throughout the season (from 12.0 to 5.0 g N kg^{-1} and from 8.5 to 4.6 g N kg^{-1} respectively, with r^2 = 0.93 and 0.97). Total N concentration showed an exponential decay over time from 16.2 to 10.0 g N kg^{-1}, reflecting increasing contribution from stems and roots (Table 2.1).

Leaves formed the largest N pool of any tissue throughout the growing season, reaching a maximum at 33 ± 2 kg N ha^{-1} at 8 WAE. Leaves and flowers (when flowers existed) together accounted for most sunn hemp N throughout the season, beginning at 76% (2WAE) and decreasing down to 62% at final sampling (12 WAE). Flower N was maximum at final sampling (18 ± 1 kg N ha^{-1}). In terms of N content and as proportion of total plant N content, stem N increased throughout the season reaching final values of 25 ± 1 kg N ha^{-1} and 32%, respectively. Except at first sampling, roots typically formed the smallest N pool (about 6-8% of total N), reaching a final N content of only 5 ± <1 kg N ha^{-1} (Figure 2.1b).

Shoot to root biomass ratio (S:R-B) increased linearly (r^2 = 0.92) from 2.7 ± 0.3 kg kg^{-1} to 6.8 ± 0.3 kg kg^{-1} over the 12 week growth season. Shoot to root N ratio (S:R-N)

also increased linearly ($r^2 = 0.95$) from 6.2 ± 0.6 kg kg^{-1} to 17.5 ± 2.3 kg kg^{-1} (Table 2.2). Both changes reflected the increasing amounts of biomass and N sent to shoots relative to roots. The ratio of S:R-N to S:R-B remained almost unchanged throughout the season at an average of 2.36 ± 0.13 (Figure 2.3a), showing that partitioning of N and biomass to roots and shoots remained consistent relative to each other. Specific leaf area (SLA) varied between 209 and 297 cm^2 g^{-1} over the season and was somewhat described by a polynomial behavior ($r^2 = 0.60$), showing a maximum at 4-6 WAE. Because leaf N concentration changed very little over the season, specific leaf N (SLN) was basically a mirror image of SLA, varying from 74 to 97 μg N cm^{-2} leaf, showing a minimum at 4-6 WAE and also being somewhat described by a polynomial ($r^2 = 0.50$; Table 2.2).

Decomposition

Residue decomposition (loss of dry matter) and N-loss were greatest during the first two weeks after death, after which reductions were much less rapid or even non-detectable (Figure 2.1). Total plant decomposition and N-loss were 40% ± 9% and 61% ± 7%, respectively, at 2 weeks after death (2 WAD). Final residue dry weight at 16 WAD was 52% ± 14% of the original 8.00 Mt ha^{-1}, but after the initial sharp drop at 2 WAD there was no little change in dry weight. Final residue N content at 16 WAD was only 20% ± 6% of the original 61 kg N ha^{-1}, and although residue N-loss was also slow and not always resolvable between sample dates final, N content was significantly lower than N content at 2 WAD (Figure 2.1b).

Most rapid decomposition and N-loss occurred for leaves and flowers (which were pooled together as they were too difficult to separate). Leaf and flower (combined) dry weight and N content at 2 WAD were only 25% ± 3% and 15% ± 2%, respectively, of the original amount before death. Rate of loss may have been inflated because two herbicide

applications were required to kill sunn hemp over a two-week period, during which leaves generally died before stems and roots. However, no significant leaf and flower material persisted by 12 WAD to sample. Roots also showed an initial flush of decomposition, with only 50% ± 8% and 25% ± 8% of dry weight and N content, respectively, remaining at 2 WAD (Figures 2.1 and 2.2). Root N concentration declined from 3.7 ± 0.2 g N kg^{-1} at death to 2.2 ± 0.1 g N kg^{-1} at 2WAD and 2.0 ± 0.3 g N kg^{-1} at 4 WAD (Table 2.3). Afterwards, roots showed little dry weight decomposition until final sampling at 16 WAD when only 0.28 ± 0.06 Mt ha^{-1} (26% ± 6% of original) remained (Figure 2.1). At the same time, roots showed a consistent trend towards N-immobilization, with N concentration rebounding steadily to 3.0 g N kg^{-1} by final sampling (16 WAD; Table 2.3) and root N content increasing back up to 40% ± 11% of the original at 12 WAD, though this trend amounted to immobilization of no more than 2 kg N ha^{-1} at that time (with a total root N content of 2 ± < 1 kg N ha^{-1}; Figure 2.2). By final sampling at 16 WAD, root N content decreased to 1 ± < 1 kg N ha^{-1} (28% ± 6% of the original; Figure 2.1b).

Stem decomposition and N-loss occurred more slowly than all other tissue types, maintaining 77% ± 14% and 89% ± 19% of original dry weight and N content, respectively, at 2 WAD. Stem dry weight remained stable after 2 WAD with little changes, with 3.86 ± 1.02 Mt ha^{-1} (81% ± 22% of original) remaining at 16 WAD. However, sample variability was quite high throughout the decomposition period (Figure 2.1). Average stem N content also showed little change after 2 WAD, though there was a general decrease and by 12 WAD stem N content (14 ± 3 kg N ha^{-1}) was significantly less than original. Stem N content at final sampling (11 ± 3 kg N ha^{-1}) was 56% ± 15% of

original (Figure 2.1b). Stem N concentration after 2 WAD also declined steadily, reaching 3.0 ± 0.1 g N kg^{-1} at 16 WAD (see Table 2.3).

Sunn hemp 2002

Growth

Figure 2.4a illustrates the accumulation and subsequent decomposition of sunn hemp biomass by tissue type for 2002, and Figure 2.4b shows accumulation and subsequent loss of sunn hemp N by tissue type. Sunn hemp produced a total of 12.26 ± 0.38 Mt ha^{-1} and 134 ± 5 kg N ha^{-1} by final sampling at 14 WAE, exceeding 2001 final production by 53% and 106% respectively (Figure 2.2b). Of 2002 production, 11.12 ± 0.35 Mt ha^{-1} (91% of total) and 127 ± 5 kg N ha^{-1} (95% of total) was above ground. Maximum LAI of 6.07 ± 0.28 occurred at 10 WAE (Figure 2.2a). Average daily maximum temperatures remained around 36 C from planting until final sampling throughout the 2002 season.

Although production was increased, dry matter partitioning among tissue fractions was almost identical to 2001. Leaf and stem production in 2002 exceeded 2001 by 6 WAE. Leaves accounted for the largest tissue fraction in samplings during the first 4 WAE (59% and 53% of total biomass at 2 and 4 WAE). By 6 WAE stems became the largest single tissue fraction, accounting for over half of total biomass by 8 WAE. Stem and root biomass increased throughout the entire growth season reaching final values of 8.76 ± 0.30 and 1.14 ± 0.05 Mt ha^{-1} respectively; leaf biomass increased for 12 weeks to a maximum value of 1.94 ± 0.15 Mt ha^{-1}, although changes in leaf biomass after 10 WAE were not significant. Flowers did not appear until 10 WAE and increased to 0.61 ± 0.05 Mt ha^{-1} by 12 WAE (Figure 2.4a).

Total N concentration and content was much higher in 2002, perhaps reflecting increased water availability (Figure 2.4b, Table 2.4). However, partitioning patterns remained similar. Leaves and flowers again had relatively high N concentration compared to stems and roots, although drops occurred in leaf N concentration just before flower appearance (10 WAE) and in flower N concentration at final sampling (probably due to a contribution from pods, which were pooled with flowers). Stems and roots again had lower N concentrations which tended to decrease as a negative exponential throughout the season (from 15 to 6 g N kg^{-1} and from 23 to 4 g N kg^{-1}, respectively, with $r^2 = 0.90$ and 0.94, respectively). Total N concentration also showed a negative exponential trend decreasing over time from 30 to 12 g N kg^{-1} (Table 2.4).

Leaves again formed the largest N pool of any tissue throughout the growing season, reaching a maximum at 63 ± 3 kg N ha^{-1} at 10 WAE. Leaves and flowers (when flowers existed) together accounted for most sunn hemp N throughout the season, beginning at 75% (2 WAE) and decreasing down to 57% at final sampling (14 WAE). Flower N-content was maximum at final sampling (15 ± 1 kg N ha^{-1}). In terms of N content and as proportion of total plant N content, stem N increased throughout the season reaching final values of 50 ± 2 kg N ha^{-1} and 37%, respectively. Except at first sampling, roots again formed the smallest N pool (about 4-9% of total N), reaching a final N content of only 7 ± 1 kg N ha^{-1} (Figure 2.4).

Biomass based shoot to root ratio (S:R-B) increased linearly ($r^2 = 0.99$) from 3.2 ± 0.2 kg kg^{-1} to 10.2 ± 0.4 kg kg^{-1} over the 14 week season. Except at final harvest (when a drop occurred), shoot to root N ratio S:R-N also increased linearly ($r^2 = 0.96$) from 4.53 ± 0.31 kg kg^{-1} to 36.0 ± 1.9 kg kg^{-1} (Table 2.5). The ratio of S:R-N to S:R-B did not remain

constant as in 2001, but increased linearly ($r^2 = 0.89$) except at final harvest when a drop occurred. This ratio increased from 1.43 ± 0.04 to 3.90 ± 0.15 from 2 to 12 WAE (Figure 2.3a), showing that partitioning to shoot biomass did not keep pace with partitioning to shoot N (relative to root N).

Specific leaf area and specific leaf N behaved similarly in 2002 as in 2001, but were greater than in 2001 by an average 26% and 69% over the season, respectively. Specific leaf area varied between 256 and 355 $cm^2\ g^{-1}$ over the season and was somewhat described by a polynomial behavior ($r^2 = 0.62$), showing a maximum at 6 WAE (Table 2.5). As in 2001, leaf N concentration changed very little over the season, and specific leaf N (SLN) was again a mirror image of SLA, varying from 105 to 135 μg N cm^{-2} leaf, showing a minimum at 10 WAE and also being somewhat described by a polynomial ($r^2 = 0.72$; Table 2.5).

Decomposition

Although residue decomposition and N-loss were again greatest during the first 2 WAD, residue decomposition proceeded more slowly and was less dramatic during this time. Total plant decomposition and N-loss were 24% ± 10% and 66% ± 3%, respectively, at 2 weeks after death (2 WAD; Figure 2.4). Final residue dry weight at 16 WAD was 6.91 ± 1.10 Mt ha^{-1} (56% ± 9% of the original 12.26 Mt ha^{-1}), but there was almost no significant change after 4 WAD (Figure 2.4a). Final residue N content at 16 WAD was only 21 kg N ha^{-1} (16% ± 3% of the original 134 kg N ha^{-1}), and, like decomposition, overall residue N-loss was virtually complete after only 4 WAD (Figure 2.4b).

Most rapid decomposition and N-loss again occurred for leaves and flowers, but the dynamics differed from 2001, with initial decomposition occurring more slowly (64% ±

8% and 46% ± 9% of original remaining at 2 and 4 WAD) and complete decomposition occurring rapidly between 4 and 6 WAD (4-5 weeks earlier than in 2001; Figure 2.4a). Nitrogen loss occurred more quickly than did decomposition, with only 28% ± 3% and 15% ± 3% of original leaf and flower N remaining at 2 and 4 WAD (Figure 2.4b).

Initial root N loss also proceeded more quickly than decomposition, with 34% ± 3% and 86% ± 12% of N content and dry weight, respectively, remaining at 2 WAD (Figure 2.4). Root N concentration declined from 6.1 ± 0.3 g N kg^{-1} at death to 3.3 ± 0.2 g N kg^{-1} at 2WAD and 1.6 ± 0.2 g N kg^{-1} at 6WAD (Table 2.6). After 6 WAD, roots showed little dry weight decomposition through final sampling at 16 WAD (61% ± 16% remaining). As in 2001, roots eventually showed a consistent trend towards N-immobilization, with N concentration rebounding at 8 WAD (3.3 ± 0.3 g N kg^{-1}) and remaining at 2.2-2.5 g N kg^{-1} through final sampling (16 WAD). However, the increase was generally not large enough to increase root N content in the face of decomposition (Table 2.6).

Stem decomposition and N-loss again occurred more slowly than all other tissue types, maintaining 82% ± 12% and 54% ± 7% of dry weight and N content, respectively, at 2 WAD (Figure 2.4). Beginning at 6 WAD, stem N concentration remained relatively unchanged at 0.25-0.30%, with only one sample date falling out of this range (Table 2.6). Stem dry weight remained stable after 6 WAD, with 6.21 ± 1.06 Mt ha^{-1} (71% ± 12% of original) remaining at 16 WAD, although sample variability was high throughout the decomposition period (Figure 2.4a). Except for a single outlying date, stem N content also remained relatively stable after 4 WAD, between 16 and 20 kg N ha^{-1} (Figure 2.4b).

Stems made up roughly 90% of total sunn hemp residue dry weight and N content after 8 WAD, with roots making up the remainder.

Lupin 2001-2002

Due to poor establishment, only treatments with lupin alone (L) were sampled until the final sampling date (20 WAE) when all lupin plots (L and SH+L) were sampled. At this sample date, a general linear model was developed to assess significance of previous sunn hemp presence on growth factors. Duncan comparisons were made at the $\alpha = 0.05$ level of significance, and effect of sunn hemp presence was non-significant. Lupin results are therefore presented as average of all treatments.

Figure 2.5 illustrates the accumulation of lupin biomass and N, respectively, by tissue type for 2001-02. Averaged over all treatments, lupin produced a total of 4.03 ± 0.18 Mt ha^{-1} and 53 ± 6 kg N ha^{-1} by final sampling at 20 WAE. Of this, 3.52 Mt ha^{-1} and 47 kg N ha^{-1} (87% and 90%) was above ground. Maximum LAI of 1.50 ± 0.09 also occurred at the final sampling at 20 WAE (Figure 2.2a).

Roots accounted for the largest tissue fraction at 4 WAE (44% of total), thereafter leaves (40% and 47% of total dry matter at 8 and 12 WAE) followed by stems (46% and 56% of total dry matter at 16 and 21 WAE) became dominant (Figure 2.5a). Stem and leaf dry matter increased throughout the entire growth season reaching final values of 2.25 ± 0.12 and 1.21 ± 0.03 Mt ha^{-1} respectively, although the increase in leaf dry matter from 16 to 20 WAE was small. Root dry matter reached a maximum 0.60 ± 0.13 Mt ha^{-1} at 16 WAE. Pods did not appear until final sampling at 20 WAE when they accounted for only 0.06 ± 0.01 Mt ha^{-1}. Large increases in biomass occurred between 8-12 and 12-16 WAE, with total dry weight more than quadrupling between each sampling and occurring

simultaneously with heavy root nodulation. However, biomass and N accumulation up to 12 WAE was relatively low (0.78 Mt ha^{-1} and 10 kg N ha^{-1}; Figure 2.5).

Leaves possessed relatively high N concentration, increasing logistically from 15.2 to 22.6 g N kg^{-1} by 16 WAE (Table 2.7). And although lupin stems and roots generally had lower N concentrations, stem N concentration increased linearly ($r^2 = 0.91$) from 5.5 to 7.5 g N kg^{-1} over the season, while root N concentration increased exponentially from 3.8 g N kg^{-1} at 4 WAE to a peak of 17.1 g N kg^{-1} at 16 WAE, then dropping to 11.0 g N kg^{-1} at 20 WAE. Total N concentration increased from 7.7 g N kg^{-1} (4 WAE) to 14.2 v (16 WAE), with a small drop at final sampling (20 WAE; Table 2.7). These trends in N concentration probably reflected the large increases in root nodulation seen around mid-season, followed by a general die-off of root nodules by final sampling.

Leaves formed the largest N pool of any tissue throughout the growing season, reaching a maximum at 27 ± 1 kg N ha^{-1} by 16 WAE and representing 52-68% of total plant N throughout the season (Figure 2.5b). Root N content as a fraction of total plant N showed an initial decrease from 4 to 8 WAE (22% to 11%) followed by an increase from 8 to 16 WAE (11% to 22%) and a final drop back to 11% from 16-20 WAE (Table 2.9); root biomass also decreased from 16 to 20 WAE (Figure 2.5b). Again, root trends were probably related to increased root nodulation at mid-season, with late-season nodule die off and pod production responsible for the drop in N concentration of other tissues. As fraction of total plant N, stems showed the opposite trend (increase from 20% to 32% from beginning to end of season, with a drop to 17% at 12 WAE). Maximum root and stem N contents were 11 ± 3 and 17 ± 3 kg N ha^{-1} at 16 and 20 WAE respectively. Roots

generally formed the smallest N pool (about 11-22% of total N), although this was greater than the relative N pool of sunn hemp roots (Figure 2.5b).

As in sunn hemp, S:R-B increased linearly ($r^2 = 0.93$) from 1.6 to 7.2 kg kg^{-1} over the 20 week growing season (Table 2.8). However, S:R-N saw periods of early and late increase (4-8 WAE and 16-20WAE) around a period of linear decrease (8-16 WAE), probably reflecting nodulation patterns. The overall range for lupin S:R-N was 3.7 to 10.8 kg kg^{-1}. As a result, ratio of S:R-N to S:R-B shows a linear ($r^2 = 0.96$) decrease for the first 16 weeks, followed by an increase from 16-20WAE. This ratio showed a range of 0.8 to 2.8 (Figure 2.3b), which was similar to that seen for sunn hemp in 2002 but not 2001 (Figure 2.3a).

Specific leaf area (SLA) varied between 154 and 103 cm^2 g^{-1} over the season, the pattern of change being well described by a negative polynomial function ($r^2 = 0.99$) with the lowest measurement made at 16 WAE. Specific leaf N (SLN) increased linearly ($r^2 = 0.99$) for the first 16 WAE, followed by a small drop at 20WAE (probably due to pod formation), varying from 98 to 219 μg N cm^{-2} throughout the season (Table 2.8).

Vetch 2002-2003

Due to variable stand performance, results for vetch are presented for the best 10 plots (of 24 total) beginning at 12 WAE unless otherwise noted. These 10 plots showed dry weight production at or above 1.00 Mt ha^{-1} by final sampling. Because these 10 plots were evenly distributed across all GM and N-rate levels without apparent trend, and because vetch growth was so variable, previous GM plantings and sweet corn chemical N applications produced no significant differences by final sampling.

Figure 2.6 shows the accumulation of vetch dry weight and N content, respectively, by tissue type for 2002-03. Averaged over the best 10 plots, vetch produced a total of

1.95 ± 0.25 Mt ha^{-1} and 37 ± 6 kg N ha^{-1} by final sampling at 18 WAE. Of this, 1.52 Mt ha^{-1} and 34 kg N ha^{-1} (78% and 93%) was above ground. Maximum LAI of 1.02 ± 0.13 also occurred at the final sampling at 18 WAE (Figure 2.2a). Two plots with excellent performance produced over 3.0 Mt ha^{-1} and 60 kg N ha^{-1} at final sampling. Roots accounted for the largest tissue fraction for the first 9 WAE (41-52% of total), thereafter leaves (44% at 12 WAE) followed by stems (45% and 43% at 15 and 18 WAE) became the largest tissue fraction. Stem, leaf and root biomass increased throughout the entire growth season reaching final values of 0.85 ± 0.13, 0.68 ± 0.11 and 0.43 ± 0.05 Mt ha^{-1}, respectively at final sampling (Figure 2.6a). Leaf N concentration remained low (22-27 g N kg^{-1}) until a linear ($r^2 = 0.97$) increase began after 9 WAE, bringing leaf N concentration to 36 g N kg^{-1} at 18 WAE. Stem N concentration (11-17 g N kg^{-1}) remained relatively constant, while root N concentration decreased linearly ($r^2 = 0.96$). Total N concentration remained constant between 16-20 g N kg^{-1} (Table 2.9).

Except at first sampling, leaves formed the largest N pool of any tissue throughout the growing season, reaching a maximum at 24 ± 3 kg N ha^{-1} at 18 WAE and representing 37-65% of total plant N throughout the season (Figure 2.6b). Stem N content increased throughout the season reaching a maximum at final sampling of 12 ± 2 kg N ha^{-1}. Stems accounted for an increasing fraction of total plant N over time (17% at 3 WAE to 34% at 18 WAE). Root N content as a fraction of total plant N decreased throughout the season, but was marked by an initial period of relative importance for the first 9 WAE (30-46% of total plant N) followed by a large drop (6-8% of total plant N) as shoot growth increased. Maximum root N content reached only 3 ± 1 kg N ha^{-1} (18 WAE; Figure 2.6b).

Neither S:R-B nor S:R-N experienced much change during the first 6-9 weeks of the season (values ranging between 0.9-1.4 kg kg^{-1} and 1.2-2.3 kg kg^{-1}, respectively; Table 2.10). However, from 6-9 WAE until final sampling both indices increased logarithmically (r^2 = 0.92 and 0.99, respectively) to 4.8 kg kg^{-1} (S:R-B) and 19.9 kg kg^{-1} (S:R-N). As a result, ratio of S:R-N to S:R-B showed a linear (r^2 = 0.98) increase at during this period, going from 1.1 to 4.1 by final sampling (Figure 2.3b).

Vetch SLA varied between 141 and 314 cm^2 g^{-1} over the season, the pattern of change being well described by a negative logarithmic function (r^2 = 0.94) beginning at 9 WAE. Vetch SLA was generally higher than lupin SLA and comparable to that of sunn hemp. Vetch SLN was highly variable, showing no overall trend and ranging from 87.4 to 326 μg N cm^{-2} over the season (Table 2.10), likely related to variable performance.

Discussion

Sunn Hemp

Growth

Sunn hemp appeared quite well adapted to the sandy soils and hot summer temperatures of north Florida with rapid nodulation and little damage from pests or disease until the end of the second year. Biomass in both years (8.00 and 12.26 Mt ha^{-1}; Figues 2.1 and 2.5) and N accumulation in 2002 (134 kg ha^{-1}; Figure 2.6) was higher than that achieved by Mansoer et al. (1997; 5-6 Mt ha^{-1} and up to 120 kg N ha^{-1}) in Alabama, but similar to findings by Seneratne and Ratnasinghe (1995) and Steinmaier and Ngoliya (2001) under tropical conditions. Nitrogen accumulation in 2001 (76 kg N ha^{-1}; Figure 2.6) appears similar to that found by Jeranyama et al. (2000) under low precipitation conditions. Sunn hemp also produced greater dry matter than that of other summer legumes including cowpea evaluated in another on-going study at the same site

(including cowpea (*Vigna unguiculata*), hairy indigo (*Indigofera hirsuta*), and velvet bean (*Mucuna atropurpureum*); Linares and Scholberg, unpublished), although its size and stemmy nature (reaching 2.6 m in 2002) may make it inappropriate for some forms of intercropping, agroforestry, or plastic mulch systems if sunn hemp is allowed to grow past 4-8 weeks.

Increased biomass and N accumulation in 2002 compared to 2001 may have resulted from both longer growing season as well as deeper root systems and improved water availability following mechanical "ripping" of a plow-pan after 2001. Although production remained excellent, water stress during the 2001 appeared to reduce sunn hemp biomass, LAI (through reductions in both leaf dry matter and SLA) as well as N concentration and SLN while decreasing both S:R-B and S:R-N (Tables 2.1, 2.2, 2.4, and 2.5). Sunn hemp dry weight in 2002 exceeded that in 2001 at similar sample dates by 6 WAE. Sunn hemp is reportedly capable of becoming extremely large (up to 20 Mt ha^{-1}), and it does appear that sunn hemp was able to take advantage of the extra two weeks from earlier planting in 2002. Final sunn hemp dry weight and N accumulation was 53% and 76% greater, respectively, in 2002 than in 2001 (Figures 2.1 and 2.4).

In both years, leaf material dominated early growth of sunn hemp (>50% of total plant dry weight for the first 4 WAE; Figures 2.1a and 2.4a) and stems retained relatively high-N through 4-6 WAE (Tables 2.1 and 2.4). Leaves and flowers made up the largest N pool throughout the growing season (57-76% of total plant N) and decomposed most quickly after death (6-12 WAD; Figures 2.1b and 2.4b). However, large decreases in total plant N concentration occurred after 6-8 WAE when stems began to dominate biomass (up to 71% in 2002) and stem N concentration became relatively low. Root contributions

to biomass and especially total plant N were relatively low and decreased with growth – sometimes to less than 10% and 3% of total biomass and N, respectively. Such root contributions were lower than that found by Griffin et al. (2000) working with temperate GMs in a cooler climate (Maine) with fine textured soil (silt loam). Relative root contributions were higher (S:R-B and S:R-N were lower) during 2001, when water availability was apparently diminished. Although root turnover or exudation was not accounted for, the extremely consistent linear increases seen in S:R-B and S:R-N over the season and the small root biomass and N-content appear to be in line with findings by Thonnissen et al. (2000a) in a tropical environment. Because it occurred so consistently in different years, this shoot-dominated growth behavior appears genetic, although differences in water availability show capability of exerting some changes (Tables 2.2 and 2.5).

Differences between years also occurred in slope of the S:R-N to S:R-B ratio over time, with slope being nearly zero in 2001 but distinctively positive in 2002 (Figure 2.3). This suggests that water stress in 2001 also created a situation where shoot growth was more N-limited. In 2001, increases in shoot N partitioning were associated with a consistent biomass partitioning response to shoots. In 2002, with higher N concentration and higher S:R-N, increases in shoot N partitioning were not "kept up with" by similar increases in biomass partitioning to shoots, suggesting biomass partitioning to shoots was decreasingly N-limited in 2002.

It therefore appears that both longer growth time and greater water availability strongly increased N accumulation and dry weight accumulation, but that the relative sizes of tissue pools were more strongly affected by growing time while water

availability may have exerted more control over tissue N concentrations and leaf characteristics (SLA and SLN).

Decomposition

Previous studies on surface applied residue and mixed residues of different recalcitrance show more rapid N-mineralization when overall plant N-concentration is high (C:N < 20 or %N > 2%), with low-N residue (C:N > 30-40) exhibiting N-immobilization and even immobilizing N from nearby, high-N sources (Kuo and Sainju 1997, Ranells and Wagger 1996, Schomberg et al. 1994, Collins et al. 1990, Mansoer et al. 1997) . However, in our study we found that leaves and flowers decomposed rapidly while low-N stems showed net N-release at all times, rather than N-immobilization as expected (Figures 2.1b and 2.4b). The spatial separation between stems (which remained somewhat upright or raised above the soil surface during decomposition) and leaves and flowers (which decomposed primarily on the ground) in our reduced tillage and reduced mowing approach may have prevented movement of N from areas of high availability to low availability. The initial N flush exhibited by stems may reflect decomposition of the relatively succulent stem-tips which others (Marshall 2002) have shown to possess high N-concentration. Lack of homogenization may have also prevented movement of N between these stem fractions.

On the other hand, root dry weight stabilized and slight N-immobilization occurred beginning at about 8 WAD in both years. The initial flush in root decomposition and N-release was probably due to decomposition of finer roots and nodules. Net N-immobilization probably occurred when only the more recalcitrant large roots remained, and also because availability of N within the soil was likely much greater than on the surface. However, the relatively small pool of root biomass could not immobilize more

than 2 kg N ha^{-1}. Residue N losses from sunn hemp totaled 60% and 66% of initial N in the first 2-4 WAD in 2001-02 and 2002-03, respectively. Final residue N-losses were 49 and 123 kg N ha^{-1} (80% and 84%) in 16 weeks of 2001-02 and in 18 weeks of 2002-03, respectively (Figures 2.2 and 2.6). Dry weight decomposition losses (44-48% in 16-18 WAD) were much less than those of N, but also demonstrated most losses during the first 2-4 WAD. While leaves and flowers decomposed rapidly, stem dry weight loss at all dates after 2-4 WAD remained within one standard error of each other, making decomposition unresolvable. Root dry matter loss was almost as slow as that of stems (Figures 2.1a and 2.4a).

Mansoer et al. (1997) homogenized sunn hemp residue by mowing but experienced similar levels of N-loss over the winter. Because it may help buffer water and temperature in a decomposing litter layer, it is unclear if mowing as a means of homogenization would lead to net N-immobilization in our environment. Had sunn hemp had much greater root production, one could also speculate greater immobilization might occur based on our results. Given the findings of numerous other investigators (for example, Schomberg et al. 1994 and Thonnissen et al. 2000b), it appears that soil incorporation would unacceptably intensify long-term N-loss of overwintering residue; Mansoer et al. (1997) found much greater N-loss from soil-incorporating sunn hemp residue in Alabama during the winter. Although the high N-losses from overwintering sunn hemp residue were contrary to our management goals, our findings suggest this reduced-tillage and reduced-mowing system may provide a “double” benefit if sunn hemp (or another legume with similar growth habit) is followed immediately by one or more economic crops. In this way, sunn hemp could provide quickly available N from

decomposing leaves and flowers; at a later date, the recalcitrant nature of left-over sunn hemp stems (once mowed or pushed down to the ground) may immobilize surface applied N, improving synchrony of N-release from chemical or animal manure sources (see Chapter 3). On the other hand, sunn hemp accumulated more than half of its N between 6 and 8 WAE in both study years, which was also around the time when leaves and stems were equally dominant in terms of dry weight. If moderate N supply with less residue is desired, our results suggest that killing sunn hemp back at this time would yield 30-70 kg N ha^{-1} and 3-7 Mt dry matter ha^{-1} (Figures 2.1 and 2.4) depending on growing conditions.

Sunn hemp is a crop which may be easily killed without pesticide by using a roller, which kills the plants by breaking their stems. Our experience and the experience of others suggests sunn hemp may be planted into directly ("live mulched") prior to cold weather. Tractor tires tend to "roll over" many of the rows and open up the canopy for a new crop. At the onset of freezing temperatures, the rest of the sunn hemp will die. This method of planting may make more efficient use of sunn hemp N by delaying much decomposition until another crop is already established beneath the sunn hemp, eliminating "gap" time that occurs between "wholesale" death of sunn hemp (from herbicide or mowing) and subsequent planting and growth of another crop.

Lupin and Vetch

As cool-weather legumes, blue lupin and cahaba white vetch behaved quite differently than sunn hemp. Their growth appeared controlled by time required for effective nodulation to begin (when growth and N-accumulation increased) and subsequent time until reproduction and rising temperatures (when total plant growth and N-accumulation slowed and root nodules died off). These legumes may require longer

periods of cool temperature combined with longer daylength during fall and spring than found in north Florida. Unseasonably warm weather (lupin, 2001-02) and poor adaptation to sandy soil (vetch, 2002-03) may also have reduced performance of these legumes, but as these conditions are typical in north Florida this may also point out general weaknesses of cool-weather legumes in the region. Lupin and vetch still accumulated 4.03 and 1.95 Mt ha^{-1} dry weight and 53 and 39 kg N ha^{-1}, respectively, similar to other results from Florida (Gallaher 1991) and New Mexico (Guldan et al. 1996; see Figures 2.5 and 2.6). However, results were highly variable and much lower than findings in temperate regions with finer soils and longer growing times (Forbes et al. 1970, Abdul-Baki et al. 1996, Cline and Silvernail 2001 and 2002, Puget and Drinkwater 2001, Ranells and Wagger 1996, Sainju and Singh 2001, Singogo et al. 1996). That neither lupin nor vetch were significantly affected by presence of sunn hemp residue probably reflects the heavy initial N-loss from sunn hemp, but also indicates that sunn hemp had no apparent allelopathic effect on either crop as well.

In our study, linear growth phase of these species probably initiated far too late (8-9 WAE) for them to significantly reduce N losses from sunn hemp residue, and any N benefit from sunn hemp residue early in the season became insignificant by final samplings. Even in lupin, biomass and N production up to 12 WAE was relatively low (0.78 Mt ha^{-1} and 10 kg N ha^{-1}). However, although these species are not always as productive as some summer legumes, they may still provide a significant source of N. As a monocrop, lupin appeared better adapted to our environment than vetch. Because its performance was generally poor, cahaba white vetch was terminated at 18 weeks. Only 13 of 24 plots produced greater than 1 Mt ha^{-1}, and at final sampling plants exhibited

severe root decay (likely caused by nematodes) and nutrient deficiency. However, some plots of cahaba white vetch produced over 3.0 Mt ha^{-1} and 60 kg N ha^{-1}, closer to reported production of 3-9 Mt ha^{-1} elsewhere but still quite lower than potential N accumulation (100-250 kg N ha^{-1}; see Table 1.1). Performance of lupin and vetch were quite variable. Nearby trials of other winter legumes including lupin, vetch, and clovers indicate lupin may be the most productive as a monocrop (Linares and Scholberg, unpublished), and the seemingly low growth of lupin and (the better plots of) vetch may simply be near potential for winter legumes in north Florida. Results from continuation of this study with a mixture of hairy vetch and cereal rye, and anecdotal evidence from 4-way mixtures of vetch, rye, crimson clover and radish (*Raphanus sativus*) in the same field suggest combinations of legumes, grasses, and/or non-leguminous dicots may provide for more uniform and productive winter GMs in our area (Lavila and Scholberg, unpublished).

Compared to sunn hemp, lupin and vetch roots accounted for a greater fraction of total biomass in the first 4-9 weeks (41-52%), but thereafter the emphasis of growth on leaves followed by stems was similar (Figures 2.1 and 2.4-2.6). Unlike sunn hemp, total N concentration increased (lupin) or remained relatively constant (vetch) over the season despite increases in stem tissue fraction, primarily because stem production was relatively low (never more than 56% for lupin and 45% for vetch) and exhibited higher N concentration than sunn hemp. Allowing these winter legumes to become more "stemmy" did not lead to an apparent increase in their recalcitrance, although lupin and vetch differed in their N concentration. Individual tissue and total N concentration of lupin was relatively low and was comparable to that found in sunn hemp during the dry summer of

2001. Vetch leaf and whole plant N concentrations were higher than lupin and comparable to sunn hemp in the rainier summer of 2002 (Tables 2.1, 2.4, 2.7 and 2.9). Total plant and root biomass, N-concentration and N-content for vetch and lupin showed exponential increases followed by a leveling off or decline near the end of the season, apparently following patterns in nodule initiation and nodule death around the onset of reproduction (Figures 2.6 and 2.7, Tables 2.7 and 2.9).

Because they die back at the onset of warm weather and/or reproduction, and because they are not extremely large, cool-weather legumes in north Florida may be good candidates for live mulch during spring. Mowing, strip tillage, strip herbicide, or tractor traffic may be used to create openings for a spring crop planted into a cool-weather legume. As mentioned earlier, this may reduce N losses from decomposition by reduction of "gap time" between the two crops. In our experience, sweet corn strip tilled into vetch suffered no adverse effects, and others (Phatak et al. 1999) have shown good results for cotton no-till planted into live clover. Mixtures of leguminous GMs with non-legumes capable of earlier growth and better "N-scavenging" may be desirable. Rye, oats, or mustards may be well suited for such mixtures (for example, Abdul-Baki et al. 1996, Cline & Silvernail 2001 and 2002, Griffin et al. 2000, Ranells and Wagger 1996, Karpenstein-Machan & Stuelpnagel 2000). Our preliminary experience with mixtures of multiple winter GMs shows great promise and should be investigated more, as performance of any one GM (especially legumes) may be variable in north Florida winters. These mixtures may also be more appropriate for systems requiring lower growing, less stemmy, and/or less aggressive GMs than sunn hemp.

Conclusions

Results of all crops from both years highlight the dynamic nature of legume cover crops. Patterns of biomass accumulation, N content and N concentration change over the course of a season, but these patterns are quite different between cool and warm season legumes, between different species growing at the same time of year and within the same species growing in different years.

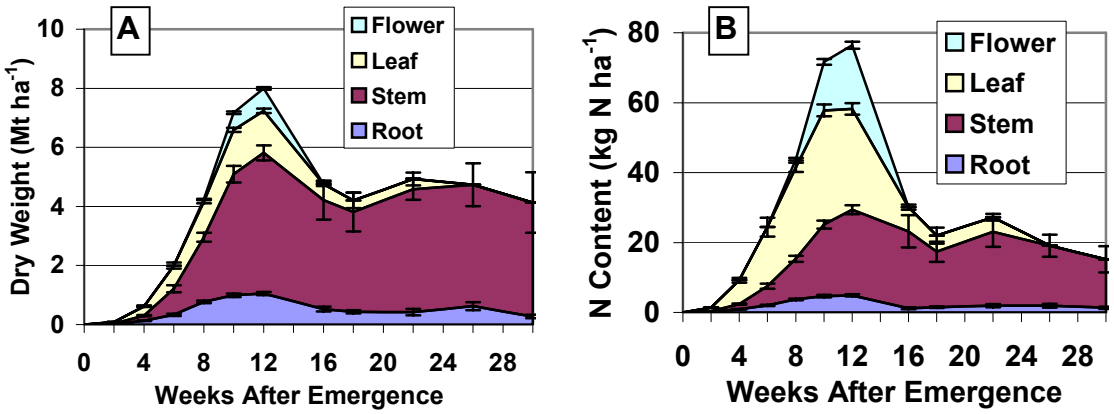

Figure 2.1. Sunn hemp dry weight (A) and nitrogen content (B) during growth and decomposition, 2001-02. Error bars reflect standard errors.

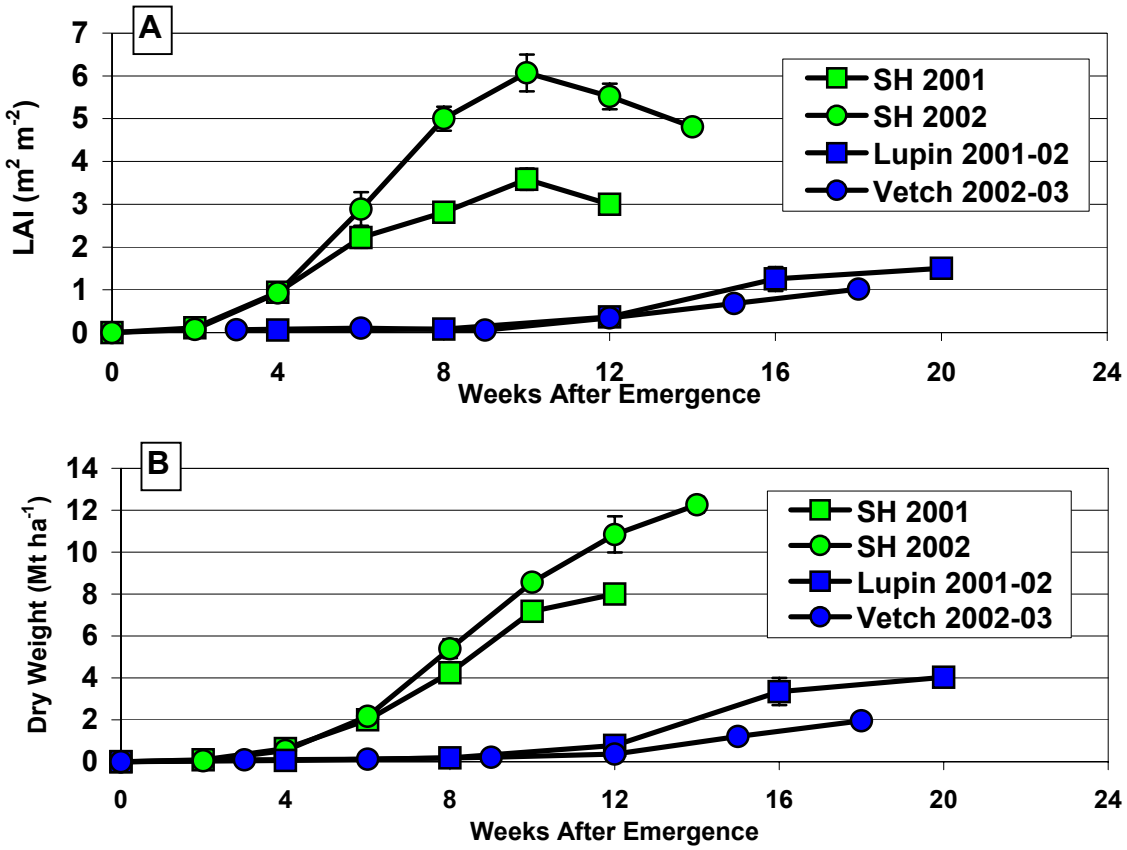

Figure 2.2. Leaf area index (A) and dry weight (B) of each GM during growth. Error bars reflect standard errors.

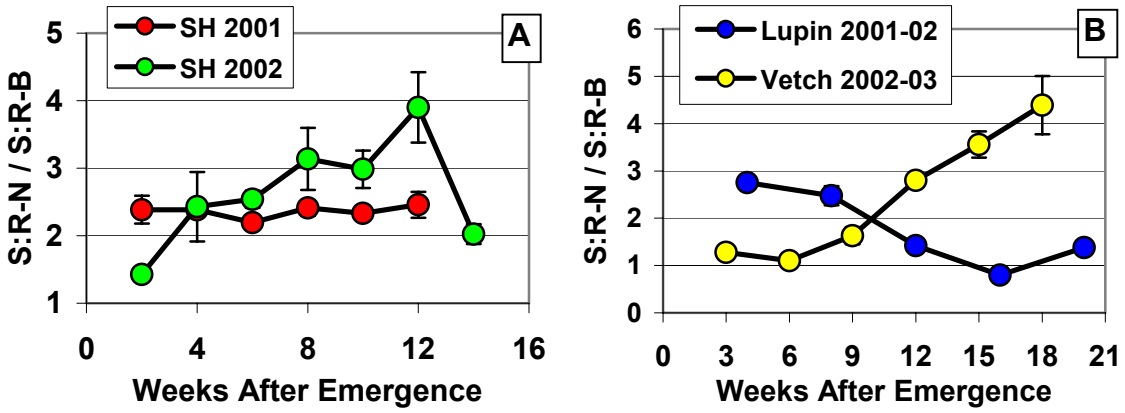

Figure 2.3. Ratio of S:R-N to S:R-B of sunn hemp (A) and lupin and vetch (B). Error bars reflect standard errors.

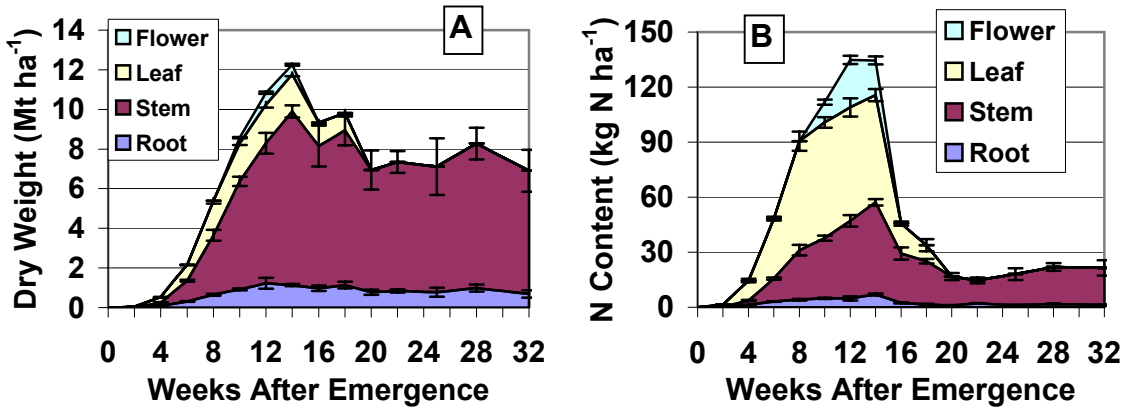

Figure 2.4. Sunn hemp dry weight (A) and nitrogen content (B) during growth and decomposition, 2002-03. Error bars reflect standard errors.

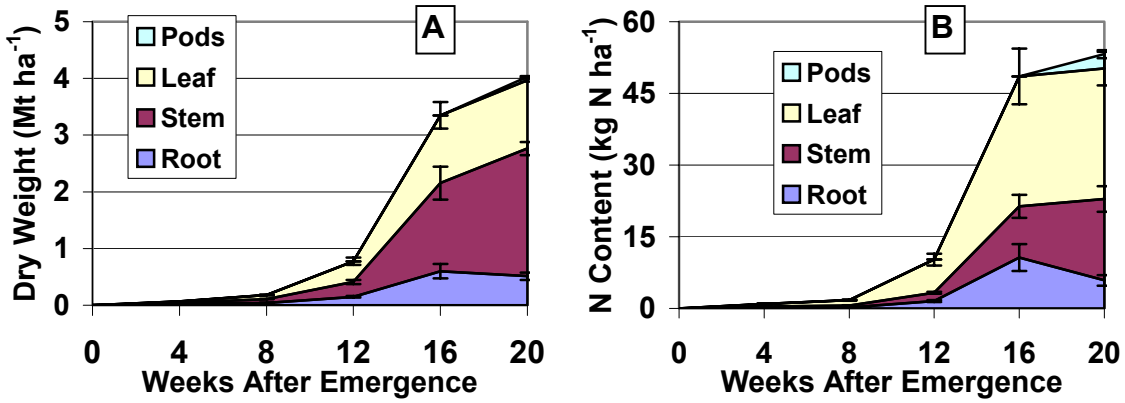

Figure 2.5. Lupin dry weight accumulation (A) and N content (B) during growth, 2001-02. Error bars reflect standard errors.

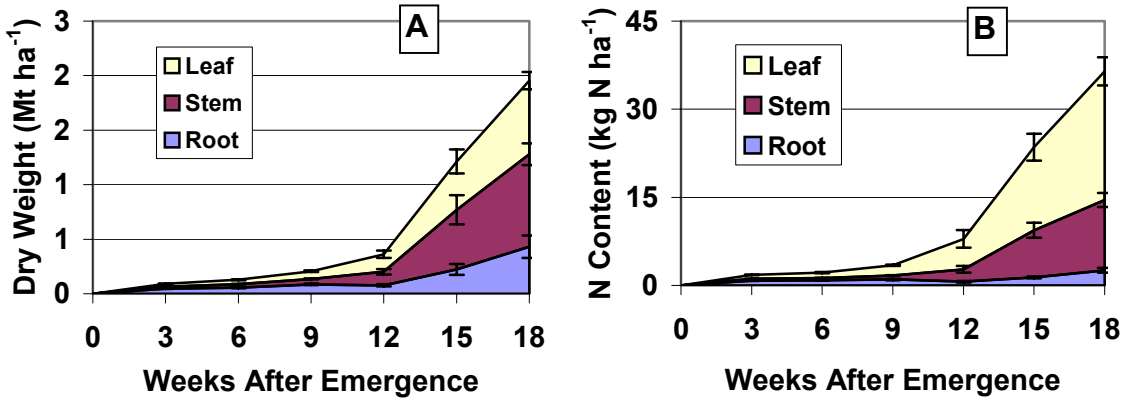

Figure 2.6. Vetch dry weight accumulation (A) and nitrogen content (B) during growth, 2002-03. Error bars reflect standard errors.

Table 2.1. Sunn hemp nitrogen concentration by tissue type, 2001.

WAE	N Concentration				
	Leaf	Stem	Root	Flower	Total
	g N kg^{-1}				
2	21.1 ± 0.7	12.0 ± 0.6	8.5 ± 0.6		16.2 ± 0.6
4	21.8 ± 0.5	8.2 ± 0.4	7.2 ± 0.4		14.9 ± 0.4
6	21.3 ± 0.5	6.2 ± 0.3	6.1 ± 0.3		12.1 ± 0.3
8	21.8 ± 0.4	5.3 ± 0.2	4.9 ± 0.2	27.3 ± 0.4	10.3 ± 0.2
10	21.7 ± 0.3	5.0 ± 0.2	4.7 ± 0.2	24.1 ± 0.5	10.0 ± 0.1
12	20.1 ± 0.4	5.2 ± 0.2	4.6 ± 0.2	29.0 ± 4.3	10.1 ± 0.5

WAE = weeks after emergence.

Table 2.2. Selected sunn hemp growth indicators, 2001.

WAE	SLA $cm^2 g^{-1}$	SLN $\mu g\ cm^{-2}$	S:R-B kg kg^{-1}	S:R-N kg kg^{-1}
2	222 ± 8	96 ± 4	2.7 ± 0.33	6.1 ± 0.6
4	297 ± 8	74 ± 2	3.8 ± 0.24	9.0 ± 0.7
6	287 ± 6	75 ± 3	5.0 ± 0.20	10.9 ± 0.6
8	235 ± 6	93 ± 3	4.5 ± 0.19	11.0 ± 0.8
10	238 ± 7	92 ± 3	6.3 ± 0.49	14.6 ± 1.1
12	209 ± 5	97 ± 3	6.8 ± 0.33	17.5 ± 2.3

WAE = weeks after emergence; SLA = specific leaf area; SLN = specific leaf N; S:R-B = biomass-based shoot to root ratio; S:R-N = N-based shoot to root ratio.

Table 2.3. Sunn hemp nitrogen concentration by tissue type after death, 2001-02.

WAD	N Concentration			
	Leaf	Stem	Root	Total
	g N kg^{-1}			
0	16.1 ± 0.3	4.2 ± 0.1	3.7 ± 0.1	7.7 ± 0.1
2	10.8 ± 0.2	4.7 ± 0.3	2.2 ± 0.2	3.5 ± 0.2
4	9.8 ± 1.0	3.6 ± 0.2	2.0 ± 0.3	3.8 ± 0.1
8	9.0 ± 0.5	3.2 ± 0.1	2.4 ± 0.3	3.5 ± 0.1
12		3.2 ± 0.1	2.9 ± 0.3	3.2 ± < 0.1
16		3.0 ± 0.1	3.0 ± < 0.1	3.0 ± 0.1

WAD = weeks after death.

Table 2.4. Sunn hemp nitrogen concentration by tissue type, 2002.

WAE	N Concentration				
	Leaf	Stem	Root	Flower	Total
	g N kg^{-1}				
2	37.7 ± 1.0	15.3 ± 0.3	23.2 ± 0.7		30.4 ± 0.8
4	39.0 ± 0.4	14.7 ± 0.1	14.7 ± 1.7		27.6 ± 0.4
6	40.3 ± 0.5	12.0 ± < 0.1	10.1 ± 0.4		22.4 ± 0.2
8	34.3 ± 0.6	9.0 ± < 0.1	6.6 ± 0.8		16.9 ± 0.2
10	32.9 ± 0.5	6.0 ± < 0.1	5.4 ± 0.4	40.2 ± 0.9	13.1 ± 0.2
12	31.8 ± 0.6	6.0 ± < 0.1	4.0 ± 0.6	42.7 ± 4.8	12.5 ± 0.5
14	31.3 ± 0.6	5.7 ± < 0.1	6.1 ± 0.3	21.1 ± < 0.1	11.7 ± 0.7

WAE = weeks after emergence.

Table 2.5. Selected sunn hemp growth indicators, 2002.

WAE	SLA	SLN	S:R-B	S:R-N
	cm^2 g^{-1}	µg cm^{-2}	kg kg^{-1}	kg kg^{-1}
2	281 ± 8	135 ± 3	3.2 ± 0.2	4.5 ± 0.3
4	331 ± 8	118 ± 3	5.0 ± 0.2	12.3 ± 0.3
6	355 ± 4	114 ± 2	6.1 ± 0.2	15.6 ± 1.0
8	288 ± 7	121 ± 7	7.3 ± 0.3	22.9 ± 3.5
10	318 ± 7	105 ± 3	8.5 ± 0.3	25.8 ± 2.9
12	284 ± 7	113 ± 4	9.2 ± 1.0	36.0 ± 6.8
14	256 ± 7	124 ± 4	10.2 ± 0.4	21.0 ± 1.9

WAE = weeks after emergence; SLA = specific leaf area; SLN = specific leaf N; S:R-B = biomass-based shoot to root ratio; S:R-N = N-based shoot to root ratio.

Table 2.6. Sunn hemp nitrogen concentration by tissue type after death, 2002-03.

WAD	N Concentration			
	Leaf	Stem	Root	Total
	g N kg^{-1}			
0	31.3 ± 0.0.6	5.7 ± < 0.1	6.1 ± 0.3	11.7 ± 0.7
2	11.2 ± 0.0.6	3.4 ± 0.2	3.3 ± 0.2	4.4 ± 0.2
4	7.3 ± 0.1.2	2.8 ± 0.2	1.8 ± 0.1	3.1 ± 0.3
6		2.7 ± 0.3	1.6 ± 0.2	2.6 ± 0.2
8		1.7 ± 0.2	3.3 ± 0.3	1.9 ± 0.2
11		2.6 ± 0.3	2.2 ± 0.5	2.5 ± 0.3
14		2.5 ± 0.1	2.5 ± 0.3	2.5 ± 0.1
18		3.0 ± 0.3	2.5 ± 0.4	2.9 ± 0.3

WAD = weeks after death.

Table 2.7. Lupin nitrogen concentration by tissue type, 2001-02

WAE	N Concentration				
	Leaf	Stem	Root	Pod	Total
	g N kg^{-1}				
4	15.2 ± 0.2	5.5 ± 0.2	3.8 ± < 0.1		7.7 ± 0.3
8	15.6 ± < 0.1	6.2 ± 0.5	4.7 ± 0.7		9.6 ± 0.4
12	19.1 ± < 0.1	6.8 ± 0.4	10.4 ± 1.4		13.1 ± 0.6
16	22.5 ± 0.4	6.7 ± 0.2	17.1 ± 0.8		14.2 ± 0.4
20	22.6 ± 0.7	7.5 ± 0.4	11.0 ± 0.7	35.0	13.0 ± 0.4

WAE = weeks after emergence.

Table 2.8. Selected lupin growth indicators, 2001-02

WAE	SLA $cm^2 g^{-1}$	SLN $\mu g\ cm^{-2}$	S:R-B kg kg^{-1}	S:R-N kg kg^{-1}
4	154 ± 4	98 ± 3	1.6 ± 0.3	4.5 ± 0.8
8	118 ± 8	135 ± 7	3.4 ± 0.1	8.3 ± 0.8
12	107 ± 8.9	185 ± 17	4.2 ± 0.6	5.9 ± 1.0
16	103 ± 3	219 ± 6	4.6 ± 0.2	3.7 ± 0.2
20	124 ± 3	183 ± 7	7.2 ± 0.5	10.8 ± 2.0

WAE = weeks after emergence; SLA = specific leaf area; SLN = specific leaf N; S:R-B = biomass-based shoot to root ratio; S:R-N = N-based shoot to root ratio.

Table 2.9. Vetch tissue nitrogen concentration, 2002-03.

WAE	N Concentration			
	Leaf	Stem	Root	Total
		g N kg^{-1}		
3	27.3 ± 1.3	16.6 ± 0.5	17.8 ± 0.5	20.2 ± 0.7
6	22.0 ± 1.0	11.3 ± 0.3	15.5 ± 0.5	16.5 ± 0.6
9	21.8 ± 0.9	13.0 ± 0.5	12.9 ± 0.8	16.1 ± 0.4
12	27.5 ± 2.5	15.0 ± 1.1	7.8 ± 0.5	18.8 ± 1.8
15	29.7 ± 2.4	13.3 ± 1.0	5.8 ± 0.3	17.0 ± 1.5
18	35.6 ± 1.5	14.5 ± 0.6	6.4 ± 0.8	20.3 ± 1.3

WAE = weeks after emergence.

Table 2.10. Selected vetch growth indicators, 2002-03.

WAE	SLA $cm^2 g^{-1}$	SLN $\mu g\ cm^{-2}$	S:R-B kg kg^{-1}	S:R-N kg kg^{-1}
3	259 ± 8	105 ± 3	0.9 ± <0.1	1.2 ± 0.1
6	252 ± 5	87 ± 4	1.3 ± 0.1	1.4 ± 0.1
9	314 ± 30	326 ± 29	1.4 ± 0.1	2.3 ± 0.3
12	210 ± 5	130 ± 10	3.5 ± 0.5	10.0 ± 1.5
15	141 ± 14	250 ± 45	4.8 ± 1.0	16.9 ± 3.7
18	141 ± 15	239 ± 10	7.2 ± 1.6	19.9 ± 3.7

WAE = weeks after emergence; SLA = specific leaf area; SLN = specific leaf N; S:R-B = biomass-based shoot to root ratio; S:R-N = N-based shoot to root ratio.

CHAPTER 3
GROWTH, YIELD, AND N-UPTAKE EFFICIENCY RESPONSE OF CORN TO AMENDMENT WITH GREEN MANURES

Introduction and Literature Review

Utilized as green manures (GMs), legumes may represent a substantial source of on-farm nitrogen (N) for subsequent crops. In temperate environments on fine textured soils, winter legumes such as vetch (*Vicia* spp.), clover (*Trifolium* spp.), and medics (*Medicago* spp.) are capable of accumulating large amounts of biomass (7-10 Mt ha^{-1}) and N (150-250 kg N ha^{-1}) and delivering substantial N benefit to subsequent crops. On a silt loam soil in Maine, Griffin et al. (2000) found alfalfa (*M. sativa*) and winter rye (*Secale cereale*) plus hairy vetch (*Vicia villosa*) combinations as GMs capable of satisfying the N requirements of sweet corn (*Zea mays* var Rugosa) in two of three study years. In Kentucky, sweet corn N requirements were fully met when vetch N was equal to or greater than 166 kg N ha^{-1} (Cline and Silvernail 2002).

In tropical environments, warm weather legumes such as sunn hemp (*Crotalaria juncea*), cowpea (*Vigna unguiculata*), and mungbean (*V. radiata*) may also accumulate large amounts of biomass and N. Because no freezes occur in tropical environments, these legumes may be followed immediately by frost-sensitive crops. For example, studies in Asia have shown such GMs capable of supplying the N-requirements of rice (*Oryza sativa*; Ladha et al. 2000, Agustin et al. 1999, Aulakh et al. 2000). However, few GM studies have been conducted with high-N demanding spring crops under north Florida conditions (sandy soils, sub-temperate climate). In this environment, the two

greatest challenges to leguminous GM approaches for spring cropping systems remain accumulation of adequate N by GMs and delay of N-release during the winter to better match timing of spring crop uptake.

As discussed in more detail in Chapter 2, temperate legumes often do not perform as well in north Florida, while the rotation from tropical legume to spring crop is interrupted by feezing temperatures over the winter. Based on ear leaf N concentration, Gallaher (1993) reported N-substitution values by blue lupin (*Lupinus angustifolius*), hairy vetch and crimson clover (*Trifolium incarnatum*) of only 67 kg N ha^{-1} compared to chemical N for a variety of different residue management systems. In another study near Gainesville, Florida, Gallaher and Eylands (1985) reported N substitution value for blue lupin near 56 kg N ha^{-1} based on sorghum (*Sorghum bicolor*) grain yields. In a low-input system on a loamy sand in Zimbabwe, Jeranyama et al. (2000) found relatively low fertilizer N equivalency for sunn hemp (36 kg N ha^{-1}). Need exists to develop GM management techniques for north Florida and like environments that deliver N benefits similar to those achievable elsewhere.

The slow release of N from decomposing GM residues may be better timed with plant uptake (Bath 2000, Wivstad 1997). Indeed, some researchers have found N-substitution values for GMs in excess of their actual N accumulation, suggesting that GM N is either used more efficiently than chemical fertilizer N, that GMs modify the soil environment and/or crop growth such that greater crop N uptake is possible, or that GMs also supply some other nutrient which is limiting crop growth (such as phosphorus). In a low-land rice system, Agustin et al. (1999) found 58 kg N ha^{-1} from indigo (*Indigofera tinctoria*) comparable to 120 kg N ha^{-1} from urea and speculated that all of the above

mentioned factors may have been involved. Also studying rice, Aulakh et al. (2000) found application of 84 kg N ha^{-1} in the form of cowpea and sesbania (*Sesbania rostrata*) equivalent to 104 kg N ha^{-1} applied as chemical-N. Green manures may provide other benefits such as reduction of soil erosion, recycling of other crop nutrients, and control of plant pests, pathogens and weeds with less reliance on off-farm chemical inputs (see Chapters 5 and 6).

In a 3-year study using several different GMs on a silt loam in Canada, N'Dayegamiye and Tran (2001) found yield benefits for wheat (*Triticum aestivum*) of 30-90 kg N ha^{-1} and an increase in fertilizer N recovery with GM use. Recovery rates for GM derived N in the same study ranged from 19-36%, which were lower than many of the fertilizer N recovery rates (25-52%). Lower recovery rates for GM-derived N may have been due to stabilization of N in organic forms rather than loss through leaching, volatilization, and denitrification. In another study by N'Dayegamiye (1990), 15% of red clover (*T. repens*) N applied to maize was taken up, while 19% and 28% were recovered in microbial biomass and soil organic fractions respectively. Steinmaier and Ngoliya (2001) evaluated the use of 11 GMs as N sources for maize on a sandy loam in Zambia. Although a formal control was not used, comparison to low producing GMs suggests a N benefit of around 50 kg N ha^{-1} or more from sunn hemp and velvet bean (*Mucuna pruriens*). On a sandy clay loam in India, Sharma et al. (2000) reported N-replacement of 60 kg N ha^{-1} for rice when a mungbean GM was plowed in prior to planting. Studying fertigated, mulched tomatoes (*Lycopersicon esculentum*), Abdul-Baki et al. (1996) found that plastic-mulch with 112 kg N ha^{-1} (recommended rate) produced lower yields than hairy vetch, crimson clover, and hairy vetch plus rye live mulches with only 56 kg N ha^{-1}.

Synchrony between GM-N availability and subsequent crop N-demand remains difficult to achieve. Many investigators have shown more rapid decomposition for plant residues when soil incorporated (see Chapter 2). Rapidly growing crops immediately following GMs may benefit from soil-incorporation of GM residues, especially in cool climates and/or on fine-textured soils with high N-retention. For example, Shrestha et al. (1998), finding no N-replacement benefit for winter canola (*Brassica napus*) in Michigan even when a spring GM produced over 100 kg N ha^{-1}, hypothesized that GM-N release occurred as the canola crop went into dormancy. Griffin and Hesterman (1991) found that legume GMs increased biomass, N uptake and N concentration of potato (*Solanum tuberosum*) but did not benefit tuber yields. They concluded that N from GMs became available too late to benefit tuber growth. However, in warm environments GM-N release more often occurs so rapidly that peak availability takes place well before peak N demand from a subsequent crop. Potential N-leaching losses under these circumstances may eliminate advantages of GMs. In Georgia, Sainju and Singh (2001) showed greater corn N-uptake and ear yield following hairy vetch for no-till compared to conventional tillage, although the opposite trend occurred for corn following (highly recalcitrant) winter wheat. In these cases reduced or zero-tillage may better synchronize leguminous GM-N release with subsequent crop demand.

The N loss incurred by overwintering of decaying residues may negate any N benefit to a subsequent spring crop. For example, on a loam soil in Saskatchewan, Brandt (1999) saw no N benefit from production of less than 3 t ha^{-1} of black lentil (*Lens culinaris*) on a subsequent crop of wheat. In Alabama, Mansoer et al. (1997) found close to 2/3 N loss in mowed, overwintering sunn hemp. Reduced tillage as means of slowing

GM decomposition during winter months may increase GM-N availability during the spring.

Modification of residue quality (especially C:N ratio or N concentration) may also control timing of residue N-release. Some field grown grass-legume mixtures have shown potential to increase GM C:N and total GM N content relative to legumes alone, improving both the amount and synchrony of GM N-release (Ranells and Wagger 1996). Nitrogen accumulation of such mixtures may be reduced, however, if legume seed rate is too low (Karpenstein-Machan and Stuelpnagel 2000, Cline and Silvernail 2002). Based on subsequent ear yields, small grain GMs do not appear capable of satisfying corn N demand (Griffin et al. 2000, Karpenstein-Machan and Stuelpnagel 2000, Cline and Silvernail 2002, Gallaher and Eylands 1985). Alternatively, overwintering residue with low N concentration and/or high C:N ratio may also highly reduce N leaching losses (Stopes et al. 1996, Wyland et al. 1996). Selecting leguminous GMs capable of accumulating large fractions of stemmy, low-N biomass may create opportunity for both high GM-N accumulation and improved N-retention. Green and Blackmer (1995) found N-immobilization (followed by N-release) by soybean (*Glycine max*) residue helped explained N benefits to subsequent corn.

Establishing a winter GM after the summer GM may significantly reduce N leaching losses and enhance performance of the winter GM, but the effective N benefit to a subsequent spring crop from such a double-GM approach has not been studied. In some systems, it may therefore be advantageous to follow a vigorous and stemmy summer GM with a well established winter GM, and to preserve as much recalcitrant litter as possible by reducing tillage.

If GMs do not supply adequate N to meet requirements of subsequent crops, then supplementary inorganic N may be required to prevent yield reductions. Many studies have compared use of GMs alone against synthetic fertilizers (for example, see Carsky et al. 2000), and others have also investigated GMs used in combination with synthetics, (for example, see Ladha et al. 2000). However, these studies usually do not establish optimums for chemical N rate whether used alone or with GMs, making it difficult to assess how much (if any) chemical N is required "on top of" GMs for optimal production. A number of studies (such as Prasad et al. 2002) do so for "cut and carry" systems where GMs are not grown in place, but this does not reflect common agricultural practice in developed countries.

As part of a larger study on improved use of GMs in vegetable cropping systems in the southeast US, we investigated a GM sequence of sunn hemp followed by a winter legume (blue lupin, winter 2001-02; cahaba white vetch, *Vicia sativa*, winter 2002-03) as an N-source for sweet corn. Details of GM growth and decomposition patterns can be found in Chapter 2. In these studies, sunn hemp followed by winter legume produced a cumulative 12-15 Mt dry matter ha^{-1} and up to 170 kg N ha^{-1}. We evaluated sweet corn growth and leaf characteristics throughout the season for GM amended and unamended corn supplemented with multiple chemical N-rates. We hypothesized the double-GM approach would significantly reduce chemical N required by sweet corn to achieve ear yields similar to an optimal level identified in the conventional approach, and that GMs would increase N-uptake efficiency of sweet corn. Objectives of the study were to gain greater understanding of the impacts of GMs on sweet corn growth throughout the season

and to estimate chemical N-supplementation needed to achieve acceptable sweet corn ear yields.

Materials and Methods

Set-Up and Design

This study consisted of 14 of the 15 overall treatments related in Chapter 1 (Table 1.2). Treatments consisted of sweet corn following rotations of sunn hemp (summer) and lupin (winter 2001-02) and vetch (winter 2002-03), denoted as SH+L; sunn hemp alone, denoted as SH; winter legume (lupin 2001-02, vetch 2002-03) alone, denoted as L; and unamended corn denoted as Conv (for conventional). Each GM level received supplementation with 0, 67, or 133 kg inorganic N ha^{-1} (0N, 67N, and 133N). Other unamended (Conv) treatments also received 200 or 267 kg inorganic N ha^{-1} (Conv 200N and Conv 267N). Only methods relevant to corn growth and N-accumulation analysis are considered here. Methods regarding GM growth and accumulation, root dynamics, and effects on soil properties and plant pests are discussed in relevant chapters. Please see Chapter 1 for overview.

Timeline of Operations

2001-02

On 7 August 2001, sunn hemp was planted following complete disking and plowing of the field. Seed was inoculated with cowpea-type rhizobium and planted at 2-4 cm depth. In-row spacing was 3.12 cm (1.25 in), between-row spacing was 76 cm (30 in). Sunn hemp emerged 11 August 2001 and grew until 31 October 2001 when it was killed with an application of Gramoxone (Syngenta; Basel, Switzerland). Lupin was inoculated with lupin-type rhizobium and planted on 19 November 2001 using a rip-strip planter and with spacing identical to sunn hemp. Lupin emerged 22 November 2001 and grew until

12 April 2002. All plots were then mowed and field treated with Round-Up (RoundUp; Columbus, OH). Sweet corn (variety GS 0966 Syngenta) was planted 26 April 2002 using a rip-strip planter, with in-row spacing of 18 cm and between-row spacing of 76 cm. Corn emerged 1 May 2002. For each treatment, chemical N was applied as NH_4NO_3 in three equal applications: at emergence and 3 and 5 weeks after emergence (WAE).

2002-03

On 19 July 2002, inoculated sunn hemp was planted with a rip-strip planter at the same spacing and depth as in 2001, emerging 21 July 2002 and growing until 30 October 2002 when it was killed with Diuron/Touchstone. Cahaba white vetch was inoculated with vetch-type rhizobium and planted 15 November 2002 with a zero-till grain-drill at a rate of roughly 40 kg ha^{-1} (35 lbs $acre^{-1}$). Sweet corn (variety GS 0966) was directly planted into vetch on 7 April 2003 with the same planter, spacing, and depth as 2002. Corn emerged 15 April 2003. For each treatment, chemical N was again applied as NH_4NO_3 in equal applications at emergence and 3 and 5 weeks after emergence (WAE).

Procedures and Measurements

At emergence a plant count was made to determine an average plant population. In both years, sweet corn biomass was sampled five times (2, 4, 6, 8, and 9 WAE) and ears were harvested at maturity (9 WAE). The final biomass samplings were taken the day before harvesting ears. Ear harvest was conducted in an inner area of the plot kept free from destructive biomass and soil sampling. This inner area was roughly 4.6 m (15 feet) by 4.6 m, allowing harvest of the central 4.6 m of row length from each of the six inner rows of corn (out of a total of 10 rows in each plot). Representative subsamples of ears from harvest were graded using USDA standards (United States Department of Agriculture 1997).

Biomass sampling was conducted outside this inner area but away from plot edges using three feet of row length representative of the entire plot in plant number, size, spacing, and appearance. Within each sample, one representative subsample plant was dug from the ground with a shovel to include roots (except at 2 WAE when all plants were dug out). All other plants were clipped at ground level. Clipped plants were weighed and counted. Roots were cut from the subsample plant and stored separately, and the subsample plant top was then weighed and refrigerated until further processing in Gainesville. The clipped plants were returned to the plots when possible. Relative humidity, air temperature at 1 m, soil temperature at 5 cm depth, and precipitation were recorded continuously with a Watchdog datalogger (Spectrum Technologies; Plainfield, IL).

At the UF Environmental Agronomy Lab (University of Florida, Gainesville, FL), height and total plant leaf numbers were taken for each subsample plant. Chlorophyll meter readings (CMR), taken with a Minolta SPAD-502 (Spectrum Technologies; Plainfield, IL), were made on the two most recently matured leaves (before tasseling) or the third and fourth leaves from the top (after tasseling). Plants were then separated into tissue type: leaves, stem, dead leaves, and ears (where applicable). Roots were washed clean of soil and debris and fresh weights were taken for all tissues. Leaf area was determined for each subsample plant using an LI-3100 (Li-cor; Lincoln, NE). All tissues were then bagged and dried for 72 hours at 65 C and then reweighed. Afterwards, all tissues were ground in a Wiley mill to pass through a 2 mm screen, and a thoroughly mixed 5 g portion of each grinding was subsequently stored. Grindings were then subjected to a wet-acid Kjeldahl digestion, diluted and filtered. The diluted samples were

then analyzed for total Kjeldahl N (TKN) at the UF Analytical Research Laboratory (University of Florida, Gainesville, FL; EPA Method 351.2; Jones and Case 1991).

Nitrogen applied to corn (NAC) for each plot was calculated as: NAC_x = Chemical-N_x + Residue-N_x; where Chemical-N_x = N applied as NH_4NO_3 to corn in plot "x" and Residue-N_x = TKN present in any winter GM, winter weeds, and sunn hemp residue in plot "x" at the final sampling prior to corn planting. Nitrogen-uptake efficiency (NUE) was calculated as: NUE_x = (Total N $Content_x$ – Total N $Content_{Conv\ 0N}$) / NAC_x; where Total N $Content_x$ = TKN present in total corn biomass in plot "x" and Total N $Content_{Conv\ 0N}$ = average TKN present in total corn biomass of Conv 0N treatment. Unaccounted applied N (UAN) was calculated as: UAN_x = NAC_x - Total N $Content_x$.

Analysis of Data

A balanced analysis of variance (ANOVA) was conducted to assess the effect of GM application on corn growth, yield, and N-uptake efficiency responses, as well as the effect of chemical N-rate and possible interactions of chemical N-rate with GMs. For all measured values, this ANOVA was conducted on SAS software (Statistical Analysis Systems; Cary, NC) using data from all treatments receiving N rates of 0, 67 or 133 kg N ha^{-1} (4 GM levels x 3 N-rates = 12 treatments; $\alpha = 0.05$). Measured values were regressed with a linear model (PROC GLM) based on GM level, N-rate, GM x N-rate interaction, and block. A randomization term for block was included. Significance of main effects and the interaction term (GM x N-rate) are shown. Where interaction of the two main effects is non-significant, Duncan multiple range test ($\alpha = 0.05$) of pooled averages are shown for main effects. Interaction between GM level and N-rate was never significant.

Pairwise contrasts were conducted to assess the parity of GM treatments supplemented with 1/3 (67N) or 2/3 (133N) the recommended N-rate for sweet corn with

conventional treatments receiving 3/3 (Conv 200N) or 4/3 (Conv 267N) of the recommended N-rate (6 GM treatments compared with 2 Conv treatments = 12 contrasts). Using SAS software, contrasts were made with an ANOVA based on a linear model (PROC GLM) of treatment and block. All 14 treatments were included in the ANOVA. Possible error from the high number of contrasts was mitigated as much as possible by evaluating relevance of contrast results within the context of the overall statistical, numerical, and graphical trends.

Results

N Applied to Corn

In 2002, average amounts of N applied to corn (NAC) derived from GM residues of SH+L (56 kg N ha^{-1}) and L (57 kg N ha^{-1}) were statistically similar to each other and greater than SH (11 kg N ha^{-1}; see Appendix C, Table C.1). In 2003, SH+L (51 kg N ha^{-1}) applied significantly more N to corn than both SH (30 kg N ha^{-1}) and L (21 kg N ha^{-1}; see Appendix C, Table C.14). As a result, NAC in both years was numerically greater for Conv 200N and Conv 267N compared to any GM with 67N or 133N, with differences significant everywhere except SH+L 133N similar to Conv 200N in 2002 (Tables 3.1 and 3.2).

Ear Yields, 2002

For all treatments, marketable ear yields (fresh weight) for 2002 are shown in Figure 3.1(A). Amendment with GM increased end-season marketable, fancy, and total ear yields by 30-45%, 46-68%, and 15-24% respectively, with no differences between GM types (Table 3.3). Yields for grades No.1 and No.2 as well as non-marketable ears were not affected by GM application (data not shown). Reduction in N-rate from 133N resulted in much lower yields for marketable ears (5% and 60% for 0N and 67N,

respectively, compared to 133N), fancy ears (2% and 50% for 0N and 67N, respectively), and total ears (17% and 73% for 0N and 67N, respectively). Interactions between GM and N-rates were non-significant in all cases (Table 3.3). For all residue levels, fraction of ear yield as fancy and marketable increased as chemical N-rate went up.

Optimal marketable ear yields were achieved with Conv 200N (within 4% of maximum yielding Conv 267N). Amendment with SH+L 133N produced statistically similar marketable and fancy ear yield to amendment with Conv 200N or 267N, and similar total ear yields to 200N, though yields with SH+L 133N were numerically less in all cases. Corn with SH 133N also produced similar fancy ear yields to Conv 200N. Otherwise, marketable, fancy, and total ear yields were significantly greater with Conv 200N or 267N than with any GM plus 67N or 133N (Table 3.1).

Ear Yields, 2003

For all treatments, fresh weight of marketable ears for 2003 are shown in Figure 3.1B. Due to earlier planting date and nearly 50% higher plant population, overall ear yields compared to 2002 increased for treatments receiving 133N or more and decreased for treatments receiving 0N or 67N. Unlike 2002, optimal ear yield for the conventional treatment was not reached at Conv 200N (Conv 267N was greater than Conv 200N by 15%).

Only amendment with SH+L significantly increased end-season marketable, fancy, and total ear yields relative to Conv (Table 3.3). Yields for grades No.1 and No.2 as well as non-marketable ears were unaffected (data not shown). Increase in N-rate again resulted in much higher yields for marketable, fancy, and total ears. Interaction between GM and N-rates was non-significant in all cases (Table 3.3). Pair-wise contrasts showed that SH+L 133N produced similar marketable, fancy, and total ear yield to Conv 200N,

but lower yields in all cases when compared to Conv 267N. Otherwise, marketable, fancy, and total ear yields were greater with Conv 200N or 267N than with any GM plus 67N or 133N (Table 3.2).

In 2003 compared to 2002, fraction of ear yield as USDA fancy grade decreased while fraction as USDA No.1 and No.2 increased for all treatments (except Conv 0N which had no fancy ears in either year). Decrease in fraction as fancy was particularly high for nearly all GM treatments (12.3-28.7 percentage points lower in 2003 than in 2002), but less for all Conv treatments as well as SH+L 0N and SH 0N (2.1-9.7 percentage points lower in 2003 than in 2002). For highest yielding treatments (Conv 267N, Conv 200N, SH+L 133N, SH 133N, and L 133N) fraction of ear yield as marketable ears decreased slightly, from 0.6-7.6% percentage points lower in 2003 than in 2002, depending on the treatment (Tables 3.1 and 3.2).

Growth Analysis, 2002

Leaf indicators

For nearly all treatments, leaf area index (LAI), chlorophyll meter readings (CMR), and specific leaf N (SLN) showed linear or logarithmic increases up through the time of ear appearance (6 WAE) or the following sample date (8 WAE; see Tables 3.4 and 3.5 and Appendix C, Table C.2). Green manures affected these indicators weakly with statistical differences appearing primarily at the beginning (2-4 WAE) or end (9 WAE) of the growing season. However, LAI, CMR, and SLN for GM-amended corn usually showed numerical advantage compared to Conv throughout the entire season. Advantages were strongest for SH+L and SH and most pronounced in LAI, often ranging from 30-45% for all the leaf indicators (except SLA) during the first 2-4 WAE and up to 16% afterwards. Specific leaf area showed no consistent response to GMs. Chemical N-

rate strongly affected LAI, CMR, and SLN at almost every sample date, always producing increases from 0N to 67N (significant at all dates) and from 67N to 133N (significant in about half of sample dates) with most pronounced benefits in the middle 4 weeks of the season (4-8 WAE). Greatest response to increasing N-rate occurred for LAI (46-126% and 70-145% increases for 67N and 133N, respectively, compared to 0N), with response from CMR and SLN on the order of 15-50% (67N compared to 0N) and 25-60% (133N compared to 0N; Tables 3.4, 3.5 and Appendix C, Table C.2). Specific leaf area (SLA) decreased in response to chemical N, but effects were less strongly significant than for other leaf indicators.

In terms of LAI, SH+L 133N and SH 133N showed numerical advantage over Conv 200N and Conv 267N at 2 and 4 WAE (Table 3.5). Otherwise, Conv 200N and Conv 267N generally showed numerical advantage over all GMs with 67N and 133N for LAI, SLN and CMR, though these differences did not become significant until 8-9 WAE. In terms of LAI, CMR, and SLN, Conv 267N showed more frequent and more significant advantages over GM treatments than Conv 200N, and SH+L 133N remained the only GM treatment statistically similar to Conv 267N and Conv 200N throughout the season (Table 3.5 and Appendix C, Table C.8).

Tissue characteristics

Dry weights and N contents for leaf, stem, and total plant increased logarithmically or exponentially during the first 6 WAE (time of ear appearance; Tables 3.6-3.9 and Appendix C, Tables C.3-C.5). During this time, benefit from GM application generally ranged from 5-45%. Consistently significant benefit from GMs occurred for dry weights and N-contents of leaf and stem tissue and (to a lesser extent) for the total plant. At or after ear appearance, GM benefit for dry weight and N content of vegetative factors

became somewhat reduced (less than 20%), but more pronounced for ears themselves (15-30%). Compared to leaf, stem, and ear dry weights, GM benefits were somewhat lower and less consistently significant for root dry weight as well as tissue N contents (generally, 5-30%) and had little effect on tissue N concentrations (see Tables 3.6, 3.8 and Appendix C, Tables C.6-C.7 and C.27). Advantages were typically greatest for SH+L and SH, although SH+L generally showed greatest tissue dry weights by late season and greatest N content throughout the season.

In terms of all tissue N contents and dry weights, SH+L 133N and SH 133N showed numerical advantage over Conv 200N and Conv 267N during the first 2-4 WAE. Otherwise, Conv 200N and Conv 267N maintained greater tissue dry weights and N contents than all GM treatments, though differences did not become significant until late season (6-8 WAE and 8-9 WAE relative to GMs with 67N and GMs with 133N, respectively). Compared to other GM treatments, late-season differences against Conv 200N and Conv 267N treatments were generally less dramatic for SH+L 133N (see Tables 3.10, 3.11 and Appendix C, Tables C.9-C.11). In regards to tissue N concentration, pairwise contrasts showed consistent statistical advantage for Conv 200N against GMs with 67N throughout the season, but not until the end of the season when compared to GMs with 133N. As with other growth factors, tissue N concentration for SH+L 133N remained closer to Conv 200N and Conv 267N than any other contrasted GM treatment (see Appendix C, Tables C.12-C.13 and C.28).

Chemical N-rate strongly affected all tissue characteristics (dry weights, N contents, and N concentrations) on all sample dates, with tissue N contents showing strongest response. Application of 0N and 67N (compared to 133N) reduced vegetative

tissue N content by roughly 60-80% and 25-40%, respectively, while reductions for vegetative dry weights were about 40-70% and 10-20%, respectively, with greatest differences occurring just before or at ear appearance (4-6 WAE; Tables 3.6-3.9 and Appendix C, Tables C.3-C.5). At final biomass sampling, application of 0N and 67N resulted in ear N content of 14% and 62%, respectively and ear dry weight by 15% and 72%, respectively, compared to 133N (Appendix C, Table C.5). Vegetative tissue N concentrations showed similar patterns to dry weight and N content before ear appearance, though reductions due to lower chemical N-rate were generally less (not more than 50%). After ear appearance, root, stem and ear N concentrations typically remained lowest for corn with 67N – even compared to 0N – primarily due to "dilution effect" (biomass increases outpaced increases in N accumulation) with stronger N remobilization to ears from vegetative tissues possibly playing a role as well (Appendix C, Tables C.6-C.7 and C.27).

Growth Analysis, 2003

Leaf indicators

Leaf indicators showed similar behavior in 2003 compared to 2002, although GM effects were weaker. In terms of LAI, CMR, and SLN, benefit from GM amendment typically remained within 20-30%, with significant differences less consistent than in 2002. However, as in 2002 greatest GM benefits occurred for SH+L and (to a lesser extent) SH (Table 3.12 and Appendix C, Table C.15). Neither GM nor chemical N-rate significantly affected SLA. Chemical N-rate again strongly affected LAI, CMR and SLN throughout the season with significant increases from 0 to 67N and from 67N to 133N at all sample dates, and smallest relative benefits at 2 WAE. As in 2002, LAI response to increased chemical N-rate (26-107% and 44-134% for 67N and 133N, respectively,

compared to 0N) was greater than for CMR and SLN (generally, 30-70% and 50-100% for 67N and 133N, respectively, compared to 0N; see Table 3.12 and Appendix C, Table C.15). Relative to 2002, LAI values were greater by 30-60% and SLN values lower by 30-45% within treatments at similar samples date in 2003. Values for SLA and CMR changed little from 2002, especially for treatments with 133N or more.

Both SH+L 133N and SH 133N maintained similar LAI compared to Conv 200N and Conv 267N, although LAI for SH 133N dropped in comparison at final sampling (Table 3.13). Values of CMR for SH+L 133N and SH 133N were statistically similar, though numerically less, than those of Conv 200N and Conv 267N. Contrasted GM treatments did not demonstrate consistent early-season numerical advantage against Conv 200N and Conv 267N in terms of CMR and SLN (see Appendix C, Table C.21).

Tissue characteristics

Amendment with SH+L and SH consistently increased tissue dry weights and N contents by 10-45% throughout the season (Tables 3.14-3.17; see also Appendix C, Tables C.16-C.18). Like 2002, relative advantages from GMs generally peaked at or just prior to ear appearance (4-6 WAE) and thereafter declined. However, more dramatic declines in some characteristics for Conv at final sampling (9 WAE) created apparent benefits for GMs similar to those seen at 4-6 WAE. Relative advantages within each GM level remained qualitatively similar across all tissue dry weights and N contents. Advantages were again stronger for SH+L and SH compared to L, and tissue N concentration again showed almost no effect from GM amendment (see Tables 3.14-3.17 and Appendix C, Tables C.16-C.18).

Changes in chemical N-rate in the 0N to 133N range also produced effects qualitatively similar to 2002. Chemical N-rate strongly affected most tissue

characteristics at all sample dates, with tissue N contents showing strongest response. Application of 0N and 67N (compared to 133N) lowered vegetative tissue N content by roughly 50-80% and 15-40%, respectively, while reductions of vegetative dry weights were about 40-70% and 10-15%, respectively, with greatest differences again occurring just before or at ear appearance (4-6 WAE; for examples, see Tables 3.14-3.17 and Appendix C, Tables C.16-C.18). At final biomass sampling, application of 0N and 67N decreased ear N content to 8% and 42%, respectively, and ear dry weight to 9% and 48%, respectively, compared to 133N (Appendix C, Table C.18). Vegetative tissue N concentrations showed similar patterns to dry weight and N content before ear appearance, though decreases due to lower chemical N-rate were generally less (as in 2002, not more than 50%). After ear appearance, root, stem and ear N concentrations again remained lowest for corn with 67N (see Appendix C, Tables C.19-C.20).

Tissue and total dry weights generally remained numerically superior throughout the season for SH+L 133N compared to Conv 200N and Conv 267N, although differences were often non-significant. Tissue and total N contents for SH+L 133N also remained similar to Conv 200N and Conv 267N throughout most of the season. Additionally, tissue dry weights and N contents of SH 133N were rarely less than Conv 200N and Conv 267N until a decline at final sampling (Tables 3.18 and 3.19 and Appendix C, Tables C.22-C.24). Tissue N concentrations for GMs with 133N again stayed lower than those of Conv 200N and Conv 267N, becoming significantly lower at or after 6 WAE but remaining closest for SH+L 133N. Stem dry weights for all GMs with 67N were often numerically (sometimes significantly) greater than for Conv 200N and Conv 267N (Appendix C, Table C.22), likely as a result of much lower ear

production by GMs with 67N. Root, leaf, and total dry weights for GMs with 67N also remained statistically similar (though numerically less) to Conv 200N and Conv 267N until final harvest. Statistical advantage of Conv 200N and Conv 267N over GMs with 67N were detected for the first 6 WAE for stem N content and N concentration and afterward for leaf and ear N contents and N concentrations (Tables 3.18-3.19, Appendix C, Tables C.24, C.26 and C.30).

Values for tissue dry weights of all treatments in 2003 (compared to values from similar sample dates in 2002) increased 20-80%, while values for total N content in 2003 fell by 40-50% for most treatments beginning at 4 WAE. Values from TKN may have been reduced by a percentage consistent for all samples, which are being resubmitted for analysis. New N data will likely be proportional to that listed here, which will therefore not change statistical trends for tissue N contents and concentrations. Also, unlike 2002, when little or no net N uptake occurred after 6 WAE (Table 3.11), tissue samples in 2003 revealed 40-45% of total plant N uptake occurred between 6 WAE and final harvest (9 WAE) for highest yielding treatments (Conv 267N, Conv 200N, and SH+L 133N; Table 3.19).

Nitrogen Uptake Efficiency and Unaccounted Applied Nitrogen

With few exceptions, N- uptake efficiency (NUE) was not significantly affected by GMs or chemical N-rate in either year, nor did any statistical differences for NUE exist between Conv 200N and Conv 267N compared to GMs with 67N or 133N (Tables 3.1-3.2 and Appendix C, Tables C.1, C.14). In 2002 and 2003 NUE showed a decreasing trend as chemical N-rate increased beyond 67N, with decreases also occurring from Conv 133N to Conv 200N and from Conv 200N to Conv 267N. Nevertheless, none of these trends were significant.

Corn amended with SH+L 133N and L 133N showed unaccounted applied N (UAN; defined as N applied at or after corn planting not accounted for in corn tissues) similar to Conv 200N in both years. Otherwise, UAN was significantly greater for Conv 200N and Conv 267N compared to all GMs with 67N or 133N. However, when one includes the N accumulated by SH and weeds during the fall of each year but lost before corn planting, UAN from SH+L 133N and SH 133N become similar to or greater than Conv 200N and Conv 267N while L 133N, SH+L 67N and SH 67N become similar to Conv 200N (Tables 3.1-3.2). However, it must be remembered that this UAN pool includes any N still present in non-corn residues or in the soil and therefore does not necessarily indicate loss from the system.

Discussion

Amendment with GMs resulted in ear yield, growth and N accumulation benefit for sweet corn. However, GM approaches in this particular management system delivered only 13-51 kg N ha^{-1}, with SH+L supplying highest N in both years (Tables 3.1-3.2). Benefits from GMs were usually greatest early in the season (2-4 WAE), strongest from the combination of SH+L and weakest for L alone (Tables 3.3-3.4, 3.6-3.9, 3.12, 3.14-3.17), and required chemical N supplementation at least two-thirds (133 kg N ha^{-1} or more) of the recommended N-rate (200 kg N ha^{-1}) to achieve ear yields similar to the conventional approach with recommended inorganic N (Figure 3.1[A,B]). Results were similar to other experiments where winter-decomposed residues from tropical GMs (Brandt et al. 1999) or low-performing temperate GMs (Gallaher 1993, Gallaher and Eyelands 1985) could not satisfy N demand for spring crops. As suggested by our GM growth and decomposition study (Chapter 2) as well as other studies of sunn hemp decomposition (Mansoer et al. 1997) and potential use of hairy vetch GMs (Sainju and

Singh 2001) in the southeast US, our GM approaches were limited by low N accumulation and/or rapid N loss during winter-time GM decomposition.

In 2002, growth of sweet corn amended with any GM plus two-thirds the recommended N-rate (133N) generally fell behind that of unamended corn with the full or high N-rate (Conv 200N and Conv 267N) after showing initial advantage during the first 2-4 WAE (Tables 3.5, 3.10-3.11). In 2003, Conv 200N and Conv 267N showed advantage over SH+L 133N for final ear harvest only, with almost no differences occurring throughout the season in terms of tissue dry weights, N contents and leaf indicators (Tables 3.13, 3.18-3.19). Significant reduction in tissue and ear yields for SH 133N relative to Conv 200N and Conv 267N during 2003 also occurred only at 8-9 WAE. Corn with SH+L 133N produced ear yields statistically similar to, though numerically lower than, Conv 200N (2002 and 2003) and Conv 267N (2002 only). All other corn amended with GMs plus 67N or 133N produced ear yields significantly lower than Conv 200N or Conv 267N (Tables 3.1 and 3.2). Griffin and Hesterman (1991) showed similar results for potato, with greater GM benefit for vegetative growth than reproductive yields.

We were unable to detect interesting differences in NUE based on GM or N-rate N, and direct measures of N-loss (via suction lysimeter sampling; see Chapter 4) failed to produce data. In terms of all N (plant and/or chemically-derived) applied to corn in each treatment SH+L 133N remained similar to Conv 200N and less than Conv 267N. However, when one includes N accumulated by SH and weed tissues but lost by decomposition before corn planting, unaccounted applied N (UAN) for SH+L 133N becomes similar to Conv 267N (Tables 3.1 and 3.2). Generally, NUE ranged from 25-

35% in 2002 and 15-25% in 2003. These results do not differ radically from those of N'Dayegamiye and Tran (2001) and N'Dayegamiye (1999).

Results for growth factors between years were similar qualitatively, although generally not quantitatively. Dry weights, N concentrations and N contents for all tissues (leaf, stem, root, ears) and total plant as well as leaf indicators such as LAI, SLN, and CMR revealed GM benefits up to 45% in the first 4 to 6 WAE in both years. Among leaf indicators, LAI responded most strongly to GM application and N-rate, as did leaf and stem dry weights and N contents among tissue factors (Tables 3.4, 3.6, 3.8, 3.12, 3.14, 3.16). Tissue N concentrations were somewhat variable, often showing lower values for GM amended corn especially at mid-season when ears appeared. These lower values for GM amended corn probably reflected greater N-stress and N remobilization to ears from vegetative tissues. Specific leaf area (SLA) never displayed any consistent response to GMs (see Appendix C, Tables C.2 and C.15).

In terms of pairwise comparisons at early and mid-season, no leaf or tissue characteristic showed statistical differences predictive of the "finer" but significant differences in final ear yield patterns among highest producing treatments (Conv 200N and Conv 267N produced greater ear yields than all GMs with 67N or 133N except SH+L 133N; Tables 3.1-3.2, 3.5, 3.10-3.11, and 3.18-3.19). Vegetative tissue and leaf characteristics often did not display differences reflective of ear final yields until 8-9 WAE, far too late for a grower to generate a yield response by adjusting management. Most net GM N release probably occurred within the first 2-4 weeks after emergence, and total N delivered to corn via GMs was significantly less than the extra 67 and 133 kg N ha^{-1} received by Conv 200N and Conv 267N – likely resulting in a "running out" effect

after the first 4 WAE (Tables 3.1 and 3.2). Early season advantages and late-season declines for GMs with 133N (especially in terms of ear-fill) may also have been the result of rapidly changing root growth and proliferation patterns, explored in detail in Chapter 4. Taken together, this suggests N content of GM residues at planting may better indicate required levels of N supplementation. Management of GM approaches to fertility may thus need to be "preventative" rather than "therapeutic" because plant and root characteristics will not provide adequate warning time to adjust management.

Despite 50% higher plant population, lower N recovery for all treatments occurred during 2003 compared to 2002 (Tables 3.11 and 3.19). While values for tissue dry weights of all treatments in 2003 (compared to values from similar sample dates in 2002) increased 20-80%, values for total N content in 2003 decreased. As mentioned above, N-values from all corn tissue samples in 2003 may have been underestimated by a constant fraction (which would not change statistical findings). However, the decreased N may be partly explained by rainfall distribution – less than 25 mm (less than one inch) fell during the first six weeks of corn growth in 2002 but greater than 100 mm (greater than four inches) fell during the same period in 2003. Chemical N, applied at 0, 3, and 5 WAE, as well as mineralized N from GM residues, may have suffered far more leaching in 2003, especially if topsoil was already near field capacity from irrigation. Suction lysimeters were installed to quantify such N-leaching losses in selected treatments, but due to coarse soil texture sample extraction was far too inconsistent to yield results. Nonetheless, unlike 2002, when little or no net N uptake occurred after 6 WAE, tissue samples in 2003 revealed 40-45% of total plant N uptake occurred between 6 WAE and final harvest (9 WAE) for highest yielding treatments (Conv 267N, Conv 200N, and SH+L 133N; Tables

3.11 and 3.19). Considering the possibly low N content of corn plants in 2003 and the lack of yield plateau at 200N, such late-season N-uptake does not seem unreasonable.

With higher plant density and lower apparent N-recovery in 2003, differences in size and location of the available N pool appear to have become more important. Treatments supplemented with less chemical N showed lower total ear yield gains and/or greater reductions in marketable ear yield as a fraction of total ear yield in 2003 compared to 2002 (Tables 3.1 and 3.2). The lower N-content of vetch residues in 2003 may have also become a greater liability. Even in the best 10 (of 24) plots where it was planted, vetch N accumulation in 2003 was 10 kg N ha^{-1} less than lupin in 2002, with 30-40 kg N ha^{-1} reductions in some of the worst plots. As a result, average N content of SH+L residue at the time of corn planting was little more than 50 kg N ha^{-1}, and N released from decomposing SH+L residue during the corn growing season may have only been some fraction of this total. Nitrogen from vetch residues – which possessed highest N concentrations of all GMs studied – may have mineralized rapidly and been especially vulnerable to leaching loss during early-season rains of 2003.

Increased root distribution near the soil surface and near the plant may have ameliorated potential N and water stresses for SH+L 133N during early to mid season, but may also have exacerbated them during late-season ear fill, especially as late-season N-uptake appears to have been a factor (see Chapter 4). Taken together, lower GM N content, greater release of N early in the corn growing season during higher rainfall, higher plant population, and root patterns combined with continued N demand through late season may have reduced the relative ear yield benefit of GMs in 2003 compared to 2002.

Decline in ear quality for GM treatments during 2003 was evidenced by greater reductions in fancy ears as fraction of total yields compared to conventional (Tables 3.1 and 3.2). At final harvest in 2003, ears from GM treatments with 133N also appeared to suffer more from overmaturity, which was not quantified but may have reduced apparent yields and grade quality. Data from a collaborative study in Tifton (Phatak et al. unpublished) suggests corn ears may indeed have matured earlier with GMs than without. These changes in ear yield timing and/or quality may also be related to some combination of rooting patterns and GM N release potential.

Given our particular management strategies, it appears insufficient N from our summer leguminous GM was immobilized over the winter until spring corn planting, nor did our winter leguminous GM perform well enough to accumulate N at levels similar to those seen in temperate environments. Our results were therefore similar to those of previous investigators in north Florida (Gallaher 1993, Gallaher and Eyelands 1985) or similar environments (Mansoer et al. 1997, Jeranyama et al. 2000), with less benefit from GMs than found in temperate (Griffin et al. 2000, Cline and Silvernail 2002) and tropical (Ladha et al. 1996, Seneratne and Ratnasinghe 1995, Aulakh et al. 2000, Agustin et al. 1999) environments. Scheduling of chemical N supplementation, which delivered two-thirds of applied NH_4NO_3 during the first 4 weeks of growth, may have conflicted with simultaneous release of N from GM residues. In both years, conventional treatments with 200N and 267N may have gained advantage by receiving more N at final application date (5 WAE) than GM treatments, especially during a year with high early season rainfall.

Notwithstanding possible long-term benefits for weed and pest control (see Chapter 6) or changes in soil properties conducive to crop production (see Chapter 5), we should

consider the following options: altering management of sunn hemp (or similar GMs) in our reduced-tillage/reduced-mowing system to better immobilize N during winter decomposition (see Chapter 2) and improve corn root growth patterns (see Chapter 4); following sunn hemp with a fall/winter economic crop that will make better use of sunn hemp N; moving sunn hemp to the spring and following it with a summer or fall economic crop; and/or substituting sunn hemp with another legume for which seeds may be harvested, thereby generating an economic benefit while removing "excess" N from the system.

Substitution of our winter GM monocrop with mixtures of winter legumes, grasses, small grains and/or non-leguminous dicots in the continuation of this project appears to have dramatically improved winter GM potential (Lavila and Scholberg, unpublished; see also Karpenstein-Machan and Stuelpnagel 2000, Cline and Silvernail 2002). We also recommend better exploitation of direct planting winter GMs or economic crops into living sunn hemp (or another easily broken GM) so as to eliminate gap time between rapid sunn hemp decomposition and crop N uptake (see also Chapters 1 and 2). Chemical (or animal manure) N supplementation in GM approaches in the north Florida environment should probably deliver more N at mid season to avoid unnecessary coincidence with early season GM N release and reduced crop N demand. Finally, organic approaches to crop production relying heavily on GM N may be less risky with lower crop plant populations and with use of crops having lower N demand and without price premiums for large fruit size.

Conclusions

Green manure approaches to N fertilization of spring sweet corn in a north Florida reduced tillage system significantly increased vegetative and reproductive tissue growth,

N accumulation and most leaf indicators. Greatest benefits often came during the first 2-4 weeks of growth, although performance of corn amended with SH+L and 133 kg N ha^{-1} and (to a lesser extent) SH and 133 kg N ha^{-1} rivaled that of corn with 200 or 267 kg N ha^{-1} but fell behind in terms of final ear yields. Final ear yield trends were best predicted by statistical differences in total N applied to corn at planting in the form of residue and subsequent NH_4NO_3 supplementation, but may also be related to timing of N availability and dynamic changes in root growth patterns (explored in Chapter 4). Improvement of GM benefits may require selection of different GMs or GM mixtures and modification of management techniques including residue management, selected crop rotation, planting procedure, and scheduling of N supplementation.

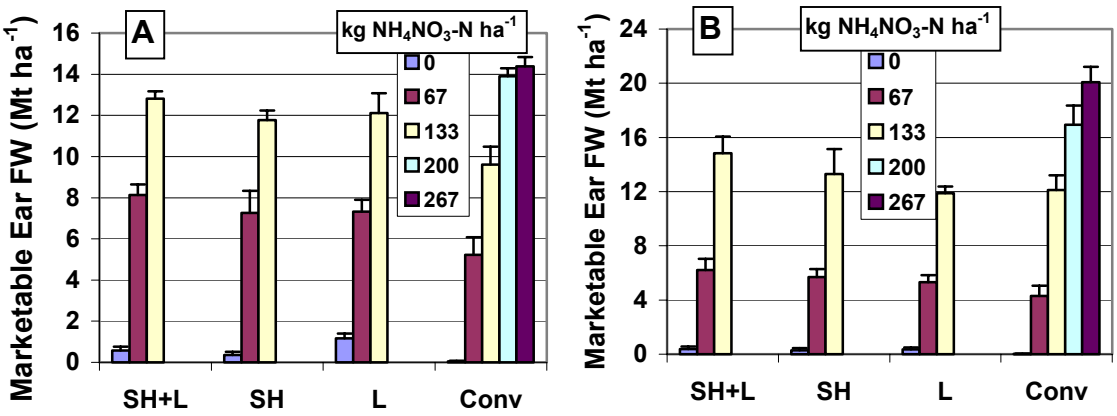

Figure 3.1. Marketable ear yields as fresh weight by treatment, 2002 (A) and 2003 (B). Error bars reflect standard errors.

Table 3.1. Pairwise contrasts of selected nitrogen factors and ear yields, 2002.

Treatment	NUE kg kg^{-1}	NAC kg N ha^{-1}	UAN kg N ha^{-1}	UAN-Total[#] kg N ha^{-1}	Fancy Ears Mt ha^{-1}	Marketable Ears Mt ha^{-1}	Total Ears Mt ha^{-1}
Conv 200N	0.33	200[†]	127[†]	129[†]	12.3	13.9	14.8
Conv 267N	0.28	267[*]	178[*]	187[*]	12.9	14.4	15.4
SH+L 67N	0.34	116[*†]	61[*†]	138[†]	6.5[*†]	8.1[*†]	9.9[*†]
SH 67N	0.40[*†]	79[*†]	32[*†]	123[†]	5.2[*†]	7.3[*†]	9.5[*†]
L 67N	0.24	127[*†]	81[*†]	96[*†]	5.3[*†]	7.3[*†]	9.3[*†]
SH+L 133N	0.28	211[†]	139[†]	218[*]	11.8	12.8	13.8[†]
SH 133N	0.34	144[*†]	79[*†]	163[*]	10.7[†]	11.8[*†]	12.9[*†]
L 133N	0.19	209[†]	151[†]	168[†]	10.6[*†]	12.1[*†]	12.9[*†]

SH = sunn hemp; L = winter legume; Conv = conventional (no green manure); N = kg NH_4NO_3-N ha^{-1}; NUE = N uptake efficiency; NAC = N applied at or after corn planting; UAN = applied N not recovered by corn; # includes N from sunn hemp residue and weeds prior to sunn hemp death; [*] mean different from Conv 200N and Conv 267N at the $p \leq 0.05$ level, respectively.

Table 3.2. Pairwise contrasts of selected nitrogen factors and ear yields, 2003.

Treatment	NUE kg kg^{-1}	NAC kg N ha^{-1}	UAN kg N ha^{-1}	UAN-Total[#] kg N ha^{-1}	Fancy Ears Mt ha^{-1}	Marketable Ears Mt ha^{-1}	Total Ears Mt ha^{-1}
Conv 200N	0.24	203	149	184	14.2[†]	17.0[†]	18.9[†]
Conv 267N	0.19	271	213	252	17.7[*]	20.1[*]	21.7[*]
SH+L 67N	0.15	113[*†]	86[*†]	214[†]	2.8[*†]	6.2[*†]	7.6[*†]
SH 67N	0.21	99[*†]	70[*†]	200[†]	2.4[*†]	5.7[*†]	7.0[*†]
L 67N	0.20	81[*†]	58[*†]	81[*†]	2.7[*†]	5.3[*†]	6.7[*†]
SH+L 133N	0.24	184[*†]	139[†]	261[*]	11.9[†]	14.8[†]	16.3[†]
SH 133N	0.20	163[*†]	128[*†]	258[*]	10.4[*†]	13.3[*†]	14.9[*†]
L 133N	0.22	168[*†]	140[†]	170[†]	8.3[*†]	11.9[*†]	13.6[*†]

SH = sunn hemp; L = winter legume; Conv = conventional (no green manure); N = kg NH_4NO_3-N ha^{-1}; NUE = N uptake efficiency; NAC = N applied at or after corn planting; UAN = applied N not recovered by corn; # includes N from sunn hemp residue and weeds prior to sunn hemp death; [*] mean different from Conv 200N and Conv 267N at the $p \leq 0.05$ level, respectively.

Table 3.3. Ear yields at final harvest, (fresh weight, kg ha^{-1}), 2002 and 2003.

	2002			2003		
	Fancy	Marketable	Total	Fancy	Marketable	Total
GM x N-Rate	NS	NS	NS	NS	NS	NS
GM	**	**	***	*	*	*
SH+L	6.1 a	7.2 a	8.7 a	4.9 a	7.2 a	8.3 a
SH	5.3 a	6.5 a	8.1 a	4.3 ab	6.4 ab	7.6 ab
L	5.5 a	6.9 a	8.4 a	3.7 ab	5.9 ab	7.1 ab
Conv	3.6 b	5.0 b	7.0 b	3.3 b	5.5 b	6.7 b
N-Rate	***	***	***	***	***	***
0N	0.2 c	0.5 c	2.1 c	< 0.1 c	0.3 c	0.9 c
67N	5.1 b	7.0 b	9.2 b	2.4 b	5.4 b	6.7 b
133N	10.2 a	11.6 a	12.7 a	9.7 a	13.0 a	14.7 a

NS: means within columns for GM and N-rate not different at the $p \leq 0.05$ level; *, **, ***: means within columns different at the $p \leq 0.05$, 0.001, and 0.0001 level, respectively; means within vertical columns for GM and N-rate followed by the same letter do not differ at the $p \leq 0.05$ level according to Duncan's Multiple Range Test.

Table 3.4. Leaf area index, 2002 (m^2 leaf m^{-2} ground).

	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE
GM x N-Rate	NS	NS	NS	NS	NS
GM	*	*	NS	NS	NS
SH+L	0.18 a	1.06 a	1.98	1.88	1.13 a
SH	0.20 a	1.17 a	2.16	1.78	1.08 ab
L	0.17 a	0.85 b	1.58	1.82	0.90 b
Conv	0.14 b	0.81 b	1.86	1.67	0.99 ab
N-Rate	***	***	***	***	***
0N	0.12 c	0.51 b	1.30 b	1.05 c	0.68 c
67N	0.18 b	1.15 a	2.18 a	1.96 b	1.05 b
133N	0.21 a	1.25 a	2.21 a	2.36 a	1.34 a

WAE: weeks after emergence. NS: means within columns for GM and N-rate not different at the $p \leq 0.05$ level; *, **, ***: means within columns different at the $p \leq 0.05$, 0.001, and 0.0001 level, respectively; means within vertical columns for GM and N-rate followed by the same letter do not differ at the $p \leq 0.05$ level according to Duncan's Multiple Range Test.

Table 3.5. Pairwise contrasts of leaf area index and specific leaf nitrogen, 2002.

Treatment	Leaf Area Index ($m^2\ m^{-2}$)					Specific Leaf Nitrogen ($\mu g\ N\ cm^{-2}$)				
	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE
Conv 200N	0.21	1.29	2.78	2.45	1.52	54.2	57.4	76.8	73.5	71.3
Conv 267N	0.20	1.40	2.83	2.76	1.67	48.2	63.5	72.8	74.4	76.3
SH+L 67N	0.18	1.18	2.31	2.09†	1.03*†	42.9*	50.7†	57.0	62.6	48.4*†
SH 67N	0.20	1.43	2.73	1.93*†	1.23*†	44.2*	47.2*†	44.9*†	47.0*†	61.4†
L 67N	0.16	1.00	1.57*†	1.97*†	0.90*†	30.8*	56.0	81.6	55.6*†	51.1*†
SH+L 133N	0.22	1.39	2.12	2.49	1.42	49.2	56.9	79.9	63.1	66.5
SH 133N	0.25	1.51	2.41	2.33†	1.29†	51.7	56.2	64.3	63.2	61.6†
L 133N	0.22	1.09	2.16	2.38†	1.34*†	49.4	58.4	71.0	61.1	65.2

WAE: weeks after emergence. SH = sunn hemp; L = winter legume; Conv = conventional (no green manure); N = kg NH_4NO_3-N ha^{-1};
* mean different from Conv 200N and Conv 267N at the $p \leq 0.05$ level, respectively.

Table 3.6. Leaf dry weight, 2002 (kg ha^{-1}).

	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE
GM x N-Rate	NS	NS	NS	NS	NS
GM	*	*	*	NS	*
SH+L	49 a	420 a	926 a	1051 a	702 a
SH	54 a	462 a	935 a	982 ab	679 a
L	45 a	357 b	951 a	953 ab	539 ab
Conv	36 b	336 b	740 b	893 b	617 b
N-Rate	***	***	***	***	***
0N	32 c	195 b	499 c	543 c	401 c
67N	48 b	462 a	1002 b	1080 b	647 b
133N	58 a	523 a	1163 a	1286 a	854 a

WAE: weeks after emergence. NS: means within columns for GM and N-rate not different at the $p \leq 0.05$ level; *, **, ***: means within columns different at the $p \leq 0.05$, 0.001, and 0.0001 level, respectively; means within vertical columns for GM and N-rate followed by the same letter do not differ at the $p \leq 0.05$ level according to Duncan's Multiple Range Test.

Table 3.7. Total dry weight, 2002 (kg ha^{-1}).

	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE
GM x N-Rate	NS	NS	NS	NS	NS
GM	*	*	NS	NS	*
SH+L	89 a	757 ab	3734	5712	5385 a
SH	98 a	825 a	3920	5492	5042 ab
L	85 ab	657 ab	3872	5063	4661 b
Conv	68 b	598 b	3375	4869	4705 b
N-Rate	***	***	***	***	***
0N	61 c	347 c	1469 b	2555 c	2373 c
67N	89 b	819 b	4551 a	6225 b	5334 b
133N	105 a	962 a	5155 a	7072 a	7138 a

WAE: weeks after emergence. NS: means within columns for GM and N-rate not different at the $p \leq 0.05$ level; *, **, ***: means within columns different at the $p \leq 0.05$, 0.001, and 0.0001 level, respectively; means within vertical columns for GM and N-rate followed by the same letter do not differ at the $p \leq 0.05$ level according to Duncan's Multiple Range Test.

Table 3.8. Leaf nitrogen content, 2002 (kg ha^{-1}).

	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE
GM x N-Rate	NS	NS	NS	NS	NS
GM	*	*	*	NS	NS
SH+L	0.8 a	5.3 ab	10.7 a	11.0 a	6.1
SH	0.9 a	5.7 a	10.0 ab	9.4 ab	6.2
L	0.7 b	4.6 ab	10.8 a	9.9 ab	5.1
Conv	0.6 b	4.3 b	8.7 b	9.0 b	5.1
N-Rate	***	***	***	***	***
0N	0.5 c	1.8 c	4.3 c	4.4 c	3.0 c
67N	0.8 b	6.0 b	11.7 b	10.4 b	5.4 b
133N	1.1 a	7.1 a	14.1 a	14.7 a	8.5 a

WAE: weeks after emergence. NS: means within columns for GM and N-rate not different at the $p \leq 0.05$ level; *, **, ***: means within columns different at the $p \leq 0.05$, 0.001, and 0.0001 level, respectively; means within vertical columns for GM and N-rate followed by the same letter do not differ at the $p \leq 0.05$ level according to Duncan's Multiple Range Test.

Table 3.9. Total nitrogen content, 2002 (kg ha^{-1}).

	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE
GM x N-Rate	NS	NS	NS	NS	
GM	NS	*	NS	NS	**
SH+L	1.5 ab	12.1 a	41.5	47.8	41.8 a
SH	1.7 a	12.6 a	39.7	42.9	36.3 a
L	1.4 ab	10.7 ab	42.8	40.8	35.7 a
Conv	1.1 b	9.3 b	37.9	39.9	32.0 b
N-Rate	***	***	***	***	***
0N	0.9 c	3.7 c	13.0 c	16.8 c	14.8 c
67N	1.4 b	13.0 b	45.9 b	47.0 b	35.7 b
133N	2.0 a	16.9 a	62.7 a	64.6 a	58.7 a

WAE: weeks after emergence. NS: means within columns for GM and N-rate not different at the $p \leq 0.05$ level; *, **, ***: means within columns different at the $p \leq 0.05$, 0.001, and 0.0001 level, respectively; means within vertical columns for GM and N-rate followed by the same letter do not differ at the $p \leq 0.05$ level according to Duncan's Multiple Range Test.

Table 3.10. Pairwise contrasts of leaf dry weight and nitrogen content, 2002.

Treatment	Leaf Dry Weight (kg ha^{-1})					Leaf N Content (kg N ha^{-1})				
	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE
Conv 200N	60	541	1314	1404	1020	1.1	7.3	17.8	17.9	10.8
Conv 267N	54	591	1338	1560	1055	1.0	8.9	19.3	20.7	12.6
SH+L 67N	49	448	984*†	1221†	635*†	0.8	5.9†	11.8*†	13.1*†	4.9*†
SH 67N	54	563	1064*†	1059*†	793*†	0.9	6.9	12.1*†	9.0*†	7.3*†
L 67N	41*	409†	1073†	1048*†	514*†	0.5*	5.6†	12.8*†	10.6*†	4.5*†
SH+L 133N	60	590	1224	1383	905	1.1	7.9	16.1	15.7†	9.4†
SH 133N	73†	600	1304	1303†	840†	1.3	8.4	14.3*†	14.8†	8.0*†
L 133N	61	471	1203	1233†	823*†	1.1	6.4†	14.1*†	14.4†	8.8†

WAE: weeks after emergence. SH = sunn hemp; L = winter legume; Conv = conventional (no green manure); N = kg NH_4NO_3-N ha^{-1}; * mean different from Conv 200N and Conv 267N at the $p \leq 0.05$ level, respectively.

Table 3.11. Pairwise contrasts of total dry weight and nitrogen content, 2002.

Treatment	Total Dry Weight (kg ha^{-1})					Total N Content (kg N ha^{-1})				
	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE
Conv 200N	107	994	5950	7886	7730†	2.2	18.4	96.9	81.5	72.5†
Conv 267N	98	1122	5800	7984	8486*	2.0	22.0	82.4	90.3	89.2*
SH+L 67N	90	800†	4345	6896	5498*†	1.4*	12.9*†	46.9*†	54.8*†	38.3*†
SH 67N	99	994	4742	6138	5675*†	1.6	14.9†	45.2*†	46.9*†	40.7*†
L 67N	78	739†	4509	6048†	4956*†	1.1*	12.6*†	46.4*†	45.8*†	33.3*†
SH+L 133N	108	1082	4856	7674	7651†	2.1	19.1	63.4*	71.8	68.9†
SH 133N	130	1093	5370	7453	6978†	2.5	19.4	62.3*	65.3†	53.3*†
L 133N	109	884	5042	6459	6834*†	2.1	15.6†	66.7*	57.8*†	57.9*†

WAE: weeks after emergence. SH = sunn hemp; L = winter legume; Conv = conventional (no green manure); N = kg NH_4NO_3-N ha^{-1}; * mean different from Conv 200N and Conv 267N at the $p \leq 0.05$ level, respectively.

Table 3.12. Leaf area index, 2002 (m^2 leaf m^{-2} ground).

	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE
GM x N-Rate	NS	NS	NS	NS	NS
GM	NS		*	NS	
SH+L	0.29	1.96 a	2.24 ab	1.95	1.64 ab
SH	0.30	1.78 ab	2.51 a	2.15	1.66 a
L	0.29	1.53 ab	1.99 ab	1.71	1.38 b
Conv	0.27	1.56 b	1.94 b	1.78	1.34 b
N-Rate	***	***	***	***	***
0N	0.23 c	0.99 b	1.33 c	1.05 b	0.96 c
67N	0.29 b	1.99 a	2.24 b	2.18 a	1.49 b
133N	0.34 a	2.14 a	2.94 a	2.46 a	2.07 a

WAE: weeks after emergence. NS: means within columns for GM and N-rate not different at the $p \leq 0.05$ level; *, **, ***: means within columns different at the $p \leq 0.05$, 0.001, and 0.0001 level, respectively; means within vertical columns for GM and N-rate followed by the same letter do not differ at the $p \leq 0.05$ level according to Duncan's Multiple Range Test.

Table 3.13. Pairwise contrasts of leaf area index (m leaf m^{-2} ground) and specific leaf nitrogen (µg N cm^{-2}), 2003.

Treatments	Leaf Area Index (cm^2 cm^{-2})					Specific Leaf N (µg N cm^{-2})				
	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE
Conv 200N	0.36	2.05	2.89	2.42	2.28	57.8	29.5	40.5†	49.1	45.6
Conv 267N	0.35	2.42	2.79	2.74	2.71	55.4	28.2	48.6*	51.6	45.6
SH+L 67N	0.31	2.13	2.32	2.25	1.42*†	43.2*†	21.9	29.7*†	36.0*†	31.1*†
SH 67N	0.30	1.94†	2.25*	2.45	1.82†	46.0*†	26.6	30.4*†	36.4*†	26.9*†
L 67N	0.31	2.01	2.28*	1.99†	1.35*†	47.7*	21.7	34.7†	32.9*†	26.9*†
SH+L 133N	0.32	2.43	2.84	2.68	2.42	54.1	27.5	40.8†	48.3	35.1*†
SH 133N	0.35	2.17	3.67*†	2.50	2.00†	55.5	33.3	38.0†	44.2	33.1*†
L 133N	0.35	1.83†	2.62	2.18	1.89†	47.6*	28.7	35.2†	45.8	32.0*†

WAE: weeks after emergence. SH = sunn hemp; L = winter legume; Conv = conventional (no green manure); N = kg NH_4NO_3-N ha^{-1}; * mean different from Conv 200N and Conv 267N at the $p \leq 0.05$ level, respectively.

Table 3.14. Leaf dry weight, 2003 (kg ha^{-1}).

	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE
GM x N-Rate	NS	NS	NS	NS	NS
GM	NS	*	NS	NS	*
SH+L	91	420 ab	1122 ab	1064 ab	953 a
SH	98	462 a	1206 a	1170 a	925 ab
L	93	357 b	1041 bc	943 ab	792 ab
Conv	84	336 b	949 c	962 b	760 b
N-Rate	***	***	***	***	***
0N	68 c	195 b	627 c	567 b	531 c
67N	95 b	462 a	1140 b	1204 a	888 b
133N	111 a	523 a	1471 a	1333 a	1155 a

WAE: weeks after emergence. NS: means within columns for GM and N-rate not different at the $p \leq 0.05$ level; *, **, ***: means within columns different at the $p \leq 0.05$, 0.001, and 0.0001 level, respectively; means within vertical columns for GM and N-rate followed by the same letter do not differ at the $p \leq 0.05$ level according to Duncan's Multiple Range Test.

Table 3.15. Total dry weight, 2003 (kg ha^{-1}).

	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE
GM x N-Rate	NS	NS	NS	NS	NS
GM	NS	*	*	NS	*
SH+L	163	757 ab	5080 a	6847 ab	8071 a
SH	174	825 a	5238 a	7297 a	7586 a
L	168	657 ab	5009 a	6032 b	7254 ab
Conv	153	598 b	4155 b	5971 b	6380 b
N-Rate	***	***	***	***	***
0N	125 c	347 c	2395 c	3289 b	3766 c
67N	171 b	819 b	5601 b	7917 a	7956 b
133N	198 a	962 a	6617 a	8404 a	10247 a

WAE: weeks after emergence. NS: means within columns for GM and N-rate not different at the $p \leq 0.05$ level; *, **, ***: means within columns different at the $p \leq 0.05$, 0.001, and 0.0001 level, respectively; means within vertical columns for GM and N-rate followed by the same letter do not differ at the $p \leq 0.05$ level according to Duncan's Multiple Range Test.

Table 3.16. Leaf nitrogen content, 2003 (kg ha^{-1}).

	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE
GM x N-Rate	NS	NS	NS	NS	NS
GM	NS	NS	*	NS	NS
SH+L	1.3	4.3 ab	7.4 a	7.5	5.3
SH	1.4	4.5 a	7.8 a	7.5	4.7
L	1.3	3.6 ab	6.4 b	6.0	3.8
Conv	1.2	3.4 b	5.3 b	6.3	4.0
N-Rate	***	***	***	***	***
0N	0.8 c	1.4 c	2.4 c	2.1 c	2.1 c
67N	1.4 b	4.6 b	6.8 b	7.1 b	4.2 b
133N	1.7 a	5.9 a	10.9 a	11.2 a	7.1 a

WAE: weeks after emergence. NS: means within columns for GM and N-rate not different at the $p \leq 0.05$ level; *, **, ***: means within columns different at the $p \leq 0.05$, 0.001, and 0.0001 level, respectively; means within vertical columns for GM and N-rate followed by the same letter do not differ at the $p \leq 0.05$ level according to Duncan's Multiple Range Test.

Table 3.17. Total nitrogen content, 2003 (kg ha^{-1}).

	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE
GM x N-Rate	NS	NS	NS	NS	NS
GM	NS	NS	NS	*	NS
SH+L	2.0	6.7	17.8 a	26.1 a	28.0 a
SH	2.2	6.8	17.9 a	25.1 ab	24.2 ab
L	2.0	5.4	16.3 ab	19.2 c	23.4 ab
Conv	1.9	5.2	12.8 b	20.0 bc	21.9 b
N-Rate	***	***	***	***	***
0N	1.3 c	2.0 c	5.8 c	7.2 c	8.5 c
67N	2.1 b	6.9 b	17.3 b	24.7 b	22.2 b
133N	2.7 a	9.2 a	25.5 a	35.8 a	42.5 a

WAE: weeks after emergence. NS: means within columns for GM and N-rate not different at the $p \leq 0.05$ level; *, **, ***: means within columns different at the $p \leq 0.05$, 0.001, and 0.0001 level, respectively; means within vertical columns for GM and N-rate followed by the same letter do not differ at the $p \leq 0.05$ level according to Duncan's Multiple Range Test.

Table 3.18. Pairwise contrasts of leaf dry weight and nitrogen content, 2003.

Treatment	Leaf Dry Weight (kg ha^{-1})					Leaf N Content (kg ha^{-1})				
	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE
Conv 200N	123	541	1400	1352	1250	2.0	6.1	11.9	12.2	10.4
Conv 267N	119	591	1406	1497	1527	2.0	6.8	13.5	13.9	12.3
SH+L 67N	95	448	1134*†	1239	920*†	1.4*†	4.7†	6.9*†	7.8*†	4.4*†
SH 67N	98	563	1151	1352	1064†	1.4*†	5.1	6.9*†	8.6*†	4.9*†
L 67N	102	409†	1206	1139†	773*†	1.5*†	4.2†	8.0*†	6.7*†	3.6*†
SH+L 133N	110	590	1467	1463	1312	1.7	6.6	11.7	12.8	8.6†
SH 133N	119	600	1752*†	1364	1085	1.9	7.0	13.7	11.1	6.8*†
L 133N	111	471	1380	1152†	1113	1.7	5.2	9.2	9.2†	6.0*†

WAE: weeks after emergence. SH = sunn hemp; L = winter legume; Conv = conventional (no green manure); N = kg NH_4NO_3-N ha^{-1};
* mean different from Conv 200N and Conv 267N at the $p \leq 0.05$ level, respectively.

Table 3.19. Pairwise contrasts of Total Dry Weight and N Content, 2003.

Treatment	Total Dry Weight (kg ha^{-1})					Total N Content (kg ha^{-1})				
	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE
Conv 200N	217	994	6328	8853	10251	3.1	9.8	30.3	40.9	54.7
Conv 267N	221	1122	5762	8857	10720	3.2	11.5	34.2	46.0	57.8
SH+L 67N	173	800†	5484	7984	8233*†	2.1*†	7.1†	17.2*†	27.2†	21.8*†
SH 67N	171	994	5740	8448	9037	2.1*†	7.4†	17.4*†	29.0†	26.1*†
L 67N	184	739†	6348	8132	7706*†	2.3*†	6.4*†	21.7*†	23.4†	21.4*†
SH+L 133N	196	1082	6560	9544	11091	2.7	10.6	27.9	44.1*	50.1
SH 133N	211	1093	7201†	8485	9424	3.0	10.8	30.2	35.3†	37.9*†
L 133N	200	884	6609	7141	10587	2.6	8.0†	22.0*†	27.9†	40.6*†

WAE: weeks after emergence. SH = sunn hemp; L = winter legume; Conv = conventional (no green manure); N = kg NH_4NO_3-N ha^{-1};
* mean different from Conv 200N and Conv 267N at the $p \leq 0.05$ level, respectively.

CHAPTER 4
EFFECTS OF GREEN MANURE AMENDMENT ON SWEET CORN ROOT LENGTH DENSITY AND DISTRIBUTION

Introduction and Literature Review

Information on root distribution patterns may improve understanding of crop responses to inputs. Root length density (RLD) – defined as length of roots per unit volume of soil – may give some indication of plant response to environmental factors. Increased RLD in response to increased nutrient and water availability, a phenomenon known as *root proliferation*, may reflect greater water and nutrient uptake potential (Paolillo et al. 1999). However, root water and nutrient uptake may be dictated by a complex interplay of RLD, soil water and nutrient availability, root age, plant stress, and soil aeration status. Additionally, soil water and nutrient status may change more rapidly (hours to days) than RLD can respond (days to weeks). For example, Coelho and Or (1999) found that RLD for a corn (*Zea mays*) row crop was most associated with root water uptake when water source was in-row and on the soil surface, but less so for buried in-row and surface between-row water sources. On a loamy sand in North Carolina, Durieux et al. (1994) found that application of NH_4NO_3 at 0 and 4 weeks after emergence (WAE) increased RLD in field corn at silking and at 20 days before silking, but reduced RLD at physiological maturity. Working with conventional tillage on a silty clay loam in Nebraska, Eghball and Maranville (1993) found that a deeply-rooted (to 0.9 m) field corn genotype had greater yield response than shallow-rooted varieties when irrigation led to

deeper water infiltration, and that moderate N and water stress increased RLD uniformly throughout the soil profile while severe water and N stress reduced RLD.

Effective rooting depth may limit plant access to water and nutrients as they move down the soil profile. In a greenhouse study with a potting soil and sand mixture, Eghball et al. (1993) removed entire corn root systems and found 52.7%, 37.6%, and 9.7% of root length in the 0-0.3 m, 0.3-0.6 m, and 0.6-0.9 m depths. Root age may also play a role in potential uptake; Gao et al. (1998) showed that short-term nutrient uptake in corn and wheat may be affected by root system age, with newer roots taking up more nutrients. However, as plants themselves became older (after 48 days), the investigators found less correlation of nutrient uptake with new RLD.

Due to different nutrient release characteristics and effects on soil water, temperature, and biota, root growth patterns may be markedly different following green manures (GMs) compared to chemical fertilizer. Because their N-release is driven by decomposition, GMs may represent a source of slow-release N. Spatial distribution of GM residue may be heterogeneous, creating localized areas of N-release and other GM-mediated impacts (for example, see Mahmoudjafari et al. 1997). Green manures may have effects on soil moisture transfers, temperature, and populations of root-parasitizing organisms such as nematodes.

To help explain ear yield patterns, Goldstein (2000) studied field corn roots on a fine textured soil in Wisconsin under three conventionally tilled management systems: corn monoculture with chemical N (CS1), corn-soybean-winter wheat-red clover rotation (CS3), and corn-oat-alfalfa with dairy cow manure (CS5; highest yielding treatment). According to Goldstein, previous research based on N application data could not account

for significantly higher corn yields responses for CS5 compared to CS1 and CS3. In the top 15 cm of soil Goldstein found RLD explained 68-79% of unexplained variability of ear yield within each system, while corn amended with organic N-sources maintained healthier roots (76%, 63%, and 59% roots without visible damage for CS5, CS3, and CS1, respectively) and required lower RLD for maximum ear yields (1.63, 1.74, and 2.12 cm cm^{-3} for CS5, CS3, and CS1, respectively) according to regression or actual data. Results apparently contradicted Pallant et al. (1997) who found greater RLD for GM-amended corn in the upper 30 cm. Goldstein (2000) may have underestimated RLD for GM treatments by not accounting for roots below 15 cm, especially as GM and animal manure material had been soil-incorporated. Further, the higher RLD for conventional monocropped corn in the upper 15 cm may have rendered it more susceptible to water stress. According to Nickel et al. (1995), RLD for corn grown in rotation with soybean (*Glycine max*) tends to be higher than for corn grown in monoculture even under high inputs. In a conventional tillage system, Nickel et al. (1995) found greater RLD for monocropped corn in the upper 12.5 cm at 4 WAE and greater RLD for corn in rotation (with soybean) at deeper soil depths of 12.5-25cm (early season), 37.5-50cm (mid-late season), and 12.5-37.5cm (mid-late season), although soybean RLD tended to be higher under monoculture. Pallant et al. (1997) also found that increases in soil organic matter significantly increased corn RLD on two of four sample dates.

For potato (*Solanum tuberosum*), Opena and Porter (1999) report that organic amendments (compost plus beef cattle manure) significantly increased RLD in the 0-30 cm plow layer and did not change relative distribution of roots by depth (~85% of RLD in 0-30 cm layer). However, Thorup-Kristensen and van der Boogaard (1999) found that

surface applying increased amounts of high-N GM residue reduced carrot (*Daucus carota*) root proliferation in the upper 1 m of soil and shifted root proliferation closer to the plant.

As part of a larger study on improved use of GMs in vegetable cropping systems in the southeast US and north Florida, we investigated a GM sequence of summer planted sunn hemp (SH) followed by a winter legume (L) of blue lupin (*Lupinus angustifolius*, winter 2001-02) and cahaba white vetch (*Vicia sativa*, winter 2002-03) as an N-source for sweet corn under reduced tillage. Details of GM growth and decomposition patterns can be found in Chapter 2, and yield responses of sweet corn to the GM sequence and to the component GMs alone is discussed in Chapter 3. In these studies, SH+L produced a cumulative 12-15 Mt dry matter ha^{-1} and up to 170 kg N ha^{-1} annually. Nitrogen benefit from SH+L to a subsequent crop of sweet corn was highest during the first 2-4 weeks after corn emergence, and although growth remained largely equivalent to conventional corn with 200-267 kg NH_4NO_3-N ha^{-1} throughout the season, ear yields and some tissue factors at maturity were not as high with SH or SH+L supplemented with 133 kg NH_4NO_3-N ha^{-1}. To better explain early season advantage and late season decline of GM amended corn, we initiated a root study of selected treatments. We hypothesized that amendment with SH+L would increase overall sweet corn RLD in the sampled area, that sweet corn RLD would be redistributed nearer to the GM residue (in this case, near the surface as we used reduced-tillage), but that corn with a high chemical N-rate (267 kg NH_4NO_3-N ha^{-1}) would show greater RLD than corn at lower N-rates (0 or 133 kg NH_4NO_3-N ha^{-1}) with or without SH+L.

Materials and Methods

Set-up and Design

Root growth analysis utilized five treatments that were part of the larger GM study described in Chapter 1. Timeline of operations and corn planting patterns are described in Chapter 3. Related experimental design and set up only are described here. The five treatments used for this analysis consisted of sweet corn following: sunn hemp and lupin/vetch rotation with 0 kg N ha^{-1} applied to corn (SH+L 0N); sunn hemp and lupin/vetch rotation with SH+L 133 kg N ha^{-1} (SH+L 133N); and "conventional" sweet corn with 0, 133, or 267 kg N ha^{-1} applied (Conv 0N, Conv 133N, Conv 267N; See Table 1.2). After initial field plow all crops were planted with zero or reduced tillage and all chemical N was band applied to corn rows by hand. Samplings of these treatments for RLD analysis took place in their second year (2003). All treatments were repeated four times within the larger randomized complete block design (see Chapter 1).

Field and Lab Procedures

Using a 5 cm soil auger (Forestry Suppliers, Inc; Jackson, MS) of known volume, soil cores were extracted at 3, 5 and 8 weeks after emergence (WAE) of sweet corn. In each plot, soil was extracted from three different depths: 0-15 cm; 15-30 cm; and 30-60 cm; and in three different surface positions: in-row and immediately adjacent to a corn plant (IR0); in-row and halfway between two corn plants (IR0.5); and between-row (halfway between two corn rows; BR), giving nine unique locations (Figure 4.1). Soil extraction was conducted away from border areas and near plants representative of the plot in both size and spacing. Soil cores were placed into plastic bags and refrigerated until root extraction (not more than 2 weeks). At that time, soil cores were washed in a grain sieve with pores 4.5 mm in diameter. Although fine roots could not be accounted

for, this grain sieve satisfactorily retained visible roots which were then separated from debris. Using software and hardware from Regent Instruments (Quebec City, Canada), roots were scanned and subsequent image analyzed with the Winrhizo program for root length. The results were transferred to MS Excel (Microsoft Corporation, Los Angeles, CA) for graphical analysis and preparation for SAS (Statistical Analysis Systems; Cary, NC).

Data Analysis

To test the effects of SH+L amendment and chemical N-rate on root length and distribution at each sample date, five different balanced ANOVAs were run for each sample date for results from SH+L 0N, SH+L 133N, Conv 0N, and Conv 133N using SAS software package. Sample data was organized in two primary ways: on a *density* basis expressing root length per cubic cm of soil (cm cm^{-3}), and on a *relative* basis with root length data expressed as a fraction of the total from that plot (unitless). Use of RLD allowed straightforward comparisons of root proliferation, while root length expression on a relative basis permitted comparisons of root distribution between treatments regardless of absolute size. Within each of these two techniques, data was expressed in two more ways: data sets with individual entries for all 9 unique locations based on the three depth levels and three positions (*location*), and data sets with pooled values based arbitrarily on whether samples were near or far from the plant (*proximity*). The proximity groupings were established to develop clearer trends based on a natural spatial pattern in root growth, with 62% or more of sampled RLD in all treatments being found in four locations “near” the plant (IR0 and IR0.5, 0-15 and 0-30cm) and the remainder of RLD (generally less than one third) found in the other five locations “far” from the plant. A

fifth ANOVA was run for average RLD of all sampled volume in each treatment to compare *overall* differences in total sampled root length.

Root length densities were log transformed by $\log_{10}(x+1)$ before ANOVA to maintain homoscedasticity. Model statements regressed RLD or relative root length as a function of N-rate (0 or 133 kg N ha^{-1}), GM application (SH+L or Conv), depth (0-15cm, 15-30cm, 30-60cm) and position (IR0, IR0.5, and BR) or proximity (near or far) where applicable, all possible first-degree interactions of these variables, and block (four blocks; see Chapter 1). Where interaction terms were significant, separate ANOVAs were run to compare levels of one interacting variable within specific levels of the other interacting variable(s). Non-interacting variables (except block) were not included in the interaction model statements. Because of the inherent variability in root measurements, $\alpha = 0.10$ was considered significant. Comparisons of means were always made with Duncan's multiple range test.

To compare root length and distribution patterns of these treatments to high-fertilized, high-producing corn, pairwise contrasts of Conv 267N were made with each of the other treatments. These ANOVAs used the same independent variables as the balanced design except that GM level and N-rate level were substituted with the appropriate overall treatment title (Conv 0N, Conv 133N, Conv 267N, SH+L 0N, and SH+L 133N). Where interaction of treatment with depth and/or location or proximity were significant to $\alpha = 0.10$, separate ANOVAs were run to compare treatments within specific levels of the interacting variable(s). Non-interacting variables (except block) were not included in the interaction model statements.

Actual data, whether expressed as RLD or relative root length, is for sampled volumes only. Because three positions (IR0, IR0.5, BR) were sampled in a triangular fashion, no more than two positions can be connected with any line within a given depth, and therefore any attempt to interpolate RLD between the two position points lacks information needed to fit any non-linear behavior.

However, the three depths sampled within each position allowed for fitting of non-linear trendlines (where appropriate) reflecting RLD as a function of depth. An effective rooting depth was therefore defined as depth at which 90% of calculated RLD within the top 100 cm of soil occurred. Using Maple 8 mathematical software (Maplesoft; Waterloo, Canada), the following equation was solved for x^*:

$(\int_{0cm}^{x^*} y\, dx) / (\int_{0cm}^{100cm} y\, dx) = 0.9$;

where y = RLD (cm cm^{-3}) as a function of x,

x = depth (cm), and x* = effective rooting depth (cm).

Three slightly different graphs could be developed to generate an equation for RLD as a function of depth. Average RLD for any given layer could be graphed: (1) once, in the center-point of the layer; (2) at both the upper and lower bounds of the soil layer; and (3) in the center-point and the upper and lower bounds of the layer. All three trendlines resulted in similar effective rooting depths (see below). Given the variability of measurements and the extrapolation of RLD beyond measured depth, this calculated effective rooting depth is a general indicator only, based on the assumption that sweet corn root growth beyond 60 cm follows the same pattern with respect to depth established within the upper 60 cm. We therefore do not make strict statistical comparisons of effective rooting depth.

Suction lysimeters (constructed with materials from Soil Moisture; Goleta, CA) and transducing tensiometers (model "R" irrometers; Spectrum Technologies; Plainfield, IL) were installed in selected plots to monitor N-leaching. Unfortunately, highly inconsistent lysimeter samples (probably due to low soil water content of our sandy soil) could not be meaningfully analyzed. Data from transducing tensiometers buried at 15, 60, and 90 cm in SH+L 133N and Conv 200N, intended to complement the lysimeter study, is, however, reported here. Data from tensiometers was recorded continuously by Watchdog dataloggers (Spectrum Technologies; Plainfield, IL). Treatment Conv 200N was not sampled for root cores.

Results

Overall RLD

Over the season, RLD for the sampled volume in the upper 0-60 cm soil layer remained within one order of magnitude in all treatments, from 0.15-1.50 cm cm^{-3}, consistent with other studies (Goldstein 2000, Pallant et al. 1997, Nickel et al. 1995). Across both N-rates, amendment with SH+L increased total corn RLD in the sampled 0-60 cm profile by 32%, 54%, and 27% at 3, 5, and 8 WAE respectively, although increases at 3WAE were not statistically significant unless sample spatial location was included in the regression model (Figure 4.2; also, see below). Increase of N-rate from 0 to 133 kg N ha^{-1} increased total RLD by 52%, 119%, and 93% at 3, 5, and 8 WAE respectively. There was no interaction between GM amendment and chemical N-rate for overall sampled corn RLD. Corn with SH+L 133N maintained highest overall RLD throughout the season, even compared to corn with 267N (SH+L > Conv 267N by 45%, 29%, and 6%, at 3, 5, and 8 WAE, respectively). However, differences in pairwise

contrasts became significant only when the model statement included spatial information (Table 4.1; also, see below).

RLD by Location

As can be seen in Table 4.2 and Figure 4.2, at 3 WAE amendment with SH+L significantly increased overall RLD when depth and position were included in the regression model ($\alpha = 0.10$). In general RLD decreased from in-row (IR0, IR0.5) to between-row (BR) and decreased with increasing depth. However, increased root proliferation towards the soil surface was most resolvable within IR0 with significant changes in RLD values occurring at both depth transitions. At the IR0.5 position, RLD dropped significantly only at the deeper transition between 15-30 cm and 30-60 cm, while at the BR position a significant drop occurred only at the first (0-15 cm to 15-30 cm) depth transition. In both 0-15 cm and 15-30cm depths a significant drop in RLD values occurred only as one moved from the IR positions to the BR position (no significant difference between IR0 and IR0.5; see Table 4.3). Corn with SH+L 133N showed greater overall RLD than Conv 267N (45% advantage), becoming significant when the model statement included depth and position (Tables 4.1 and 4.4). Otherwise no other treatment showed significantly different RLD from Conv 267N nor did treatment level interact with depth and/or position at 3 WAE.

At 5 WAE, position, GM amendment and N-rate all interacted individually with depth (Table 4.2). Application of SH+L increased RLD within all depths, but increase was greatest and significant only in the upper soil depth (64% for 0-15 cm compared to 36% for 15-30 cm and 55% for 30-60 cm; Figure 4.3). Application of 133N also increased RLD at all depths (44%, 58%, and 27% for 0-15, 15-30, 30-60 cm, respectively) but the increase was non-significant at the 15-30 cm level due to variability

(Table 4.3). Interactions between position and depth at 5 WAE remained identical to those seen at 3 WAE except that a significant decrease in RLD occurred at all soil depths (including 30-60 cm) when moving from either of the IR positions to the BR position (Table 4.3). The full ANOVA used for pairwise contrasts showed treatment interacted individually with depth and position (Table 4.4). Root length densities for Conv 267N were statistically greater than RLDs for SH+L 0N and Conv 0N in the 0-15 cm and 15-30 cm layers and the IR0.5 position but statistically less than SH+L 133N in the 0-15 cm and 30-60 cm layers (Table 4.5). However, high values for SH+L 133N in the 30-60 cm layer may have been affected by sample variability (Table 4.5).

At 8 WAE, a significant 4-way interaction occurred between position, depth, GM, and N-rate ($\alpha = 0.06$; Table 4.4; see Appendix D for sub-effects). Amendment with SH+L benefited corn RLD more and more uniformly at the zero N-rate (0N). In all locations but two (IR0 and IR0.5 15-30 cm) both percent-wise and absolute increases in RLD from amendment with SH+L was greater for non-fertilized corn (relative to corn with 133N). At all locations but one (IR0.5 15-30 cm), RLD for non-fertilized corn showed increase (23%-105%) when amended with SH+L, with the benefit significant in four of eight locations. For corn at 133N, increase in RLD from SH+L amendment occurred only at positions IR0 and IR0.5 for depths 0-15 cm and 15-30 cm only (9%-53% increases) while at all other locations (all BR and all 30-60 cm) SH+L amendment on top of 133N actually decreased RLD (2-43% reductions). However, only one of these differences (decrease of RLD at BR 15-30 cm) was statistically significant.

Application of chemical N (133N) also benefited RLD for unamended (Conv) corn more and more uniformly than for SH+L amended corn. Root length density for

unamended corn increased at all locations with application of 133N (compared to 0N) by 74%-204%, and these increases were statistically significant everywhere except at IR0.5 15-30 cm and 30-60 cm only. For SH+L amended corn, increased RLD (by 6%-122%) in response to chemical N fertilization took place at all depths for both IR positions and at all positions across the 0-15 cm soil layer, although these increases were smaller than seen for Conv and significant only at IR0 15-30 cm and IR0.5 15-30 cm and 30-60 cm. At the 133N level, amendment with SH+L produced non-significant reduction in RLD at BR 15-30 cm (53%) and 30-60 cm (17%), and in fact the weakest increase for SH+L 133N compared to Conv 133N was also seen at BR 0-15 cm (6%; See Appendix D).

Compared to any Conv treatment (even with 267N), corn with SH+L 133N maintained numerically higher RLD in 7 of 9 sampling locations at both 3 and 5 WAE (data not shown). At 8 WAE, however, RLD for SH+L 133N showed numerical advantage only in the four "near" locations (IR0 and IR0.5 at 0-15 cm and 15-30 cm) while RLD for Conv 133N and/or Conv 267N was numerically higher in all five "far" locations (all locations within BR and within 30-60 cm depth). Despite these numerical trends, data analysis using depth and position resolved few effects of SH+L and few differences between SH+L 133N and Conv 267N at 8 WAE (Table 4.6; Appendix D). Greater analytical resolution at this date came with data grouped on a proximity basis (see below).

Relative Root Length by Location

Statistical patterns of relative root length by depth and position were similar to those of absolute RLD, although relative root length distributions were less affected by GM amendment and N-rate (data not shown). Corn with SH+L exhibited significantly greater root length distribution towards the soil surface at 3 WAE, and the trend

continued (though non-significantly) at 5 and 8 WAE. Few statistical differences existed in pairwise comparisons of relative root length between Conv 267N and all other treatments throughout the season. Throughout the season, relative root length sampled remained greatest in the IR0 0-15 cm location (23-27%) compared to all other locations, roughly half or more (up to 55%) of sampled root length was always in the 0-15 cm layer, with both the upper 30 cm as well as the two IR positions together each containing roughly 85% of sampled root length (data not shown).

RLD by Proximity

Effects of SH+L on RLD by proximity became increasingly resolved over time. At 3 WAE, amendment with SH+L increased near RLD by 22% and far RLD by 68%. However, ANOVA based on proximity at 3 WAE was not as sensitive as that based on depth and position. No significance was detected for GMs, proximity, or the interaction of the two when making up a linear model (Table 4.7), nor did ANOVA show significant differences between RLD for SH+L 133N and Conv 267N based on proximity analysis (Table 4.8). At 5 WAE, the increase in RLD from amendment with SH+L (41% and 98% in near and far RLD, respectively) was significant with proximity included in the regression, but the interaction between GM level and proximity was again non-significant (Table 4.7). At 8 WAE, the interaction between amendment and proximity became significant (Table 4.7 and 4.9), with SH+L preferentially increasing near RLD. Corn with SH+L 133N maintained (non-significantly) greatest RLD in both near and far categories throughout the sample period except at 8 WAE, when far RLD for Conv 267N was statistically greater (Tables 4.10). Although the three-way interaction was not detected as significant at 8 WAE (Table 4.7), effects of SH+L on far RLD may have differed

depending on chemical N-rate; application of SH+L at 0N appeared to increase far RLD, while SH+L at 133N may have led to decrease of far RLD (Table 4.10).

At 3 WAE, application of chemical N (133N) significantly increased RLD by 65% near the plant (0.62 vs 0.37 cm cm^{-3} for 0N and 133N, respectively), but increase was lower (19%) and non-significant far from the plant (0.07 vs 0.08 cm cm^{-3} for 0N and 133N, respectively; Table 4.9). For both N-rates, however, sampled RLD near the plant was more than 5 times greater far RLD. Although ANOVA indicated significant interaction of N-rate with proximity at 5 and 8 WAE, Duncan comparisons of sub-effects revealed no differences (Table 4.9). Compared to Conv 0N, both SH+L 0N and Conv 133N showed numerical increases in near and far RLD with far RLD increasing more dramatically than near RLD and 133N giving greater numerical benefit than SH+L. Near RLD continued to be 3-3.5 times greater than far RLD in all treatments at both 5 WAE and 8 WAE (Table 4.10).

Relative Root Length by Proximity

Trends for relative root length by proximity differed little from those of RLD. A three-way interaction between N-rate, GM amendment, and proximity occurred at all three sample dates for relative RLD (data not shown). Generally, amending corn with SH+L only (SH+L 0N) increased root distribution far from the plant compared to amendment with both SH+L and 133N (SH+L 133N) or neither (Conv 0N). At 8 WAE, amendment with both SH+L 133N shifted root distribution towards the plant (76% near) compared to amendment with SH+L 0N (64% near) and Conv 133N (62% near).

Effective Rooting Depth

Root length density always decreased exponentially with increasing depth from the surface. In general, effective rooting depth (depth at which 90% of calculated RLD of

the top 100 cm occurred) remained within 40-60 cm of the soil surface for all treatments and dates. No apparent differences existed in effective rooting depth between the surface positions, or between any GM or chemical N-rate, reflecting the general lack of differences in measures of relative root length by depth, especially below 30 cm (discussed above). The method used to generate the RLD trendline as a function of depth also created no apparent differences.

Soil Water Potential

Soil water potential for SH+L 133N and Conv 200N at 15 cm showed two distinct phases. From 17 April until 20 May (~0-5 WAE) soil water potential under SH+L 133N remained significantly higher than Conv 200N by an average of 2.6 ± 0.2 kPa (See Table X). Average soil water potentials at 15 cm during this period were -16.5 ± 0.4 kPa for SH+L 133N and -19.1 ± 0.5 kPa for Conv 200N. Greatest differences occurred during the 12-day period from 19 April to 1 May when soil water potential under SH+L 133N was 3.9 ± 0.1 kPa higher than under Conv 200N. From 21 May until final harvest on 19 June (~5-9 WAE) this trend reversed, with soil water potential under Conv 200N (-13.7 ± 0.2 kPa) becoming significantly higher than in SH+L 133N (-14.9 ± 0.1 kPa) by an average of 1.2 ± 0.2 kPa. Overall, average daily soil water potential for both treatments increased logarithmically over the season, probably reflecting greater water potential near the surface after canopy closure and shading (Figure 4.5A).

Soil water potential at 60 cm also underwent two distinct phases but with an intermediate “buffer” period during which water potential in both SH+L 133N and Conv 200N were relatively equal. From 17 April to 5 May (~0-3 WAE) soil water potential at 60 cm remained lower in SH+L 133N (-15.1 ± 0.5 kPa) compared to Conv 200N (-13.9 ± 0.3 kPa) by an average of 1.2 ± 0.3 kPa. Soil water potential for the two treatments at 60

cm were not significantly different from 6 May to 25 May (~3-6 WAE; Figure 4.5B), but from 26 May to final harvest (~6-9 WAE) tensiometer readings showed higher soil water potential for SH+L 133N (-11.8 ± 0.4 kPa) compared to Conv 200N (-13.8 ± 0.5 kPa) by an average of 2.0 ± 0.2 kPa. Tensiometer readings from 90 cm showed lower soil water potential throughout the season for SH+L 133N (-10.2 ± 0.4 kPa) compared to Conv 200N (-8.8 ± 0.3 kPa) by an average of 1.4 ± 0.3 kPa (data not shown).

Discussion

Despite variability inherent in root core work, data analysis from several different aspects resolve definite patterns of corn root distribution within the study environment. These patterns help explain corn growth and yield performance detailed in the previous chapter. Generally, amendment with SH+L increased RLD throughout the season, but as the season progressed overall advantages declined and became more concentrated at the upper soil depths and near the plant, especially when chemical N was band applied.

In terms of rooting patterns, RLD decreased from in-row (IR0, IR0.5) to between-row (BR) and decreased with increasing depth. For all treatments throughout the season relative RLD sampled remained greatest in the IR0 0-15 cm location nearest the plant (23-27% of sampled root length) compared to all other locations; roughly half or more (up to 55%) of sampled RLD was always in the 0-15cm layer, with roughly 85% of sampled RLD occurring in the IR positions (combined) as well as in the upper 30 cm, similar to findings reported by Eghball et al. (1993). However, interactions between depth and position altered these distribution patterns on all sample dates. Early in the season (3 WAE), RLD showed more pronounced distribution towards the soil surface as one moved to positions closer to the plant. At the BR position, early-season root exploration below 15 cm remained so little that RLD in these two layers were not

significantly different from each other but were significantly less than RLD in the top soil layer (BR 0-15cm). Root exploration of the 30-60 cm soil layer was so sparse at 3 WAE that position relative to the plant had no effect at this depth. By mid-season (5 WAE), RLD values were close to maximum recorded during the study, but rooting patterns by depth and position were similar to those at 3 WAE. However, by this time RLD in both IR positions showed similar tendency towards proliferation in the upper soil layer. Root length densities in the 30-60 cm layer became much greater in the IR positions, but RLD values in BR 30-60 cm remained low (Table 4.3). By late-season (8 WAE) RLD patterns significantly interacted with GM amendment and/or N-rate (discussed below).

Amendment of corn with a substantial SH+L green manure (15 Mt ha^{-1} $year^{-1}$) over two years significantly increased total corn RLD in the top 60 cm of soil in two of three sample dates (Figure 4.2), and when the statistical model included terms for sample depth and position the increase became significant at all dates notwithstanding interactions. Overall RLD with SH+L 133N showed advantage even over Conv 267N, though this diminished over time (Table 4.2). At no time could increased biomass (total or root dry weights) by SH+L amended corn explain benefits in RLD. Root and total dry weight benefits from SH+L varied between 7%-31% over the season, and were always 5-30 percentage points less than the benefit associated with RLD. At 2 and 4 WAE, root and total plant dry weights for SH+L 133N were less than those of Conv 267N despite significantly greater overall RLD for SH+L 133N at 3 WAE (Table 4.2; see also Chapter 3).

However, GM effects on RLD interacted with sample location, chemical N supplementation, and sample date. Analysis of variance with a regression model

containing arbitrarily chosen depth and position of samples was most useful early and mid-season, whereas regression model based more “natural” categories of sample proximity (near or far) to plant provided more resolution of trends during late-season.

In general, corn amended with SH+L alone (SH+L 0N) exhibited greater distribution of sampled root length far from the plant compared to corn with both SH+L and 133N (SH+L 133N) or neither (Conv 0N). Early during the season (3WAE) GM amendment increased RLD throughout the soil profile with little interaction with specific location or proximity (Tables 4.2 and 4.7), though analysis of relative root length at this time indicated greater proliferation in the upper 15 cm of soil for SH+L amended corn. Application of chemical N also tended to increase near RLD (by 65%) more than far RLD (increase of 19%) at this time. At mid-season (5WAE) SH+L application increased RLD most at 0-15 cm depth (Figure 4.3) and RLD for SH+L 133N demonstrated significant advantage against Conv 267N in this soil layer (Table 4.5). A large jump in RLD far from the plant also occurred for SH+L 133N (Table 4.10), but this may have been due to sample variability.

At final sampling (8 WAE; one week before maturity) GM effects interacted with chemical N-rate, soil depth, and position. These patterns were most succinctly described when analyzing data by natural grouping based on sample proximity to the plant (near or far). At this time, amendment with SH+L significantly increased RLD near the plant but had almost no effect on RLD far from the plant (Figure 4.4). Although analysis of variance detected no signifcance for the interaction term (GM x N-rate), the effect may have been particularly pronounced for SH+L amended corn supplemented with 133N (which was band applied to rows) and not for corn with SH+L only (Tables 4.7 and 4.10).

Such root proliferation near the plant during time of intense ear-fill may have increased vulnerability to water and N stress for corn with both surface applied GM and banded chemical N. Similar root distribution effects were reported by Thorup-Kristensen and van der Boogard (1999) for carrot amended with large amounts of surface applied GM. Additionally, at 8 WAE Conv 267N showed significantly greater RLD far from the plant compared to SH+L 133N (Table 4.10). These results complement and contrast findings under conventional tillage, where GM amendment also appears to increase overall RLD but at lower soil depths (Pallant et al. 1997, Nickel et al. 1995).

Coelho and Or (1999) showed that for a crop of corn a relatively minor fraction of total RLD located between-rows can make disproportionately large contributions to root water uptake when water becomes more available there than closer to the plant. These far roots may therefore have benefited conventionally fertilized corn in terms of water and N-uptake potential during late season. In the 2003 season, when N may have been particularly limiting, between 40-50% of total plant N uptake occurred from 6-9 WAE for many treatments, including Conv 267N and SH+L 133N (see Chapter 3, Table 3.19). Differences may have been exacerbated as effective N application for Conv 267N was nearly 90 kg N ha^{-1} greater than SH+L 133N (Chapter 3, Table 3.2).

Tensiometer data reveals surface residue in combination with band-applied chemical N may have created an environment of greater water and N availability near the surface, especially early in the season before canopy closure. Coupled with possible net N-release from decomposition, this promoted root proliferation and may have benefited plants during early season. By late season moisture level near the soil surface in SH+L 133N treatments dropped below that of conventionally fertilized corn. Higher late season

water potential at 60cm in SH+L 133N plots (compared to conventional) also suggests that SH+L 133N roots were unable to adjust growth further away from plants at this time (Figure 4.4).

Because RLD always dropped exponentially with depth, and because sampled RLD in the 30-60 cm layer was relatively small (~10-15% of total), a total RLD was calculated for the upper 100cm of soil. The depth at which 90% of this calculated RLD occurred was defined as the effective rooting depth. Effective rooting depth generally existed no deeper than 40-60 cm regardless of treatment, positions, GM levels, and N-rates at all sample dates, and regardless of the manner in which the sampled RLD was graphed so as to generate trendlines for RLD as functions of depth (see Materials and Methods). More detailed statistical analysis that could reveal greater differences would not have been appropriate without more root samples taken from more finely divided soil layers. However, these results generally agree with those from Eghball et al. (1993) who excavated intact root systems from corn grown under controlled conditions and found an effective rooting depth of roughly 60cm. These data suggest water and nutrients leached well below 40-60 cm become less available to sweet corn regardless of GM application, chemical N-rate, and stage of growth, unless a more deeply rooted variety is used (Eghball and Maranville 1993). Irrigation management of sweet corn should probably use 50 cm as an effective rooting depth in our Florida environment. Additionally, although sweet corn at 3 WAE showed an effective rooting depth of 40-60 cm, actual RLD values and N-demand are so small that water and N uptake around such a depth are probably insignificant, and an effective rooting depth of 30 cm may be more appropriate.

Conclusions

To summarize, amendment with SH+L in a reduced tillage system with band applied chemical N increased RLD throughout the season, but as the season progressed overall advantage declined and became more concentrated in the upper 15-30cm of soil nearest to the plant, especially for plants receiving chemical N. Corn with high amounts of chemical N (Conv 267N) sustained greater root growth far from the plant in the between row area and at 30-60cm depth during late season. This may help explain the advantages of GM-amended corn during the early season and in terms of vegetative growth as well as late-season gains in ear yield by chemically fertilized corn.

Soil incorporation of GM residue to help encourage deeper root growth under these circumstances would be favorable if subsequent nutrient loss from decomposition did not negate the benefits. However, in warm humid areas with coarse textured soil, reduced tillage is often desired to slow organic matter decomposition and nutrient loss and improve low soil water retention. In such reduced tillage systems, improved use of GMs may necessitate different irrigation management, including drip lines buried below surface residue to increase infiltration. Use of GMs or GM mixtures with more substantial below ground production may be an even less expensive and laborious way to create a better rooting environment at deeper depths. Using early season deficit irrigation to encourage root exploration or development/use of varieties of economic crops with deeper root systems may help, but providing GMs with N-content closer to that applied with chemical fertilizer must remain a priority.

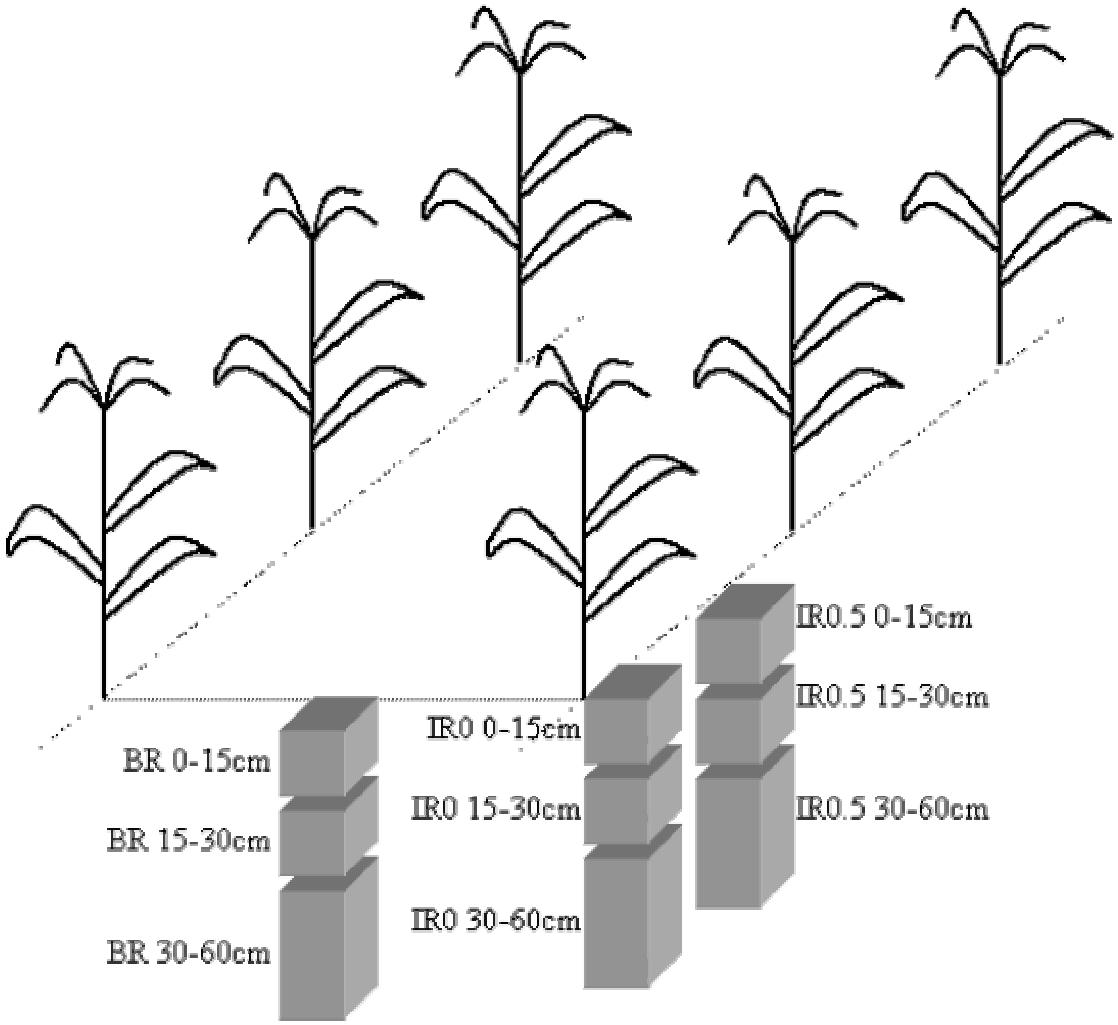

Figure 4.1. Name, location and relative volume of root core samples.

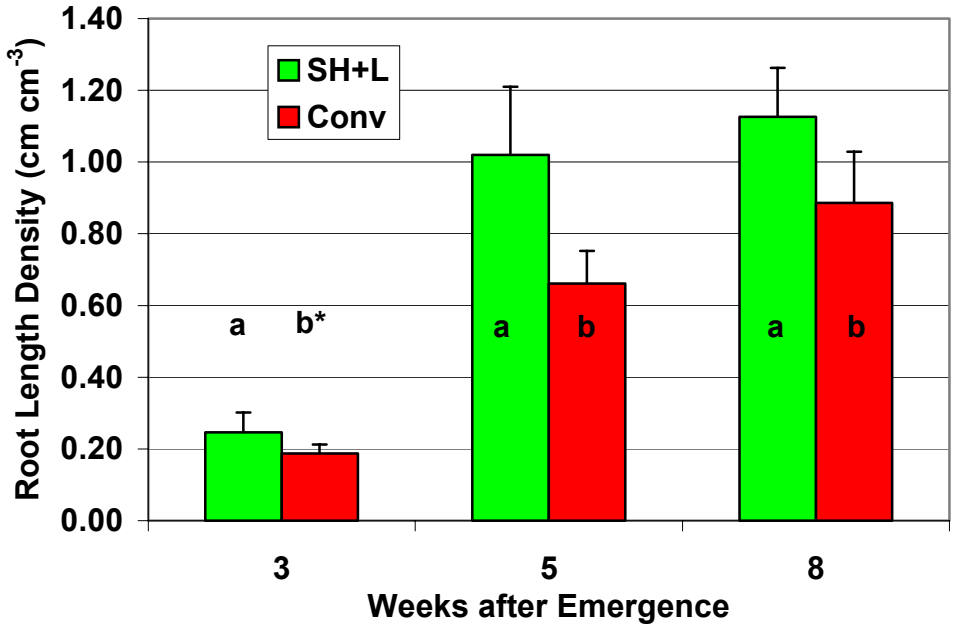

Figure 4.2. Effect of amendment with SH+L on sampled sweet corn root length density. Error bars reflect standard errors; lower case letters reflect ANOVA differences within sample date, $p \leq 0.10$; * means significantly different when depth and position included in regression model.

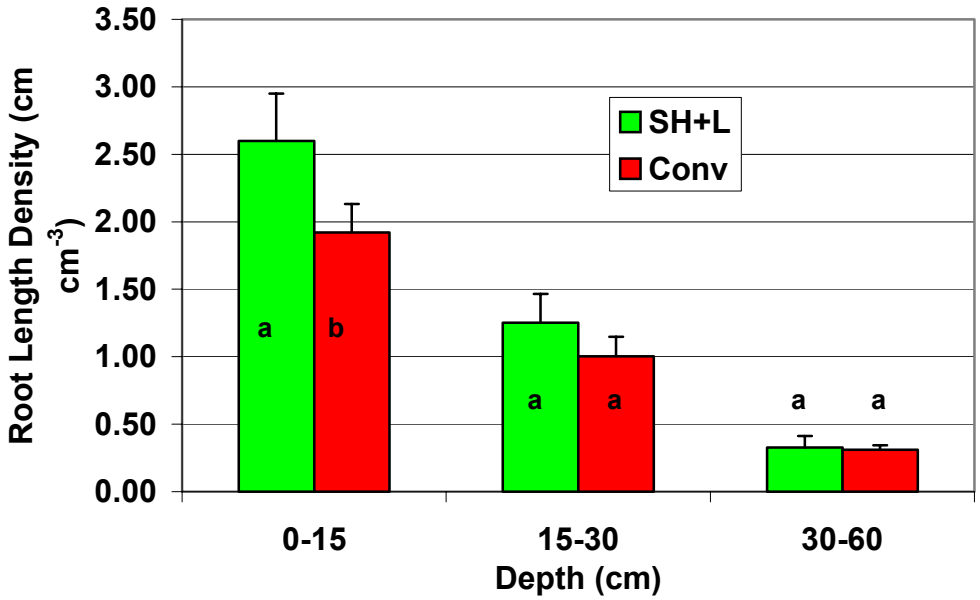

Figure 4.3. Effect of amendment with SH+L on sampled sweet corn root length density by depth at 5 weeks after emergence. Error bars reflect standard errors; lower case letters reflect ANOVA differences within sample depth, $p \leq 0.10$.

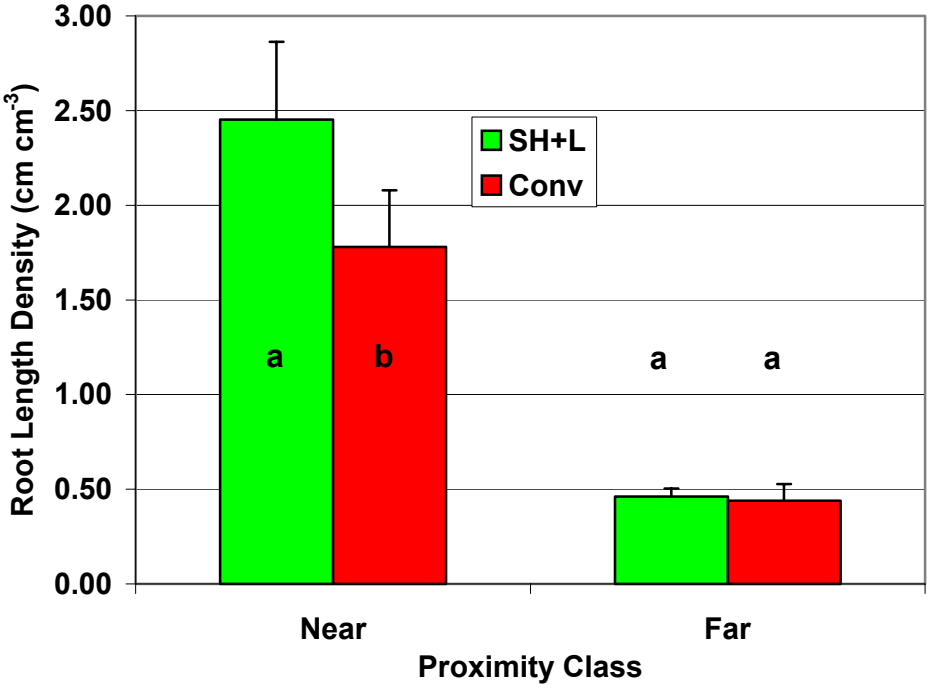

Figure 4.4. Effect of amendment with SH+L on sampled sweet corn root length density by proximity class at 8 weeks after emergence. Error bars reflect standard errors; lower case letters reflect ANOVA differences within proximity class, $p \leq 0.10$.

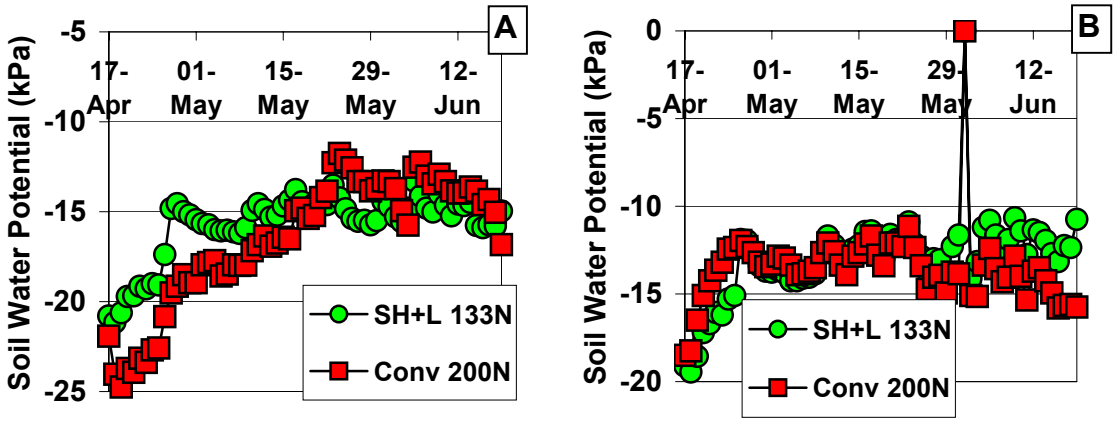

Figure 4.5. Soil water potential at 15 cm (A) and 60 cm (B) during sweet corn growth.

Table 4.1. Pairwise contrasts against Conv 267N for overall sampled root length density (cm cm^{-3}), 0-60 cm.

Treatment	3 WAE	5 WAE	8 WAE
Conv 267N	0.22	1.11	1.32
SH+L 0N	0.17	0.62†	0.86†
Conv 0N	0.17	0.44†	0.51†
SH+L133N	0.32X	1.42	1.39
Conv 133N	0.20	0.88	1.26

WAE = weeks after emergence; † means within column for date different from Conv 267N at the $p \leq 0.05$ level. X SH+L 133N different from Conv 267N at the $p \leq 0.10$ level when sample depth and position are included in the regression model.

Table 4.2. Significance of green manure, nitrogen rate, position and depth and sub-effects when constituting linear model for sampled root length density.

Model Term	Probability (p)		
	3 WAE	5 WAE	8 WAE
N-rate x GM x Pos x Depth	NS	NS	0.0602&
N-rate x Pos x Depth	NS	NS	-
GM x Pos x Depth	NS	NS	-
Pos x Depth	0.0006*	0.0036*	-
N-rate x GM x Depth	NS	NS	-
N-rate x Depth	NS	0.0021*	-
GM x Depth	NS	0.0448†	-
N-rate x GM x Pos	NS	NS	-
N-rate x Pos	NS	NS	-
GM x Pos	NS	NS	-
N-rate x GM	NS	NS	-
Pos	-	-	-
Depth	-	-	-
GM	0.091#	-	-
N-rate	0.011	-	-
0N	0.17 cm cm^{-3}		
133N	0.26 cm cm^{-3}		

WAE = weeks after emergence; Pos = Position; NS not significant at the $p \leq 0.10$ level; * See Table 4.3; # See Figure 4.2; † See Figure 4.3; & See Appendix D; N = kg NH_4NO_3-N ha^{-1}.

Table 4.3. Various interactions with depth for root length density (cm cm^{-3}) at 3 and 5 weeks after emergence.

Depth	3 WAE			5 WAE				
	Position			Position			N-rate	
(cm)	IR 0	IR 0.5	BR	IR 0	IR 0.5	BR	0N	133N
0-15	0.61Aa	0.51Aa	0.21Ab	2.61Aa	2.05Aa	1.11Ab	1.15Ab	2.69Aa
15-30	0.40Ba	0.47Aa	0.08Bb	1.35Ba	1.34Ba	0.25Bb	0.71Ba	1.25Ba
30-60	0.06Ca	0.06Ba	0.05Ba	0.36Ca	0.27Ba	0.06Bb	0.13Cb	0.33Ca

WAE = weeks after emergence; $\alpha = 0.10$; means within rows for depth having same lower case letter do not differ at the $p \leq 0.10$ level according to Duncan's MRT; means within columns for position or N-rate having same capitalized letter do not differ at the $p \leq 0.10$ level according to Duncan's Multiple Range Test.

Table 4.4. Significance of treatment, position and depth when constituting linear model for sampled root length density.

Model Term	Probability (p)		
	3 WAE	5 WAE	8 WAE
Treatment x Pos x Depth	NS	NS	NS
Treatment x Pos	NS	0.0354†	0.0008$^{\&}$
Treatment x Depth	NS	0.0084†	0.0040$^{\&}$
Pos x Depth	<0.0001	0.0004	<.0001
Pos	NS	-	-
Depth	NS	-	-
Treatment	0.0169*	-	-

WAE = weeks after emergence; Pos = position; NS not significant at the $p \leq 0.10$ level; * See Table 4.1; † See Table 4.5; $^{\&}$ See Table 4.6.

Table 4.5. Pairwise root length density (cm cm^{-3}) comparisons against Conv 267N by depth and position at 5 weeks after emergnce.

Treatment	Depth			Position		
	0-15cm	15-30cm	30-60cm	IR 0	IR 0.5	BR
Conv 267N	2.42	1.62	0.20	1.18	1.69	0.46
SH+L 0N	1.41^{X}	0.80^{X}	0.13	0.82	0.74^{X}	0.30
Conv 0N	0.89†	0.62^{X}	0.12	0.68	0.45†	0.19
SH+L 133N	3.37^{X}	1.46	0.42^{X}	1.92	1.59	0.76
Conv 133N	2.02	1.04	0.24	1.26	1.16	0.23

WAE = weeks after emergence; ^{X}, † means within column for depth or position different from Conv 267N at the $p \leq 0.10$ and 0.05 levels respectively.

Table 4.6. Pairwise root length density (cm cm^{-3}) comparisons against Conv 267N by depth and position at 8 weeks after emergence.

Treatment	Depth			Position		
	0-15cm	15-30cm	30-60cm	IR 0	IR 0.5	BR
Conv 267N	2.96	1.39	0.46	2.04	1.08	0.83
SH+L 0N	1.98^{X}	0.88	0.29^{X}	1.20	0.85	0.53
Conv 0N	1.01†	0.70^{X}	0.17†	0.66^{X}	0.61	0.27^{X}
SH+L 133N	3.22	1.63	0.36	2.13	1.56	0.49
Conv 133N	2.83	1.31	0.45	1.62	1.49	0.67

WAE = weeks after emergence; ^{X}, † means within column for depth or position different from Conv 267N at the $p \leq 0.10$ and 0.05 levels respectively.

Table 4.7. Significance of green manure, nitrogen rate, and proximity to plant (near vs far) when constituting linear model for sampled root length density.

Model Term	Probability (p)		
	3 WAE	5 WAE	8 WAE
GM x N-rate x Proximity	NS	NS	NS
N-rate x Proximity	0.0716*	0.0324	0.0032
GM x Proximity	NS	NS	0.0914
GM x N-rate	NS	NS	NS
Proximity	-	-	-
N-rate	-	-	-
GM	NS	0.005	-

WAE = weeks after emergence; NS not significant at the $p \leq 0.10$ level; * see Table 4.8.

Table 4.8. Significance of green manure, nitrogen rate, and proximity to plant (near vs far) when constituting linear model for sampled root length density.

Model Term	Probability (p)		
	3 WAE	5 WAE	8 WAE
Treatment x Proximity	NS	0.0740	0.0106
Proximity	0.0708	-	-
Treatment	<0.0001*	-	-

WAE = weeks after emergence; NS not significant at the $p \leq 0.10$ level. * Mean of Conv 267N not significantly different from mean of any other contrasted treatment at the $p \leq 0.10$ level.

Table 4.9. Interactions between nitrogen rate and proximity for root length density (cm cm^{-3}).

Proximity	3 WAE		5 WAE		8 WAE	
	N-rate		N-rate		N-rate	
	0N	133N	0N	133N	0N	133N
Near	0.37 Ab	0.62 Aa	1.18 Ab	2.50 Aa	1.37 Ab	2.86 Aa
Far	0.07 Ba	0.08 Ba	0.21 Bb	0.48 Ba	0.35 Bb	0.56 Ba

WAE = weeks after emergence; means within rows for proximity class having same lower case letter do not differ at the $p \leq 0.10$ level; means within columns for N-rate having same capitalized letter do not differ at the $p \leq 0.10$ level according to Duncan's Multiple Range Test.

Table 4.10. Pairwise root length density comparisons against Conv 267N by proximity at 8 weeks after emergnce.

Treatment	5 WAE		8 WAE	
	Proximity		Proximity	
	Near	Far	Near	Far
Conv 267N	2.60	0.37	2.57	0.70
SH+L 0N	1.39^{X}	0.24	1.69^{X}	0.44^{X}
Conv 0N	0.96^{X}	0.18^{X}	$1.05^{\dagger}$	$0.25^{\dagger}$
SH+L 133N	2.91	$0.68^{\dagger}$	3.21	0.48^{X}
Conv 133N	2.09	0.28	2.52	0.63

WAE = weeks after emergence; ^{X}, † means within column for proximity class different from Conv 267N at the $p \leq 0.10$ and 0.05 levels respectively.

CHAPTER 5
EFFECTS OF A GREEN MANURE APPROACH TO SWEET CORN FERTILIZATION ON SOIL PROPERTIES

Introduction

Crop requirements and climate aside, soil fertility largely determines nutrient and water supplementation required in agricultural production – thereby having major economic and ecological implications. Texture, organic matter content, and geological composition usually exert greatest influence on soil fertility (Brady and Weil 1999, Tinker and Nye 2000). Soil texture and geological composition are interrelated and cannot be altered in any practical sense. In contrast, changes in soil organic matter (SOM) including content, spatial distribution, chemical properties (such as carbon-to-nitrogen ratio, C:N), and related soil biological properties (such as microbial biomass and activity) may be more readily driven by agricultural practices. Current management practices utilizing regular soil disturbance (tillage) and exclusively dependent on chemical fertilization may limit equilibrium SOM to the detriment of potential production and input use efficiency, especially in sub-tropical, sandy areas such as Florida. In such environments, leguminous green manure (GM) and reduced tillage approaches to soil fertility may provide significantly greater organic matter inputs and slow rates of organic matter decomposition compared to chemical fertilization, but without the often inhibitive costs and phosphorous imbalances associated with animal manure application.

Nevertheless, modification of SOM is typically a long-term process. For example, for every 1% of dry weight as SOM in the upper 15 cm, a soil contains roughly 25 Mt

SOM ha^{-1} (assuming a soil bulk density of about 1.65 g cm^{-3}). Many economic crops contribute no more than 5 Mt ha^{-1} post harvest organic matter (dry weight). Effective leguminous GMs, grown during fallow periods and without need for chemical N fertilization, may provide 5-10 Mt ha^{-1} or more. However, decomposition occurring after death of crops and GMs reduces the fraction of such residues transforming into stable SOM. In two similar experiments after ~10 years of a pearl millet and wheat rotation on a low organic matter (~0.40-0.50% organic C) sandy loam (65-69% sand) in India, Goyal et al. (1992, 1999) found combinations of inorganic fertilizer and organic amendments (wheat straw, manure, or sesbania green manure) generally increased soil organic C (SOC), total N (TN), microbial biomass C (MBC), and enzyme activity more than inorganic fertilizer alone in the top 15 cm of soil (plow-layer). Still, with manure/sesbania and crop stover additions in these studies varying between 8-15 Mt ha^{-1} annually, these increases in SOC amounted to only about 5-15%. Realization of greater SOC/SOM increases in hot, humid, sandy environments may require greater and/or more consistent residue additions, especially under conventional tillage.

Generally, organic matter associated with the finer (smaller) sized soil fractions – silt and clay – may experience more physical and chemical protection from decomposition than that associated with more coarse (larger) sized soil fractions. For example, even on a sandy loam soil having about 35% sand and 1.6% SOC, Kandeler et al. (1999) found most SOC associated with the clay-sized soil fraction (<2μm) and roughly 90-95% of total SOC accounted for within silt and clay-sized fractions together (<63 μm). Extreme sand content of Florida mineral soils (in many cases 95-97% sand) has therefore provoked doubt that organic matter can be meaningfully increased in such

soils. Data from native upland and anthropogenic silvicultural systems appears somewhat limited. Daubenmire (1990) determined SOM at five sites representing three widespread Florida tree communities on sandy soil (with and without fire protection), finding average SOM levels less than 1.50% in the upper 10 cm in all communities. Gholz and Fisher (1982) quantified SOM in sandy soils under slash pine management of seven ages between 2 and 34 years. In pine 5 to 34 years of age, organic matter in the A1 horizon (~12-14 cm) averaged 2.18%. Despite large standing plant biomass in these systems, actual leaf litter-fall additions may be only on the order of 1-4 Mt ha^{-1} annually, depending on age (Nemeth 1972).

Early indicators of long-term changes in SOM are desirable given the time limitations of agricultural research. Pool size of coarse particles of SOM – known as the particulate organic matter (POM) pool – often reflects the most recent additions of plant residues that have yet to undergo major decomposition. Results from Magid et al. (1997), Magid and Kjaergaard (2001), and Mueller et al. (1998) show recent additions of plant residues primarily contributed to low-density ("light"; density < 1.4 g cm^{-3}) fractions of POM, with C-loss during the first 2-4 months occurring primarily from these light POM fractions. Carbon to nitrogen ratios for all POM fractions in these studies also tend to decrease with decomposition over time. On sandy, loamy and clayey soils, Hassink (1995) studied decomposition rate constants of SOM, separating "macroorganic" matter (>150 μm; heavy, intermediate and light densities) from "microorganic" matter (150-20 μm and < 20 μm), finding decomposition rate constants fastest for macroorganic matter and for lighter fractions – independent of soil type. These results complement those of Kandeler et al. (1999), suggesting that larger-sized POM tend to be less physically

protected within the soil matrix and that lighter POM facilitates enzymatic action (see also Wander and Bidart (2000), who use an alternative POM separation into physically "loose" and "occluded" fractions). Consequently, changes in POM levels may provide early indication of ongoing changes of in overall SOM as well as potential soil nutrient release via decomposition.

Because decomposition and nutrient release from plant residues is a microbially mediated process, levels of microbial biomass reflect instantaneous decomposition rates and may also indicate potential soil nutrient release or immobilization as well as gross differences in SOM (for example, see Franzluebbers et al. 1999). Investigators use combinations of periodic field sampling of soil, laboratory soil incubation techniques, and/or ^{13}C and ^{15}N radioisotope techniques to quantify decomposition and inter-pool movements of soil organic matter (Gonzalez-Prieto et al. 1995, Hadas et al. 1993). Soil microbial biomass can be determined directly by chloroform fumigation (Blet-Charaudeau et al. 1990, Wardle et al. 1999, Franzluebbers 1999a, Franzluebbers and Arshad 1996, Franzluebbers et al. 1995 and 1996, Goyal et al. 1992 and 1999) and indirectly by bioluminescence (Blet-Charaudeau et al. 1990), near-infrared reflectance spectroscopy (Palmborg and Nordgren 1993) and plate-count techniques (Blet-Charaudeau et al. 1990). Respiration procedures used to estimate potential microbial activity also provide an indirect estimation of microbial biomass (Blet-Charaudeau et al. 1990, Neely et al. 1991, O'Connell 1990, Palmborg and Nordgren 1993, Wardle et al. 1999, Franzluebbers 1999a,b, Franzluebbers and Arshad 1996, Franzluebbers et al. 1995 and 1996), as do relatively simple arginine ammonification protocols (Franzluebbers et

al. 1996). Most of these investigations, conducted on soils with significant clay and silt fractions, find that microbial biomass responds positively to plant residue additions.

Tillage reduction may increase equilibrium soil organic matter compared to conventional tillage, but may also shift organic matter accumulation closer to the soil surface. Investigating long-term (~10 years) tillage effects within different soil depths and particle size classes in a sandy loam in Austria, Kandeler et al. (1999) found reduced and minimum tillage increased overall SOC, TN, and microbial biomass N of the bulk soil (top 30 cm), doing so mainly within the largest particle-size fraction (>200 μm) and the top 10 cm of soil. Microbial biomass N and enzyme activity per unit SOC remained relatively uniform in the top 30cm under conventional tillage, but increased both toward the soil surface and in larger particle size fractions with reduced and minimum tillage. Franzluebbers et al. (1995) found potential C and N mineralization and MBC in the upper 30 cm of a silty clay loam generally greater under zero tillage compared to conventional tillage. However, incorporation of crop residues in conventional tillage resulted in temporary increases in soil MBC, potential C mineralization and immobilization of inorganic N, indicating immediate and rapid decomposition. Many other workers have shown slower decomposition and greater N-immobilization for surface applied residues compared to soil-incorporated residues (see Chapter 2 for discussion).

These results suggest long-term tillage reduction potentially increases soil organic matter and nutrient cycling by creating a slowly decomposing litter layer where plant residues accumulate followed by delayed transfer to the uppermost soil layers. Over the long-term, potential SOM levels may therefore increase under reduced tillage, with POM and microbial biomass fractions indicating changes earlier than the total SOM pool.

Because the soil environment speeds decomposition by buffering water and temperature regimes (see Chapter 2), and because soil disturbance promotes microbially-based decomposition by destroying macroaggregates (Franzluebbers 1999b), long-term conventional tillage may reduce overall residence times for organic matter and promote more rapid nutrient release after tillage events. Tillage reduction may therefore be more important to increase SOM and soil/residue nutrient retention in hot, humid environments where decomposition already takes place rapidly, and on coarse-textured soils with negligible small-sized particle fractions (see also Franzluebbers and Arshad 1996 and Franzluebbers et al. 1995).

To test if significant increases in soil C and N pools can be achieved in coarse-textured soils under Florida conditions, we investigated a GM sequence of summer planted sunn hemp (SH) followed by a winter legume (L) of blue lupin (*Lupinus angustifolius*, winter 2001-02) and cahaba white vetch (*Vicia sativa*, winter 2002-03) as N-source for sweet corn (*Zea mays* var Rugosa) on a sandy soil using reduced tillage. Sweet corn treatments with one GM or no GMs (conventional), as well as complete fallow (no corn or GMs, zero-tillage and periodic weed control) were also included. Effects of treatments on dry matter additions, total soil C (TC), total soil N (TN), particulate organic C (POC), particulate organic N (PON), microbial biomass C (MBC) and soil pH were assessed. We hypothesized that the double GM approach would add significantly more dry matter to the system than other approaches, driving greater increases in the soil C and N pools than all other treatments, and that increases in soil C and N pools would generally be greater with any GM approach compared to the conventional. We expected to see greatest differences in POC and MBC pools.

Materials and Methods

Set-Up and Design

The 15 overall treatments as well as site and experimental design are more fully described in Chapter 1. Treatments consisted of sweet corn preceded by: a summer GM of sunn hemp and a winter GM of blue lupin (winter 2001-02) and cahaba white vetch (winter 2002-03) denoted as SH+L; sunn hemp only (SH); lupin (winter 2001-02) and vetch (winter 2002-03) only (L); and unamended "conventional" corn (Conv). Each GM level was supplementated with 0, 67, or 133 kg inorganic N ha^{-1} (0N, 67N, and 133N). Unamended (Conv) treatments also received 200 or 267 kg inorganic N ha^{-1} (Conv 200N and Conv 267N). A complete fallow (Fal) receiving only weed control (no tillage and no planting) was also used for comparison.

The study was conducted at the Plant Science Research and Education Unit near Citra, Florida. Candler and Lake fine sands (~95-97% sand in the upper 15 cm) were dominant soil types (see Appendix A) with soil survey indicating organic matter between 1.1% and 2.1% depending on location within the field (data not shown).

Procedures and Measurements

Dry matter additions to the field from crop residues over both study years were calculated for each plot from data presented in Chapters 2 and 3. These included all residues from sunn hemp, winter legumes, weeds, and corn stover (corn vegetative tissue) at respective final samplings.

Due to resource limitations, only pH was determined for all treatments at all dates. Evaluation of soil MBC was conducted at all dates for all treatments receiving 0N and 133N as well as Conv 267N and Fal. Total soil C and N, POC and PON were determined for all treatments after the end of each year's sweet corn crop (July 2002 and June 2003).

Soil samples of no less than 200 g were removed from each plot on four sample dates: November 2001 (at the end of sunn hemp), April 2002 (at the end of lupin), July 2002 (at the end of sweet corn) and June 2003 (at the end of sweet corn). Samples were taken from the top 15 cm from different areas within each plot, stored in plastic bags and refrigerated immediately. Samples were homogenized and subsamples of 30-40 g were weighed, dried at 100 C for 24 hours, and reweighed to determine gravimetric water content. Microbial biomass C was determined via chloroform fumigation method (procedure provided by Dr. Yu Wang, UF Wetlands Biogeochemistry Lab, Gainesville) for all GM levels (SH+L, SH, L, Conv) at 0N and 133N N-rates, as well as Conv 267N and Fal treatments. Fumigated samples were exposed to chloroform in an evacuated vacuum chamber for 24 hours, with as much chloroform as possible removed by repeated air entry and evacuation. Carbon from fumigated samples and non-fumigated controls was extracted using 25 ml of 0.5 M K_2SO_4 solution. Samples and extractant were shaken for 1 hour and then centrifuged for 10 minutes at 6000 rpm. Resulting supernatant was seperated, vacuum filtered, acidified using 37 N sulfuric acid, and refrigerated. Solutions were then analyzed for dissolved carbon using a TC analyzer and original soil samples frozen until further analysis. Microbial biomass C for each plot was calculated as $(C_f - C_{uf})/0.41$, where C_f and C_{uf} were C contents of fumigated and unfumigated samples, respectively, and 0.41 was a calibration constant as determined by Voroney and Paul (1984).

Particulate organic matter was separated using a procedure adapted from one provided by Dr. Alan Franzluebbers (USDA Agricultural Research Service, Watkinsville, GA). Subsamples of no less than 50 g soil were mixed with 100 ml of 0.1 M $Na_4P_2O_7$ and

shaken overnight for 12-16 hours to disperse soil coatings and other inorganic C. Subsamples were then rinsed and filtered using a 0.053 mm sieve with debris greater than 0.5 cm removed. Separated, sieved subsamples were then dried at 100 C for 24 hours and weights recorded. After thorough homogenization, roughly 10 g of this material was ground using a ball mill and analyzed for C and N using a Carlo Erba CN analyzer (Carlo Erba Reagenti; Milan, Italy). Ground subsamples of unseparated soil were also analyzed for C and N using the same equipment. This total C and N and particulate organic C and N were ascertained for all treatments after sweet corn crops in both July 2002 and June 2003. However, to further resolve differences, samples in June 2003 were taken and analyzed for both 0-7.5 cm and 7.5-15 cm soil layers (samples were later recombined for MBC and pH analysis).

Soil pH was determined for all treatments at all sample dates using procedure of the UF-IFAS Analytical Research Lab (University of Florida, Gainesville, FL). A mixture of 20 g soil was stirred with 40 g of pH-neutral DDI water and allowed to equilibrate for 20 minutes, with pH measured afterwards using a pH probe.

Data Analysis

Data were analyzed using SAS (Statistical Analysis Systems; Cary, NC). Balanced analysis of variance (ANOVA) was conducted with results for observations from all GM levels (SH+L, SH, L and Conv) and N-rates of 0N, 67N, and 133N (where applicable) for all sample dates. Results were regressed linearly on sample date, GM level, chemical N-rate, all interaction terms of these three variables, and block. A randomization term was included for block. Where interaction terms became significant, separate ANOVAs were run to compare treatments within specific levels of the interacting variables. Non-interacting variables (except block) were not included in the

interaction model statements. Comparisons of means were always made with Duncan's multiple range test.

To compare results of treatments with GMs plus 133N against high-fertilized, high-producing conventional corn, pairwise constrasts against Conv 267N and Conv 200N were made (where available). These treatments (GMs with 133N, Conv 200N and Conv 267N) were also constrasted against Fal, with Conv 200N and Conv 267N also contrasted against each other. For these contrasts, necessary ANOVA used the same independent variables as the balanced design except that GM level and N-rate level were substituted with the appropriate overall treatment title (SH+L 67N, SH+L 133N, SH 67N, SH 133N, L 67N, L 133N, Conv 200N, and Conv 267N where applicable). The same protocol was followed when interaction between sample date and treatment became significant. All significant differences discussed occurred at $p \leq 0.05$.

Results

Dry Matter Additions

End-of-year dry matter additions from all plant residues (GMs, sweet corn, and weeds) ranged from 4.1 to 23.3 Mt ha^{-1} depending on treatment and year (Figure 5.1A,B). Additions remained significantly lower for Conv compared to all GM levels in both years. In 2001-02, when winter legume production was higher, SH+L added 144% more residue than Conv, while additions with SH and L alone were 96% and 59% greater, respectively, than Conv; residue contributions significantly increased from Conv to L to SH to SH+L in that order. Dry matter production for SH in 2002 was about 50% greater than in 2001 (see Chapter 2), leading to greater year-long residue additions for SH and SH+L in 2002 (about 20 Mt ha^{-1} in 2002, which was about 230% more than produced by Conv). The low yield of cahaba white vetch in 2002-03 resulted in no statistical

difference ($p > 0.05$) for dry matter additions between SH and SH+L in that year. Residue contributions for L and Conv did not differ statistically between years despite 50% higher corn plant population in 2003 compared to 2002 (Figure 5.1A,B; see Chapter 3).

By increasing corn vegetative growth, increase from 0N to 67N or 133N resulted in a significant increase in dry matter addition of 19-32% depending on N-rate and year. Increase from 67N to 133N generally increase ear growth more than vegetative growth (Chapter 3), therefore no difference in dry matter additions occurred between 67N and 133N (Figure 5.1A,B). Interaction between year and N-rate was not significant (not shown).

In both years, treatments with any GM plus 133N added significantly more dry matter to the system than Conv 267N and Conv 200N. All GMs with 133N as well as Conv 200N and Conv 267N produced greater dry matter additions than Fal. However, dry matter additions from weeds in Fal amounted to 45-50% of the total from Conv 200N and Conv 267N, and numerically these two high-N treatments contributed little more biomass than did Conv 67N and Conv 133N (Figure 5.1A,B).

Microbial Biomass C

Microbial biomass C (MBC) showed no response to date, GM, or chemical N-rate over the course of the study (data not shown). Pairwise treatment contrasts showed no significant differences for GMs plus 133N relative to Conv 200N, Conv 267N or Fal, nor did pairwise contrasts show differences among Conv 200N, Conv 267N and Fal (data not shown). The overall study average for soil MBC was 105 ± 4 mg C kg^{-1} dry soil.

Total and Particulate C and N pools

Values for TC and TN ranged from 7.1-8.9 g C kg^{-1} (0.71-0.89%) and 0.35-0.57 g N kg^{-1} (0.035-0.057%) depending on treatment and year. These results corresponded

roughly to pre-existing soil survey data indicating soil organic matter varying from 1.1-2.1% across the field (not shown). Particulate organic C and N generally made up 30-40% and 20-30%, respectively, of the total soil C and N pools, while TC:TN and POC:PON values remained near 19:1 and 26:1, respectively (Table 5.1). Across both years, amendment with SH+L and SH increased TN (by 15% and 18%, respectively), POC (by 17% and 18%, respectively) and PON (by 27% and 24%, respectively) compared to Conv while lowering TC:TN (by 7% for both SH+L and SH; Table 5.1). Amendment with L showed similar effects only for TC:TN and PON, but otherwise was not significantly different from Conv, SH+L or SH (Table 5.1).

Over the period of one year, values for POC, PON, POC:TC and PON:TN all increased significantly (by 12%, 20%, 18% and 25%, respectively) when ANOVA was conducted for the balanced design (12 treatments including all four GM levels at three chemical N-rates; Table 5.1). However, ANOVA for the full study (balanced design plus Conv 200N, Conv 267N, and Fal; Table 5.2) revealed significant interaction between treatment and year for POC and PON. The apparent discrepancy occurred because POC and PON decreased for Conv 200N (by 36% and 30%, respectively), Conv 267N (26% and 27%, respectively) and Fal (12% and 21%, respectively) from 2002 to 2003, although only the decrease in PON for Fal was significant. Subsequent pairwise contrasts of treatments within years showed greater POC and PON for treatments with any GM plus 133N compared to Conv 200N, Conv 267N and Fal at the end of the second year (2003) only. Relative increases for GMs plus 133N compared to these treatments amounted to roughly 30-50% for POC and 30-100% for PON (Table 5.3). Otherwise, pairwise

contrasts between GMs with 133N against Conv 200N, Conv 267N, and Fal resolved few differences (Table 5.2).

Similarly, full ANOVA revealed a significant decrease for TC across all treatments from 2002 to 2003 – a trend weakly significant ($p \leq 0.06$) in the balanced ANOVA as well (see Tables 5.1 and 5.2). The decrease may reflect conversion of the field from pasture to tilled row-crop system about 2 years prior to the start of our experiment. Assuming a soil bulk density of 1.65 g cm^{-3}, the decrease of about 0.5 g C kg^{-1} soil was roughly equivalent to a loss of 2.5 Mt SOM ha^{-1}. Increases in POC, especially for GM treatments, appear of similar size.

In 2003, analyzing samples from the upper 7.5 cm of the 0-15 cm showed similar trends regarding the soil C and N pools (data not shown). Especially for SH and SH+L treatments, POC and PON values were 30-40% greater in the upper 7.5 cm of soil compared to the upper 15 cm of soil as a whole. However, due to variability, p-values for these differences between GM levels and between contrasted treatments became larger with ANOVA for the upper 7.5 cm (compared to the upper 15 cm). Soil C and N pools displayed more homogenized values from 7.5-15 cm, with no significant differences between GM levels, N-rates, years, or treatment (data not shown). By reducing variability, averaging the 0-7.5 cm and 7.5-15 cm layers together (for the 0-15 cm layer) increased statistical resolution. Nevertheless, these results show changes in soil C and N pools as result of GM use under reduced tillage is occurring primarily in the upper 7.5 cm.

Soil pH

Soil pH was close to neutral (Table 5.4), higher than indicated by pre-existing soil survey data (not shown) by about 0.5, although this may have occurred as a result of

fertility management during the intervening time or due to use of different pH-determination procedure. Compared to Conv, amendment with SH+L and SH significantly decreased soil pH in the upper 15 cm, though differences were small (7.18 for Conv, 7.09 for SH, and 7.10 for SH+L). Sample date also significantly affected soil pH, with average higher values in April 2002 (7.31; at the end of lupin) and lower values in October 2001 (7.03; at the end of sunn hemp) and July 2003 (7.06; after sweet corn). Differences by sample date may have been related to temperature; the 5-6 months prior to April 2002 would have been colder, probably slowing soil organic matter decomposition and other biological activity. Chemical N-rate showed no significant effect on soil pH, nor were any interactions between N-rate, sample date, and/or GM ($p > 0.05$; Table 5.4). Pairwise contrasts of GMs with 133N against Conv 200N, Conv 267N and Fal showed no interesting trends, nor did contrasts among Conv 200N, Conv 267N and Fal (data not shown).

Discussion

Soils in this study are highly sandy, although typical of those found in Florida. Dominant soil types for the experimental field (Lake Fine Sand and Candler Fine Sand) are characterized as having 95-97% sand in the upper 15 cm (Carlisle et al. 1988; see Appendix A). Amendment with GMs, especially SH+L and SH, significantly increased annual field residue additions (Figure 5.1A,B), POC, PON, and TN in both years, as well as decreased TC:TN (Table 5.1), compared to Conv in the upper 15 cm of soil, with changes probably taking place mostly in the upper 7.5 cm. Furthermore, analysis of variance for all treatments (including complete fallow and high-N, chemically fertilized treatments not present in the balanced GM/N-rate/year ANOVA) not only confirmed that TC among all treatments declined from 2002 to 2003, but indicated a year by treatment

interaction suggesting that POC and PON for treatments with combined GM and chemical approach may be growing while that for conventionally fertilized treatments (Conv 200N and Conv 267N) and complete fallow (Fal) may be declining (Tables 5.2-5.3).

These patterns may reveal important trends "superimposed" on each other. The decline in TC likely reflects conversion from pasture in the medium-term past (2-3 years prior to the study) and the changes in POC and PON signaling shorter-term changes in the current regime of SOM additions. Across all treatments, the decline in TC (about 0.5 g kg^{-1} soil) appears roughly matched by increases in POC for treatments with SH and SH+L. As the current POC and PON pools turnover into smaller-fraction organic matter, declines in TC for conventionally fertilized corn (Conv 200N and Conv 267N) and complete fallow (Fal) treatments may become increasingly rapid while TC declines in GM treatments may slow or even reverse. However, changes in the size of future additions to POC as well as its potential decomposition rate will determine what divergence, if any, we see between these cropping approaches.

Higher POC and PON of soil under GMs plus 133N compared to soil under Conv 200N, Conv 267N, and Fal in 2002 became highly significant after two years. Even though it is considered an early indicator, changes in the soil POM pool may still require several years to reach equilibrium with steady inputs, especially after recent adoption of reduced tillage; large pieces of sunn hemp stem residue visibly remain on the soil surface for 2 or more years in our system. Additionally, because many of these patterns became significantly resolved only after data from the second year became available for analysis, we expect differences between treatments to become larger and more significant in the

future. However, relative increases generated in the POC (30-50%) and PON (30-100%) pools by GM use after two years are still small in an absolute sense, indicating additions of only about 0.5-1.0 g C kg^{-1} and 0.03-0.07 g N kg^{-1}, respectively. Without greater POM increases in the future, SOM increase due to GM addition may never exceed a fraction of a percent – especially on sandy soils.

In our system, PON may be the earliest and most sensitive indicator to changes in other SOM pools. After the initial year of data, only PON showed a significant trend (all GMs > Conv), and after two years of data the significant trends in PON always occurred at the highest levels of significance (Tables 5.1 and 5.3). At the same time Fal (complete fallow treatment; receiving identical herbicide application as all other treatments, but otherwise undisturbed) received significantly less dry matter inputs than all other treatments (only 4.1-4.6 Mt ha^{-1} annually; Figure 5.1A,B). Therefore, the significant decrease in PON for Fal after two years is likely one of the earliest significant year-to-year responses we would expect to generate due to a specific experimental treatment (Table 5.3).

Work by Robles and Burke on a sandy loam (~65% sand) in Colorado showed POM fraction (53-2000 μm) accounted for 30-40% of SOM, similar to our results (POC and PON equaled 30-40% TC and 20-30% TN, respectively; Table 5.1). Hassink (1995) showed decomposition rate of POM to be closely related to particle density irrespective of source soil texture. Results from Magid and Kjaergaard (2001) suggest that POM density may correspond directly to particle size, which would facilitate inexpensive and readily simple manual separation, allowing more detailed analysis of POM decomposition potential. It would be of interest to examine relationships of size and

density to occlusion as well, as this may further explain POM decomposition potential (Wander and Bidart 2000). Because decomposition is known to decrease POC:PON values (Magid et al. 1997, Magid and Kjaergaard 2001, and Mueller et al. 1998), decreased values for POC:PON from 2002 to 2003 may reflect partial decomposition of the 2002 POM additions.

Unlike studies on soils with greater clay and silt fractions, MBC values exhibited in this study remained low (105 ± 4 mg kg^{-1}) and exhibited no differences based on amendment regime. Using similar methodology (chloroform-fumigation), Goyal et al. (1992, 1999) and Franzluebbers (1999a) found MBC values of 180-355 mg kg^{-1}, 147-423 mg kg^{-1}, and roughly 200-600 mg kg^{-1}, respectively, on soils in India and Texas with 65-80% sand. Expressed as a fraction of TC (~13.5 mg^{-1} g) or on a land area basis (~25.5 g m^{-2}), MBC values recovered in this study also amounted to about 25-30% of those reported by Goyal et al. (1992, 1999) and Franzluebbers at el (1995). However, results from Kandeler et al. (1999) for chloroform-extracted microbial biomass N associated with soil particle-size fractions (coarse sand, fine sand, silt, and clay) suggest our values may be expected for sand. Because such low levels of microbial biomass appear associated with sand fractions, MBC may be a poor indicator of potential microbial action in our soils.

Significantly decreased soil pH following SH+L and SH compared to Conv is expected because soil pH is known to fall as a consequence of organic matter decomposition (for example, Goyal et al. 1992, 1999, Simek et al. 1999). The small change (7.09 and 7.10 for SH and SH+L, respectively, compared to 7.20 for Conv) probably creates no practical difference but does indirectly indicate greater (microbial)

soil decomposition activity following GM additions – even if microbial biomass was unaltered. From results presented in Chapter 2, we certainly know that large GM residue additions are being decomposed (~65% of sunn hemp decomposes in 14-16 weeks, with winter legumes likely faster). Comparison of POC and TC suggests differences in soil C of about 1-2 Mt ha^{-1} between GM and Conv treatments, whereas SH and SH+L residue addition probably amounted to an additional 6-7 Mt ha^{-1} C annually.

Kandeler et al. (1999) showed microbially-based xylanase and protease enzymes were more highly associated with sand fractions; activities of these enzymes and/or measures of substrate-induced respiration would probably better gauge potential activity of the microbial community in our sandy soil. It is possible that increased microbial enzyme activity and respiration (not increased microbial biomass) account for decomposition in regions such as Florida. Therefore, soil microbes conceivably function with reduced N-limitation in our environment. If so, they cannot be expected to immobilize significant amounts of N here, and this would have major implications for residue management intended to immobilize N via increased tissue recalcitrance (as discussed in Chapter 2).

The relatively high TC:TN (~19:1) and POC:PON (~26:1) ratios seen in our study (Tables 5.1 and 5.2) may support this theory. Most studies (conducted in temperate environments and/or on fine textured soils) report equilibrium soil organic C:N around 12:1. Residue with higher C:N values do not result in net-N release upon decomposition because the potential microbial biomass increase associated with the potential C respiration is N-limited until C:N ratio approaches 12:1. Our equilibrium value of soil TC:TN (which did not change from 2002 to 2003) suggests microbial respiration

(decomposition) in our system is N-limited only beyond 19:1. Even higher values for POC:PON are expected because of greater physical and/or enzymatic accessibility to POM (Hassink 1995, Kandeler et al. 2000, Wander and Bidart 2000). The greater sensitivity (to residue additions) of the PON and TN pools compared to POC and TC, and the significantly lower TC:TN values found with GM amendment, may result from increased microbial respiration or enzyme activity per unit biomass N. Soil microbes may in sandy soils may "burn off" more GM-derived C additions without attacking N, making POC and TC levels more homogenized than PON and TN between different treatments. If, like microbial biomass C, microbial biomass N did not change with GM decomposition, but substrate induced respiration and/or enzyme activity increased, we would have further support for this hypothesis.

Conclusions

High residue additions (15-23 Mt ha^{-1} $year^{-1}$) under reduced tillage increased soil C and N pools and reduced C:N ratios of particulate and total C and N pools – even on a sandy Florida soil after only 2 years. Given a historical conversion from pasture into row-crop system, use of GMs may create important SOM differences in the future. However, for differences to become of practical significance, greater increases in POC and PON pools may be required. Also, microbially-based decomposition in Florida sandy soils may be less characterized by biomass increase and less N-dependent than that found in temperate environments and/or on fine-textures soils. For residue management systems in our region, this may reduce the effectiveness of attempts to immobilize N through microbial biomass growth via increased C and/or lignin inputs.

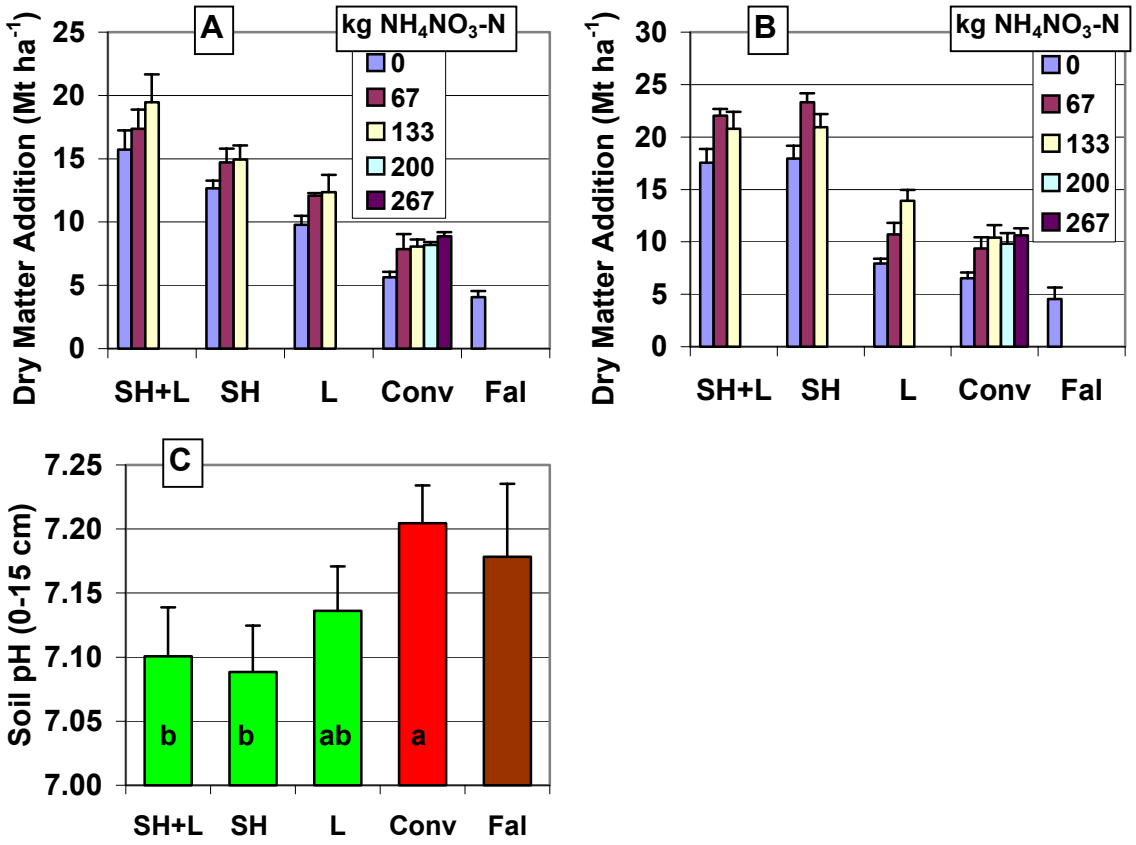

Figure 5.1. Dry matter additions by treatment (2001-2002, A; 2002-2003, B) and average soil pH by GM over two years (C). Error bars reflect standard error; means with the same lower case letter are not significantly different at the $\alpha = 0.05$ level according to Duncan's Multiple Range Test.

Table 5.1. Significance of green manure, nitrogen rate, and year in balanced analysis of variance for soil TC, TN, TC:TN, POC, PON, POC:PON, POC:TC, PON:TN, for samples taken in July 2002 and June 2003.

	Probability (p)							
	TC	TN	TC:TN	POC	PON	POC:PON	POC:TC	PON:TN
Year x GM x N-rate	NS	NS	NS	NS	NS	NS	NS	NS
Year x GM	NS	NS	NS	NS	NS	NS	NS	NS
Year x N-rate	NS	NS	NS	NS	NS	NS	NS	NS
N-rate x GM	NS	NS	NS	NS	NS	NS	NS	NS
N-rate	NS	NS	NS	NS	NS	NS	NS	NS
Year	NS	NS	NS	**	***	*	***	***
	($g\ kg^{-1}$)	($g\ kg^{-1}$)	($g\ g^{-1}$)	($g\ kg^{-1}$)	($g\ kg^{-1}$)	($g\ g^{-1}$)	($g\ g^{-1}$)	($g\ g^{-1}$)
2002	8.3	0.45	19.1	2.7	0.10	26.1	0.33	0.24
2003	7.9	0.42	19.2	3.0	0.13	24.6	0.38	0.30
GM	NS	*	*	**	***	NS	NS	NS
	($g\ kg^{-1}$)	($g\ kg^{-1}$)	($g\ g^{-1}$)	($g\ kg^{-1}$)	($g\ kg^{-1}$)	($g\ g^{-1}$)	($g\ g^{-1}$)	($g\ g^{-1}$)
SH+L	8.3 ab	0.45 a	18.7 b	3.0 a	0.13 a	24.5	0.37	0.29
SH	8.4 a	0.46 a	18.7 b	3.0 a	0.12 a	25.1	0.36	0.27
L	8.0 ab	0.44 ab	19.0 b	2.8 ab	0.11 a	25.2	0.36	0.27
Conv	7.7 b	0.39 b	20.1 a	2.6 b	0.10 b	26.4	0.34	0.26

GM = green manure; TC = total soil C; TN = total soil N; POC = particulate organic C; PON = particulate organic N; NS model term not significant at the $p \leq 0.05$ level. *,**,*** model term significant at the $p \leq 0.05$, 0.01, and 0.001 levels, respectively; means within columns for measured quantities and within year or GM group having identical letters not significantly different at the $p \leq 0.05$ according to Duncan's Multiple Range Test.

Table 5.2. Significance of treatment and year in full analysis of variance and pairwise contrasts of selected treatments for soil TC, TN, TC:TN, POC, PON, POC:PON, POC:TC, PON:TN, for samples taken in July 2002 and June 2003.

	Probability (p)							
	TC	TN	TC:TN	POC	PON	POC:PON	POC:TC	PON:TN
Year x Treatment	NS	NS	NS	* (see Table 5.3)	* (see Table 5.3)	NS	NS	NS
Year	*	NS	NS	-	-	NS	*	*
	(g kg^{-1})	(g kg^{-1})	(g g^{-1})	(g kg^{-1})	(g kg^{-1})	(g g^{-1})	(g g^{-1})	(g g^{-1})
2002	8.3	0.44	19.3	-	-	26.5	0.33	0.25
2003	7.8	0.41	19.3	-	-	25.5	0.37	0.28
Treatment	NS	NS	*	-	-	*	NS	NS
	(g kg^{-1})	(g kg^{-1})	(g g^{-1})	(g kg^{-1})	(g kg^{-1})	(g g^{-1})	(g g^{-1})	(g g^{-1})
Conv 267N	8.0	0.40	20.0	-	-	32.7†	0.35	0.22
Conv 200N	7.7	0.40	19.2	-	-	26.4	0.35	0.26
SH+L 133N	8.5	0.45	19.0	-	-	25.0	0.36	0.27
SH 133N	8.3	0.49	17.3†	-	-	24.0	0.38	0.27
L 133N	7.9	0.41	19.4	-	-	26.0	0.38	0.28
Fal	8.3	0.41	20.4			27.0	0.31	0.24

TC = total soil C; TN = total soil N; POC = particulate organic C; PON = particulate organic N; NS model term not significant at the $p \leq 0.05$ level. *,**,*** model term significant at the $p \leq$ 0.05, 0.01, and 0.001 levels, respectively; † mean different from Fal at the $p \leq 0.05$ level.

Table 5.3. Analysis of variance for all treatments and pairwise contrasts of selected treatments within years for POC and PON.

	Probability (p)			
	POC 2002	POC 2003	PON 2002	PON 2003
Treatment	NS	***	NS	***
	(g kg^{-1})	(g kg^{-1})	(g kg^{-1})	(g kg^{-1})
Conv 200N	3.5	2.2	0.10	0.07
Conv 267N	3.0	2.5	0.11	0.09
SH+L 133N	2.9	3.2 †‡#	0.11	0.14 †‡#
SH 133N	2.9	3.3 †‡#	0.12	0.14 †‡#
L 133N	2.6 †	3.3 †‡#	0.11	0.12 †‡#
Fal	2.8	2.4	0.11&	0.09&

POC = particulate organic C; PON = particulate organic N; NS model term not significant at the $p \leq 0.05$ level. *,**,*** treatment significant within year at the $p \leq 0.05$, 0.01, and 0.001 levels, respectively; † mean different from Fal at the $p \leq 0.05$ level; †,‡,# mean different from Conv 200N, Conv 267N, and Fal at the $p \leq 0.05$ level, respectively; & years significant within treatment at the $p \leq 0.05$ level.

Table 5.4. Significance of date, green manure and nitrogen rate in analysis of variance for pH of sampled soil.

Model Term	Probability (p)
Date x GM x N-rate	NS
Date x GM	NS
Date x N-rate	NS
GM x N-rate	NS
GM	* (See Figure 5.1)
Date	***
October 2001	7.03 b
April 2002	7.31 a
July 2003	7.06 b
N-rate	*
0N	7.12 ab
67N	7.19 a
133N	7.09 b

GM = green manure; NS model term not significant at the $p \leq 0.05$ level. *, **, *** model term significant at the $p \leq$ 0.05, 0.01, and 0.001 levels, respectively; means within columns for date or N-rate having identical letters not significantly different at the $p \leq$ 0.05 according to Duncan's MRT.

CHAPTER 6
EFFECTS OF GREEN MANURE APPROACHES ON CROP PESTS: PARASITIC NEMATODES AND WEEDS

Introduction and Literature Review

Concerns about environmental and economic costs have created interest in alternative methods of weed and pest control in agricultural systems that make use of ecological processes. When weeds occur in cropping systems they may compete with crops for resources, possibly reducing economic profits beyond the potential costs of their control. Nematodes, a group of unsegmented roundworms, represent major actors in the soil food web including micro-floral grazers, predators, and plant parasites. Like weeds, some plant-parasitic nematodes may cause an unacceptable level of economic loss in cropping systems. Some weeds may also act as hosts for parasitic nematodes.

With proper selection and management, green manures (GMs) may provide multiple services by supplying biologically fixed nitrogen (N) to crops and adding carbon (C) to soils while also suppressing weeds and parasitic nematodes that might otherwise require chemical or cultural (physical) intervention. Green manures may control weeds and nematodes through physical, biotic, allelopathic, and adaptive interactions.

Physically, GMs may outcompete weed species for light, nutrients, and water at crucial stages and may otherwise disrupt the life-cycle of nematodes by acting as non-hosts. Blackshaw et al. (2001) found yellow sweet clover (*Melilotus officinalis*) suppressed weed biomass by 77%, 96%, and 99% in each of three years by direct competition. Ross et al. (2001) investigated seven clover species, finding them to have

greatest weed suppression on a low-fertility site when unmowed, especially with taller-growing annual clovers such as berseem clover (*Trifolium alexandrinum*). In the same study, weed suppression by clovers on high-fertility sites was enhanced by mowing and did not differ among species.

Selection of resistant crops or crop varieties represents one of the most important aspects of nematode damage control. Resistance to particular nematodes may differ among varieties of the same species, and resistance to different nematodes may also vary within a crop species or variety. Plants may also show different levels of susceptibility to regional races and local isolates of nematode species. Overuse of resistant crop varieties may also select for resistance "breaking" nematodes (see McSorley 2001 for discussion). Crop rotation with a non-host or nematode suppressant GM may help reduce such selection pressures by providing an alternative opportunity to disrupt nematode life cycles. *Meloidogyne* spp. (root-knot nematodes), one of the most problematic nematodes in Florida for corn (*Zea mays*) and tomato (*Lycopersicon esculentum*), have a wide host range. Greenhouse and field studies have shown a number of GMs act as non-hosts or suppressors of one or more species of root-knot nematodes: castor (*Ricinus communis*), iron-clay cowpea (*Vigna unguicalata* cv. Iron Clay), showy crotalaria (*Crotolaria spectabilis*), jointvetch (*Aeschynomene americana*), marigolds (*Tagetes minuta* and *T. erecta*), sesame (*Sesamum indicum* cv. Paloma), sunn hemp (*Crotalaria juncea*), barley (*Hordeum vulgare*), green panic (*Panicum maximum*), glycine (*Neonotonia wightii*), horsebean (*Canavalia ensiformis*), velvetbean (*Mucuna* spp.), and Sudex (*Sorghum bicolor* x *S. sudanese*) (McSorley 1999, Sipes and Arakaki 1997, Al-Rehiayani and Hafez 1998; also see McSorley 2001 for discussion).

On the other hand, use of potential GMs may be limited if they exacerbate infestations of plant parasitic nematodes by acting as hosts. In Hawaii, Sipes and Arakaki (1997) found populations of *Meloidogyne* spp. on taro (*Colocasia esculenta*) increased significantly following alfalfa (*Medicago sativa*), sweet corn (*Zea mays* var Rugosa), cowpea (*Vigna unguicalata*, variety unreported), lablab (*Lablab purpureus*), hairy vetch (*Vicia villosa*), mustard (*Brassica napus*), oat (*Avena sativa* cv Coker), okra (*Hibiscus esculentus*), rhodes grass (*Chloris gayana*), cereal rye (*Secale cereale* cv Danka), grain rye (*Lolium multiflorum* cv Alamo), siratro (*Macroptileum atropurpureum* cv Siratro) and wheat (*Triticum aestivum*, multiple cultivars). In Florida, McSorley (1999) found significantly increased root-knot nematode populations on roots of pearl millet (*Pennisetum typhoides* syn *P. glaucum*) and Japanese millet (*Echinochloa frumentacea*). Some GMs known as non-hosts or direct suppressors of *Meloidogyne* spp. may have undesirable characteristics, or may vary in their adaptability to a particular environment and management system. As discussed above, some GMs well-suited for control of one type of nematode may show susceptibility to others; sunn hemp has been found to be a poor host of reniform nematodes (*Rotylenchulus reniformis*) but may support a slow population increase over time (Caswell et al. 1991; Wang et al 2001). Al-Rehiayani and Hafez (1998), working in Idaho, found varieties of buckwheat (*Fagopyrum esculenta*), mustard (*Brassica napus*) and corn to be non- or poor hosts for a *Meloidogyne chitwoodi* race, while Sipes and Arakaki (1997) found opposite results for with *Meloidogyne javanica* in Hawaii.

Green manures may control pests indirectly by providing habitat for organisms that feed on or parasitize weeds and nematodes. Yeates et al. (1999) conducted a 7-year study

on impacts of different weed management strategies (two types of cultural control, two types of herbicides, and application of sawdust mulch) on nematode population and diversity in annual and perennial cropping systems. Over the long-term, saw-dust mulch raised populations of predatory nematodes more than other treatments, possibly by increasing availability of fungal and bacterial grazing nematodes. Greenhouse studies in Florida using sandy soil have shown sunn hemp can increase omnivorous and predatory nematodes on soils with low organic matter (< 2%), though perhaps not enough to control parasitic nematodes such as *Meloidogyne* spp. (Wang et al 2003a). Wang et al. (2001) found application of sunn hemp residues to a silty clay at a somewhat high rate (1 g dry residue $100g^{-1}$ dry soil) enhanced nematode-trapping fungi.

Release of allelopathic chemicals by GMs may directly inhibit weed growth and nematodes, although this is difficult to prove formally. Leachate collected from sunn hemp residues have shown allelopathic properties against *Rotylenchulus reniformis* (Wang et al. 2001). Blackshaw et al. (2001) found up to 97% lower weed density 10 months after yellow sweet clover had been terminated. Because no difference in weed suppression existed when yellow sweet clover residues remained in the field or were removed, the authors speculated that isoflavanoid and phenolics (identified in other studies) released during growth and/or root decomposition may have explained some of the suppression.

Small-seeded weeds may be more susceptible to growth-reducing stresses than larger seeded crops (see Davis and Liebman, 2001, for discussion). Allelopathic chemicals and slower release of N from decomposing GMs may therefore reduce small-seeded weed growth more than that of large seeded crops. Davis and Liebman (2001)

found red clover (*Trifolium pratense*) residues significantly reduced and delayed the maximal relative growth rate for wild mustard (*Brassica kaber*) but not for corn. Based on other studies, investigators speculated allelopathic were responsible. Dyck et al. (1995) suggest more slowly available N from decomposing GMs favors large-seeded crops over small-seeded weeds. These investigators found clover residue reduced lambsquarters (*Chenopodium album*) biomass more than that of corn at 2 weeks after emergence (72% and 31% reductions, respectively). By final harvest, corn biomass following crimson clover recovered to levels achieved by chemical fertilizer, while lambsquarters remained 39% lower relative to conventionally fertilized treatments.

We initiated a study to evaluate use of combined summer and winter GMs in a reduced tillage system as an N source for sweet corn in Florida. Weed and nematode pressure may have long-term implications for the profitability of such a system. Therefore we also assessed effects of GM and conventional approaches on weed growth and nematode populations. We hypothesized that GMs would significantly outcompete (reduce biomass) of weeds and lower damage potential and population counts of parasitic nematodes, particularly *Meloidogyne* spp. (root-knot nematodes), *Pratylenchus* spp. (lesion nematodes), *Paratrichodorus* spp. (stubby-root nematodes), and *Criconemella* spp. (ring nematodes). Study objectives were to quantify weed dry matter production in each cropping approach and assess impacts of GMs on parasitic nematode populations and damage potential in general.

Materials and Methods

Set-Up and Design

The 15 overall treatments as well as site and experimental design are more fully described in Chapter 1 (Table 1.2). Treatments consisted of sweet corn preceded by: a

summer GM of sunn hemp and a winter GM of blue lupin (*Lupinus angustifolius*; winter 2001-02) and cahaba white vetch (*Vicia sativa*; winter 2002-03; rotation denoted as SH+L); sunn hemp only (SH); lupin (winter 2001-02) and vetch (winter 2002-03) only (L); and unamended "conventional" corn (Conv). Each GM level was supplementated with 0, 67, or 133 kg inorganic N ha^{-1} (0N, 67N, and 133N). Other unamended (Conv) treatments also received 200 or 267 kg inorganic N ha^{-1} (Conv 200N and Conv 267N). A complete fallow (Fal) receiving only weed control was also used for comparison.

Procedures and Measurements

Weed samples consisted of roots and shoots taken from a representative, 0.23 m^2 (2.5 ft^2) area in each plot at the end of sunn hemp (2001 and 2002) and vetch (2003). All samples were bagged and dried for 72 hours at 65 C, then weighed for total dry weight after removal of soil from roots. Afterwards, all samples were ground in a Wiley mill to pass through a 2-mm screen, and a thoroughly mixed portion of each grinding was then subjected to a wet-acid Kjeldahl digestion, diluted and filtered. The diluted samples were analyzed for total Kjeldahl N (TKN) at the University of Florida Analytical Research Laboratory (EPA Method 351.2; Jones and Case 1991).

Soil samples for nematode analysis were collected on six occasions during the two-year study. Each sample consisted of six soil cores (2.5 cm diameter x 20 cm deep) from a plot. After thorough mixing of the aggregate sample, a 100 cm^3 subsample was removed for nematode extraction using a sieving and centrifugation procedure (Jenkins, 1964). Extracted nematodes were identified and counted under an inverted microscope. Data was analyzed using log-transformation:

$$y = \log(x+1)$$

where y = log-transformed data point

x = nematode population count in a single sample

Initially, limited plantings of cucumber in all plots (summer 2002) were used to assess potential for root galling. However, after results showed extreme variability this procedure was terminated. Therefore, plots used for nematode soil samples did not constitute all treatments until the final two samplings (when nematode numbers had increased and when it became known that cucumber root data could not be used). Previous to that, soil samples were collected from selected plots only to gauge effects of GM, N-rate, and/or fallow on nematodes. In those cases, balanced ANOVAs were developed to compare appropriate effects. Data from weed samplings and full nematode samplings were analyzed similarly to corn biomass data (Chapter 3) except that the complete fallow treatment (Fal) was also contrasted against GM and Conv treatments.

Results

Nematodes

Root-knot, lesion, stubby-root, and ring nematodes remained present for counting throughout the study. *Xiphinema* spp. (dagger nematodes), *Helicotylenchus* spp. (spiral nematodes), and *Belonolaimus* spp. (sting nematodes) appeared only periodically; their populations are discussed but not shown in tables.

October 2001

Plots planted to sunn hemp only were compared to conventional (Conv) plots that had not been planted with any GM. Soil counts of ring nematodes were weakly higher ($\alpha = 0.10$) in plots with sunn hemp (42 ± 11 individuals 100 cm^{-3}) compared to plots without (19 ± 5 individuals 100 cm^{-3}). Samples taken from Conv plots showed weakly higher ($p \leq 0.10$) stubby-root counts compared to sunn hemp plots, but counts of these nematodes were very low (2 or less individuals 100 cm^{-3}). No significant differences existed between

plots with and without sunn hemp for lesion, root-knot, and spiral nematodes at this time, with plot counts for these nematodes also very low (never more than 7 individuals 100 cm^{-3}; Table 6.1).

March 2002

Near the end of lupin growth, plots planted to lupin only were compared to Conv plots not planted with any GM. No significant differences existed for stubby-root, lesion, root-knot, sting, and dagger nematodes at this time. Average counts were never more than 11 individuals 100 cm^{-3} for any nematode within either treatment and no significant differences occurred (Table 6.1).

April 2002

Plots were sampled about six weeks after the March 2002 sampling, just after corn planting. Plots previously planted to lupin only were again compared to Conv plots that were previously fallow (before corn planting). Soil counts made for root-knot nematodes were much higher ($p \leq 0.05$) in plots that had lupin (199 ± 94 individuals 100 cm^{-3}) compared to plots previously fallow (5 ± 2 individuals 100 cm^{-3}). Soil counts for stubby-root, lesion and ring nematodes were of the same order of magnitude as in the previous sampling and again showed no statistical differences between lupin and fallow (Conv) treatments (Table 6.1).

July 2002

Plots were sampled just after corn harvest. Nine different treatments were compared: SH+L 133N, SH 133N, L 133N, Conv 0N, Conv 67N, Conv 133N, Conv 200N, Conv 267N, and Fal. Soil counts for root-knot were highest (generally, 30-160 individuals 100 cm^{-3}), but counts for lesion and ring nematodes were also higher than in earlier samplings (generally, 10-20 individuals 100 cm^{-3}). Stubby-root nematode counts

remained low (not more than 11 individuals 100 cm^{-3}). Balanced ANOVA for GM level (comparing SH+L 133N, SH 133N, L 133N, Conv 133N) showed that, by the end of the corn season, lesion nematodes were significantly lower in all plots previously planted with GMs compared to Conv treatments (Table 6.2). Root-knot, stubby-root, and ring nematodes were not significantly affected by GM history at this time. Average counts for all four nematode types remained lower ($p \leq 0.05$) in Fal treatments compared to L and Conv treatments. Balanced ANOVA for stubby-root nematode as affected by N-rate level (Conv 0N, Conv 67N, Conv 133N, Conv 200N, Conv 267N) showed somewhat of a polynomial response to N-rate peaking at 200N, but soil counts of stubby root nematode were rather low across all N-rates (Table 6.2).

March 2003

All plots were sampled at the end of vetch growth (prior to corn planting). Nematode populations were generally less than just after corn in July 2002 (Table 6.2) but greater than one year earlier in March and April of 2002 (Table 6.1). Root-knot nematode soil counts were not statistically affected by GM history, but stubby-root nematodes were significantly increased after presence of winter legumes and decreased by sunn hemp (L > SH+L > SH ≈ Conv). Ring nematode populations increased weakly in response to SH relative to SH+L or Conv. Although significant only for stubby-root nematodes, Fal plots showed population counts numerically as low or lower than all other treatments. Chemical N-rate from the previous year's corn produced no trends, nor did any interaction exist between N-rate and GM type (Table 6.2).

June 2003

All plots were sampled at the end of corn growth. Soil counts for root-knot, lesion and ring nematodes showed populations higher than those seen at any other time (Table

6.2). However, none of these nematodes showed clear responses to GM or chemical N-rate. Complete fallow plots showed nematode levels lower ($p \leq 0.05$) than all GM or Conv groups for lesion and root-knot, but significant against SH only for ring. Root-knot nematodes remained the dominant plant parasite present with average counts typically > 100 individuals 100 cm^{-3}. Treatment averages for lesion and ring generally remained between 35-100 individuals 100 cm^{-3}, with treatment averages for stubby-root nematodes around 5-15 individuals 100 cm^{-3} (Table 6.2).

Weeds

Sunn hemp, October 2001

At the end of the 2001 growing season, weed dry weight under sunn hemp totaled 2.60 ± 0.17 Mt ha^{-1}, a reduction of 38% compared to 4.19 ± 0.18 Mt ha^{-1} weed dry weight in plots without sunn hemp (Figure 6.1A). Although relatively low, weed plant N concentration was significantly higher (by 42%) under sunn hemp compared to fallow (0.48% ± 0.01% and 0.34% ± 0.11% for sunn hemp and fallow plot weeds, respectively; Figure 6.1B). As a result, no significant difference existed for weed N content under either sunn hemp (12.4 ± 0.8 kg N ha^{-1}) or in fallow plots (14.2 ± 0.9 kg N ha^{-1}) at this time. Although not quantified in any way, crow's foot grass (*Dactyloctenium* sp.) was the dominant weed, with other grasses such as *Digitaria* sp., and non-leguminous dicots such as Florida pusley (*Richardia scabra*) and purslane (*Portulaca* sp.), making moderate contributions. Legumes such as alyce clover (*Alysicarpus vaginalis*), hairy indigo (*Indigofera hirsuta*), and volunteer peanuts (*Arachis glabrata*) contributed a small amount of weed biomass.

Sunn hemp, October 2002

Weed dry weight under sunn hemp (SH and SH+L treatments) at the end of the 2002 growing season totaled only 0.76 ± 0.11 Mt ha^{-1}, amounting to 21.5% of the 3.52 ± 0.17 Mt ha^{-1} found in plots without sunn hemp (Conv and L treatments; Figure 6.1C). Weed dry weight in 2002 was 29% and 84% of 2001 values in SH and non-SH plots, respectively. Lower weed biomass may have been due in part to reduced tillage, possibly reducing germination of weed seeds through decreased soil disturbance and increased light absorption by the litter layer. Anecdotally, crow's foot grass became much less prevalent while pusley and other non-leguminous dicots made up a majority or near-majority of weed biomass. Alyce clover and hairy indigo again made small contributions. Reduced biomass may have also been due to a change in weed species composition (though this may have been related to reduced-tillage).

Weed N concentration was again significantly greater under sunn hemp, this time by 114% (1.46% ± 0.06% versus 0.68% ± 0.02% for weeds in sunn hemp and fallow plots, respectively; Figure 6.1D). Compared to 2001, weed N concentration was 2-3 times as high, possibly as a result of the shift in weed species composition from grass to non-leguminous dicots and/or from greater available N derived from decomposing residues. Also unlike 2001, weed N content under sunn hemp (10.3 ± 1.3 kg N ha^{-1}) was significantly less than in fallow plots (24.3 ± 1.6 kg N ha^{-1}). Competition for N from sunn hemp may have produced more effect in 2002 because sunn hemp was 50% larger than in 2001. Weed N content for SH plots in 2002 was 27% lower compared to 2001, but was 71% greater in non-SH plots during 2002 compared to 2001.

Vetch, April 2003

Greatest weed dry weight occurred for SH (1.81 ± 0.11 Mt ha^{-1}) , lowest weed dry weight for L (0.66 ± 0.05 Mt ha^{-1}), and mid-level weed dry weights for Conv (0.97 ± 0.07 Mt ha^{-1}) and SH+L (1.04 ± 0.13 Mt ha^{-1}; Figure 6.1C). Similar grouping occurred for weed N content, except that Conv was not significantly different from L. Nitrogen content in weeds was quite low, ranging from 2.2 to 8.1 kg N ha^{-1} depending on treatment. Nitrogen concentrations were unaffected by GM and ranged from 0.37% to 0.46%. Both Chemical N-rate and N-rate/GM interaction were again insignificant for weed dry weight, N concentration, and N content. Weeds consisted almost entirely of small non-leguminous dicots including *Richardia spp*., *Gnaphalium pennsylvanicum*, *Lepidium* spp., and *Geranium* spp.

Discussion

Although patterns in nematode population may require some time to equilibrate to new conditions, data from the first two years of the study already indicate changes based on cropping system and GM presence. Root-knot, lesion, stubby-root, and ring nematode all showed greatest increase following corn with strongest responses coming from root-knot and lesion. Populations of these pest nematodes also appeared to climb over time in all treatments with sweet corn compared to complete fallow, with root-knot nematode maintaining highest population counts (over 100 individuals 100cm^{-3} by the end of the sample period; Tables 6.1 and 6.2). Many investigators have demonstrated host status of corn to these parasitic nematodes (Al-Rehiayani and Hafez 1998, Sipes and Arakaki 1997).

In the first year of the study, lesion nematode populations showed a significant increase under lupin from March to April (2002) coinciding with warming weather and

longer availability of increased lupin biomass (Table 6.1). However, by the end of the subsequent corn crop (July 2002), lesion nematode population counts were significantly lower in all plots previously planted with GMs (including lupin) compared to Conv treatments. Root-knot nematode counts were numerically higher for corn following L and lower following SH (Table 6.2). Reduction of parasitic nematodes due to specific non-host or suppressive interaction, especially with sunn hemp, may therefore have occurred in some instances. Sunn hemp has demonstrated allelopathic and antagonistic effects on root-knot and reniform nematodes under greenhouse conditions (Wang et al. 2001, 2003), and non-host or poor-host status of sunn hemp with respect to root-knot nematode is well documented by previous studies (McSorley 1999, Sipes and Arakaki 1997, Al-Rehiayani and Hafez 1998).

In March 2003 (prior to sweet corn planting), stubby-root nematodes showed a significant increase following vetch and decrease following sunn hemp, but by the end of the 2003 corn crop no clear trends existed based on GM level or chemical N-rate. It is possible that stubby-root may have demonstrated a slight increase with increased chemical N-rate, and that ring nematodes may have increased following sunn hemp, but the low populations and count variability prevent any firm conclusion without further data. Over time, the favorable host status of corn to many of the nematodes present affected their population dynamics more than GM crops. The increase of parasitic nematodes under corn may have possibly masked repressive effects from GMs. Trends based on GMs may therefore become more detectable as nematode populations increase toward their potential over time and become more spatially uniform within plots, but these trends may remain short-lived if preferred hosts such as corn continue to be used.

Given an initial plow-down or herbicide kill of weeds, sunn hemp showed excellent potential for reducing weed growth. Greatest reduction was seen in 2003 when a 14 week growth season and maximum sunn hemp leaf area index approaching around 6 m^2 leaf m^{-2} ground limited weed production to less than 1 Mt ha^{-1}, a 78.5% reduction compared to plots without sunn hemp (Figure 6.1B). Data from an ongoing study at the same research facility suggests close to 100% reduction of weeds when between row spacing was decreased from 75 cm to 30 cm (Linares and Scholberg, unpublished). However, after death, sunn hemp residue significantly increased winter weed biomass (Figure 6.1C), likely because the unmowed stems settled down linearly along the rows (rather than spreading in random directions) leaving much exposed ground while residue released large amounts of N (Chapter 3). Broadcast planting and/or mowing may help spread residue more uniformly. On the other hand, a more vigorous stand of winter GMs or economic crops planted directly into living sunn hemp or immediately after death may provide highly effective weed control after sunn hemp no matter the residue management. Even relatively poor stands of vetch provided significant weed suppression (Figure 6.1C), and continuation of this project using a multi-species mixture as a winter GM appeared to be much more successful in providing uniform winter coverage and weed suppression (Avila and Scholberg, unpublished).

Initial changes in both weed biomass and N over time appeared to reflect simultaneous changes in weed species composition. Grass species heavily dominated weeds in 2002 following a clean-plow of the field, but after a few growing seasons under reduced and zero-tillage, weed species shifted to non-leguminous dicots in 2003. These changes may help explain reduced weed biomass and increased weed N concentration

from the first (October 2001) to the second sampling (October 2002; Figure 6.1A,B). Reduced tillage may have acted to suppress or change patterns of weed seed germination through lower disturbance of the soil seed bank and lower light penetration through the increasing litter layer. Sunn hemp in 2002 (which was 50% larger than in 2001) appeared to exert a greater competitive effect for N than in 2001, significantly reducing weed N content relative to plots without sunn hemp. Decomposing residue in our reduced tillage system may also have made greater contributions to weed N content in plots not planted to sunn hemp. Short-term changes in weed species composition, biomass and N content may therefore reflect aspects of the system related to reduced tillage, biomass additions, and competitive effects of GMs.

As shown in Figure 6.1D, weeds under sunn hemp in both years showed significantly higher N concentration than in conventional (non-GM) plots, especially after a full year of reduced tillage. Evidence from other studies shows non-legumes growing in shaded environments tend to have higher N concentration than when grown in full sun (for example, Senanayake 1995 and Wilson 1996). An interesting possibility deserving more study would be to combine sunn hemp with a low growing, less massive non-legume for more complete weed suppression. Should a farmer not desire or be able to narrow sunn hemp row spacing, or should sunn hemp suffer from pest, disease, or other environmental stress, such a mixture might offer some buffering ability for weed control. Preliminary results from further studies related to this project shows mixtures of two or more winter GMs provided far more uniform coverage and weed control than winter legume monocrops used previously (Avila and Scholberg, unpublished). Additionally, residue from a low growing “carpeting” GM may complement sunn hemp

by suppressing weeds in open spaces otherwise left empty between sunn hemp stem residue. Such voids created major opportunity for weeds after sunn hemp death during the course of the study.

Conclusions

During the two years of this study, cropping system and GMs significantly affected parasitic nematode populations as well as weed production and N characteristics. Root-knot, lesion, stubby-root, and ring nematodes all showed greatest increases following corn. Sunn hemp or its residues periodically exhibited suppressive effects on root-knot and stubby-root nematodes, while lupin and vetch showed mixed impacts on lesion and stubby-root nematodes. Sunn hemp and vetch significantly reduced weed biomass production at the end of their respective growing seasons. However, data and anecdotal evidence suggest that changes in management may improve weed control, especially during winter and early spring.

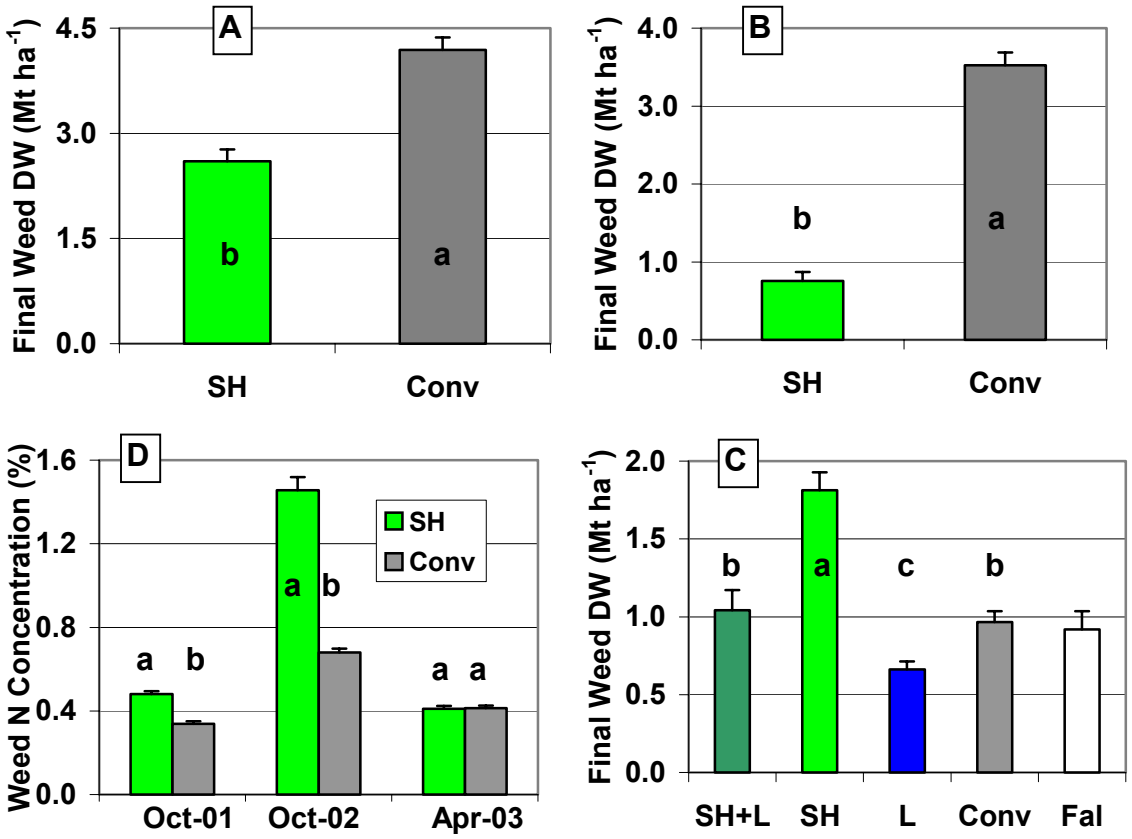

Figure 6.1. Final weed dry weights and N concentrations. (A) Final weed dry weight after sunn hemp in October 2001 and (B) in October 2002; (C) final weed dry weight after vetch in April 2003; (D) final weed N concentration (%) after sunn hemp (October 2001 and 2002) and vetch (April 2003). Error bars reflect standard errors; columns within GM levels (A, B and C) or sample dates (D) with identical lower case letters not significantly different to the $\alpha = 0.05$ level according to Duncan's Multiple Range Test.

Table 6.1. Nematode soil population counts (individuals 100 cm^{-3}) from selected treatments at selected dates.

	Root-Knot	Lesion	Stubby-Root	Ring
Oct. 2001			X	X
Conv	<1	3	1 a	19 b
SH	<1	<1	<1 b	42 a
Mar. 2002				
Conv	<1	<1	3	7
L	2	<1	3	11
Apr. 2002	*			
Conv	5	<1	<1	2
L	199	2	3	1

SH = sunn hemp; L = winter legume; Conv = conventional (no green manure)
X, * = Significantly different from Conv at $p \leq 0.10$ and 0.05 levels, respectively.

Table 6.2. Nematode soil population counts (individuals $100cm^{-3}$) at selected dates.

	Root-Knot			Lesion			Stubby-Root			Ring		
	Jul. 02	Mar. 03	Jun. 03	Jul. 02	Mar. 03	Jun. 03	Jul. 02	Mar. 03	Jun. 03	Jul. 02	Mar. 03	Jun. 03
GM	NS	NS	NS	*	NS	NS	NS	**	NS	NS	NS	NS
SH+L	57	21	85	6 b†	4	88 †	6	11 b†	11	2	9 b	35
SH	32	23	112 †	5 b	7	82 †	1	1 c	8	16	24 a	119 †
L	90 †	29	89 †	12 b†	2	59 †	7	42 a†	11	16	16 ab	41
Conv	95 †	28	129 †	29 a†	1	45 †	9	1 c	6	19	8 b	71
Fallow	5	15	56	2	1	1	3	1	4	10	16	12
N-Rate	NS	NS	NS	NS	NS	NS	**	NS	NS	NS	NS	NS
0N	154	27	136	30	2	44	4 cb	1	4 b	19	7	57
67N	82	31	125	11	<1	55	2 c	1	4 ab	13	10	87
133N	95	25	126	29	1	35	9 ab	1	11 ab	19	8	69
200N	98	14	178	30	1	38	11 a	<1	9 ab	2	9	22
267N	47	29	183	15	1	91	5 ab	1	12 a	11	8	18

SH = sunn hemp; L = winter legume; Conv = conventional (no green manure); N = kg NH_4NO_3-N ha^{-1}; NS means not significantly different at $p \leq 0.05$ level; *,**,*** means significantly different at $p \leq 0.05$, 0.01, and 0.001 level, respectively; † mean significantly different than Fallow at $p \leq 0.05$ level; means in vertical columns for GM or N-rate followed by the same letter do not differ at $p \leq 0.05$ according to Duncan's Multiple Range Test.

CHAPTER 7
CONCLUSIONS

Review and Synthesis of Findings

Green manure (GM) approaches are inherently dynamic and system oriented. Unlike chemical inputs, GMs are biological organisms both affecting and affected by the cropping system. The breadth of useful GM species, growing environments and management strategies summarized in Table 1.1 highlights the complexity of options for such approaches to crop production. Yet proper assessment of GM techniques requires an even greater understanding of the site-specific relationships between the life-cycles of the plant species used (both GMs and economic crops), the production environment (climate, weather, soil, and pests), and management options (for example: type, patterns, and timing of tillage, planting, irrigation, and fertility and pest control inputs, as well as production goals). Although such detailed information often remains lacking, the whole-systems nature of GMs presents opportunity to develop integrated approaches to nutrient supply, soil properties, and pest management using on-farm, biologically-based resources.

This study focused on a GM approach to a particularly challenging production system and environment: a spring planted, high-N demanding vegetable crop (sweet corn; *Zea mays* var Rugosa) in north Florida (see Chapter 1 for discussion). The overall project, funded by the USDA-SARE (grant number LS02-140, "A System Approach for Improved Integration of Green Manure in Commercial Vegetable Production Systems")

and involving collaborative studies in south Georgia and south Florida production environments, is envisioned to continue for another 2-3 years depending on external funding. Results of this study and preliminary data from the parallel studies (Phatak et al. unpublished, Roe et al. unpublished) reinforce the patterns seen in the scientific literature: that GM management often falls into three major categories based on regions of climate and soil. Especially in the southeast US, these three management zones are: (1) temperate regions with freezing winters but also fine-textured soil and cool, predictable climate; (2) tropical regions sometimes having coarse-textured soil but remaining free from winter freezes; and (3) transitional zones with coarse-textured soil, freezing winter temperatures, and variable climate.

In the first (temperate) region, soil organic matter (SOM) may be more readily increased, allowing greater storage potential for nitrogen (N) derived from decomposing residues (see Chapter 5 for review). Additionally, cool-weather legumes of temperate origin appear better adapted to the climate and soil of this region. In the second (tropical) region, vigorous tropical legumes and the crops that follow them are never limited by freezing temperatures. Living plants can therefore store N year-round, and the low potential SOM of these regions can be countered if crops and GMs are rotated quickly or intercropped so as to prevent N leaching loss (see Chapters 1 and 2 for reviews). The third (transitional) region, however, has none of the advantages of the other two. Here, coarse soils and hot, humid climate limit – or at least slow – potential SOM accumulation (Chapter 5); freezing winter temperatures interrupt use of tropical legume GMs for spring crop production; and temperate legumes appear poorly adapted to the variable climate, sandy soils, and pests of the region, especially when grown as a monocrop (Chapter 2).

Green manure management options from temperate and tropical regions, which can be relatively straightforward, may therefore be inappropriate for transitional regions.

Our experience indicates leguminous GMs decompose very rapidly on warm, humid, sandy soils in north Florida, with greatest GM N-loss occurring too quickly (within 2-4 weeks) to match peak N demand from a subsequent crop. Production of large amounts of recalcitrant stem biomass did not result in net N-immobilization during leguminous GM decomposition, likely because the residue was not homogenized (Chapter 2). We also found that the microbial mode of decomposition is not associated with biomass C increases, and thus may not be as N-limited, as in other environments (Chapter 5). This indicates potential microbial N-immobilization via increased C and/or lignin inputs may not be as much as found elsewhere. Nitrogen immobilization demonstrated by roots remained relatively small and unimportant due to low root biomass of our selected GMs. On the other hand, most winter-hardy GM monocrops in north Florida appear incapable of accumulating enough N to satisfy the requirements of many spring crops (Chapters 1, 2 and 3).

Our results suggest producers and researchers in our region should consider several GM alternatives including: changes in rotation order (planting a fall/winter economic crop immediately after sunn hemp or moving sunn hemp to the spring prior to a subsequent summer economic crop); changes in planting method and GM termination (direct planting into living sunn hemp, using vehicle action to break stems and open the canopy); changes in GM residue management (homogenization of residue through mowing, or use of warm season legumes for which pods can be harvested to remove potentially labile N and deliver economic benefit); changes in GM species choice

including those with greater below ground production (to increase N-immobilization); and/or use of winter GM mixtures of legumes, small grains, cool-season grasses and non-leguminous dicots (instead of monocrops).

Nevertheless, we sometimes found that tissue growth, N content, and leaf indicators for sweet corn amended with combined chemical N and GM residue remained comparable to chemically fertilized, high-N corn – but with reduced final ear yield at season's end – even though the combined GM/chemical approach applied 90-110 kg N ha^{-1} less than the high-N chemical approach (Chapter 3). The competitiveness of the GM/chemical approach despite lower applied N, and the relative decline in ear yields for these treatments compared to high-N chemical treatments, appears partly explained by patterns of root growth (Chapter 4). Amendment with GMs in a no-till system and band application of chemical N to the in-row area apparently encouraged root proliferation close to the soil surface and near the plant by creating an environment of greater water (and probably N) availability during the first half of the season. However, increased root growth in this area may have increased vulnerability to water stress in the second half of the season. Because total applied N was much lower for GM approaches relative to the high-N chemical only approach, increased root growth in the upper soil area may also have brought on N-depletion for GM treatments toward the end of the season. Because it exhibits such low organic matter and nutrient retention, our sandy soil may have further encouraged these rooting patterns and further exacerbated water and N-stress than would have fine-textured soils more often found elsewhere.

Near season's end, root length density far from the plant was significantly greater for high-N chemically fertilized corn compared to the combined GM/chemical approach.

Other studies (Coelho and Or 1999) show these "far" roots may contribute significantly to water uptake and N-uptake, offering some explanation for differences in late-season ear-fill. Roots from high-N chemically fertilized corn may have also been more likely to grow further from the plant during late season if some significant amount of the "extra" 90-110 kg N ha^{-1} still remained in between-row areas and at lower soil depths (30-60 cm). Estimates of effective rooting depth (40-60 cm) suggest such N would have been available (Chapter 4).

Because such late-season changes leave producers without adequate time to detect need for and implement adjustments, management of GM approaches in the Florida environment must be "preventative" rather than "therapeutic." Greatest predictive power for end-season yields came from N-content of GM residues and chemical N applied to corn. Afterwards, statistical analysis of plant growth characteristics at early to mid-season could only distinguish gross disparity in yield potential despite significant final yield differences among treatments with closer N application rates.

Soil incorporation of GM residue to help encourage deeper root growth under these circumstances would be favorable if subsequent nutrient loss from decomposition did not negate the benefits. However, in warm humid areas with coarse textured soil, reduced tillage is often desired to slow organic matter decomposition and nutrient loss and improve low soil water retention. In such reduced tillage systems, improved use of GMs may necessitate different irrigation management, including drip lines buried below surface residue to increase infiltration. Use of GMs or GM mixtures with more substantial below ground production may be an even less expensive and laborious way to create a better rooting environment at deeper depths. Early season deficit irrigation to

encourage root exploration or use of varieties of economic crops with deeper root systems may help, but providing GMs with N-content closer to the optimal rate applied with chemical fertilizer must remain a priority. Given our particular management strategies, the GM species chosen, and the environment, we found a GM benefit of roughly 50-70 kg N ha^{-1} in terms of final sweet corn ear yields (Chapter 3). Corn amended with GMs remained more competitive with conventionally fertilized corn during a year with lower plant population (2002). Organic approaches to crop production relying heavily on GM N may be less risky with lower crop plant populations and with crops having lower N demand and price premiums not requiring large fruit size.

Besides the short-term consequences on crop growth, we found our GM approaches also affected soil and pest properties, possibly with long-term implications for the efficacy of the system within the context of the north Florida "transition zone." Sweet corn cropping systems with combined use of sunn hemp and winter legume or sunn hemp alone contributed roughly 20 Mt dry matter ha^{-1} annually to the field. These GM approaches significantly increased pools of the soil C and N that we would consider most indicative of recent changes in soil organic matter inputs – even on very sandy (95-97%) soil under reduced tillage and after only 2 years. Although best resolved when evaluating the entire 0-15 cm soil layer, changes probably occurred mostly in the upper 7.5 cm of soil.

Analysis also revealed a decline in total soil C (TC) for all treatments over time, possibly reflecting historical conversion from pasture to row-crop system. Depending on the size of future organic matter transfers into the soil fractions, we predict trends in total soil C may diverge, with integrated GM/chemical approaches possibly slowing or

reversing TC loss and conventional chemical approaches possibly speeding it. Size of future soil transfers will determine whether any differences from GMs result in practical changes of soil organic matter (on the order of 1% or more). Such a result would probably be unprecedented in agronomic research in sandy Florida soils, and might also affect future root growth, N and water uptake potential and yield patterns of sweet corn (or other crops) as investigated in Chapters 3 and 4. Notwithstanding, these results show short-term boosts in soil organic matter on the order of 1% are unlikely in our production environment without even higher additions of organic amendments. Immediate goals of GM management techniques in the Florida environment should instead focus on delivering adequate N to economic crops.

Cropping approaches that ill-suit pest pressures face little hope for farmer adoption. On the other hand, low-cost, on-farm based approaches delivering multiple benefits of nutrient supply, increased yields and enhancement of agricultural soil properties as well as partial pest control may be economically desirable or even necessary. Even during the first two years of this study, cropping system and GMs significantly affected parasitic nematode populations as well as weed production and N characteristics (Chapter 6). Root-knot, lesion, stubby-root, and ring nematode all showed greatest increase following corn with strongest responses coming from root-knot and lesion. Populations of these pest nematodes also appeared to climb over time in all treatments with sweet corn compared to complete fallow, with root-knot nematode maintaining highest population counts. Sunn hemp or its residues periodically exhibited suppressive effects on root-knot and stubby-root nematodes, while lupin and vetch appeared to be hosts for lesion and stubby-root nematodes, respectively. However, in one of two years, soil under corn

following any GM showed lower populations of all monitored nematodes, with significant reduction for lesion nematode despite possible host status of lupin. This suggests indirect effects, such as increased biological activity following GM additions, may also have played a role. The increase of parasitic nematodes under corn may have masked further repressive effects from GMs. Trends based on GMs may therefore become more detectable as nematode populations increase toward their potential over time and become more spatially uniform within plots.

Sunn hemp and vetch significantly reduced weed biomass production at the end of their respective growing seasons. However, data and anecdotal evidence suggest that changes in management may further improve weed control, especially during winter and early spring. Broadcast planting and narrower row spacing, as well as GM mixtures (of sunn hemp with a carpeting legume or non-leguminous dicot during summer and of legumes, grasses, small grains, and/or non-leguminous dicots during winter), show promise and should be further investigated. Short-term changes in weed species composition from grasses to non-leguminous dicots, reduced biomass and increased N concentration may also reflect aspects of the system related to reduced tillage and biomass additions. Future changes in these factors could possibly serve as indicators for developmental changes in GM and conventional approaches.

Future Work

As mentioned earlier, potential usefulness and adoption of GM approaches to cropping systems probably depend on reducing need for supplementary inputs for nutrient supply and pest (weed, herbivore/parasite, and disease) control, concomitant with an overall reduction in operation costs. True “whole-systems” economic evaluation of GM approaches should therefore include as many aspects as possible of real production.

Having gained more understanding of GM management in our region, future projects should probably conduct medium to long-term input and economic evaluation of well planned GM cropping systems on field scale (rather than smaller plot scale) in research and eventually on-farm. This approach, similar to that of Phatak et al. (1999), would allow for more accurate assessment of pest pressures operating on larger scales as well as better evaluation of management needs representative of actual farmers.

APPENDIX A
CHARACTERIZATION OF DOMINANT SOIL TYPES PRESENT IN FIELD

Characterization data from representative soils provided by Carlisle et al. (1988).

Table A.1. Selected characteristics from a Lake Fine Sand; Typic Quarzipsamments, hyperthermic, coated; Citrus County, FL.

Depth	Horizon	Sand	Silt	Clay	Organic C	pH	Base Sat
cm		% of all particles ≤ 2 mm			%	1:1 H_2O	%
0-18	Ap	97.0	0.6	2.4	0.84	4.6	3
18-68	C1	96.3	1.4	2.3	0.25	4.3	2
68-102	C2	96.5	1.0	2.5	0.14	4.3	3
102-142	C3	96.4	0.9	2.7	0.06	4.7	5
142-203	C3	96.4	0.7	2.9	0.05	4.7	4

C = carbon; 1:1 H_2O = equal weights soil and water; Base Sat = base saturation.

Table A.1. Continued.

Depth	CEC	Sat Hydr Cond	H_2O Cont (% by weight)			Bulk Density
cm	meq $100g^{-1}$	cm hr^{-1}	1/10 Bar	1/3 Bar	15 Bar	g cm^{-3}
0-18	7.96	16.4	8.0	5.3	2.3	1.50
18-68	3.91	17.4	6.0	3.8	1.5	1.54
68-102	3.52	26.6	5.5	3.1	1.6	1.47
102-142	2.91	25.9	5.2	3.0	1.3	1.53
142-203	2.79	26.3	5.3	2.9	1.3	1.52

CEC = cation exchange capacity; Sat Hydr Cond = saturated hydraulic conductivity; H_2O Cont = water content at specified tension.

Table A.2. Selected characteristics from a Candler Fine Sand; Typic Quarzipsamments, hyperthermic, uncoated; Alachua County, FL.

Depth	Horizon	Sand	Silt	Clay	Organic C	pH	Base Sat
cm		% of all particles ≤ 2mm			%	1:1 H_2O	%
0-15	Ap	98.3	0.3	1.4	0.48	5.5	17
15-41	E1	98.2	0.8	1.0	0.18	5.3	7
41-71	E2	98.4	0.6	1.0	0.09	5.1	8
71-145	E3	98.1	0.5	1.4	0.05	5.2	5
145-178	E4	98.5	0.3	1.2	0.03	5.3	3
178-208	E/B	98.9	0.1	1.0	0.01	5.2	13

C = carbon; 1:1 H_2O = equal weights soil and water; Base Sat = base saturation.

Table A.2. Continued.

Depth	CEC	Sat Hydr Cond	H_2O Cont (% by weight)			Bulk Density
cm	meq $100g^{-1}$	cm hr^{-1}	1/10 Bar	1/3 Bar	15 Bar	g cm^{-3}
0-15	2.52	26.0	7.1	5.1	1.2	1.49
15-41	1.96	33.2	4.8	3.2	0.7	1.53
41-71	1.06	37.8	4.3	3.0	0.6	1.52
71-145	0.55	37.1	4.1	2.7	0.6	1.49
145-178	0.68	37.4	4.6	3.0	0.6	1.50
178-208	0.38	33.5	4.5	3.0	0.4	1.49

CEC = cation exchange capacity; Sat Hydr Cond = saturated hydraulic conductivity; H_2O Cont = water content at specified tension.

APPENDIX B
CONTINUOUS MEASUREMENTS

Table B.1. Continuously measured environmental factors.

	Radiation* w m^{-2}	Tmax C	Tmin C	Rainfall* cm	Irrigation cm	RH %
SH 2001	178	35.5	11.9	23	NA	77.3
L 2001-02	143	30.9	0.3	20	NA	74.7
Corn 2002	217	35.4	19.2	14	NA	68.8
SH 2002	176	35.3	20.4	33	NA	79.0
L 2002-03	137	24.0	6.0	57	NA	59.0

SH = sunn hemp; L = winter legume; T_{max} = average maximum daily temperature; T_{min} = average daily minimum temperature; RH = average relative humidity; * radiation and rainfall data provided by Florida Automated Weather Network (2004); NA = not available.

APPENDIX C
SELECTED TISSUE FACTORS AND LEAF INDICATORS FOR SWEET CORN, 2002 AND 2003

Table C.1. Corn applied nitrogen, unaccounted for applied nitrogen and chlorophyll meter readings by green manure and nitrogen rate, sweet corn, 2002.

	NUE	Corn Applied N†	UAN	Total UAN	Chlorophyll meter readings				
	kg kg^{-1}	kg N ha^{-1}	kg N ha^{-1}	kg N ha^{-1}	2WAE	4WAE	6WAE	8WAE	9WAE
GM x N-Rate	NS	NS	NS	NS	NS	NS	NS	NS	NS
GM	*	***	***	***	NS	NS	NS	NS	NS
SH+L	0.32 ab	123 a	75 a	152 a	39.0	38.7	42.6	44.7	44.4 a
SH	0.37 a	78 b	35 b	121 b	39.7	38.4	45.5	43.6	40.6 ab
L	0.22 b	124 a	83 a	100 c	37.4	38.7	42.4	45.2	40.3 ab
Conv	0.37 a	67 c	27 b	50 d	37.5	38.1	44.2	45.4	37.5 b
N-Rate	NS	***	***	***	**	***	***	***	***
0N	-	29 c	12 c	61 c	34.2 c	30.8 b	33.4 b	33.7 b	32.4 c
67N	0.34	97 b	50 b	101 b	38.7 b	41.3 a	47.4 a	48.4 a	40.8 b
133N	0.30	168 a	103 a	154 a	42.4 a	43.3 a	50.7 a	52.0 a	48.9 a

GM: green manure. N-rate: chemical nitrogen rate (kg N ha^{-1}). NUE: nitrogen uptake efficiency (calculated without 0N treatments). UAN: Unaccounted for applied nitrogen. Total UAN includes N content of sunn hemp and weeds prior to winter decomposition. WAE: weeks after emergence. † Corn Applied N includes contributions from GMs and chemical N. NS: means within columns not significantly different to the 0.05 level. *, **, ***: means within columns significantly different to the 0.05, 0.001, and 0.0001 level, respectively. Letters reflect vertical Duncan's MRT comparisons at the 0.05 level.

Table C.2. Specific leaf area and specific leaf nitrogen by green manure and nitrogen rate, sweet corn, 2002.

	Specific Leaf Area ($cm^2\ g^{-1}$)					Specific Leaf N ($\mu g\ N\ cm^{-2}$)				
	2WAE	4WAE	6WAE	8WAE	9WAE	2WAE	4WAE	6WAE	8WAE	9WAE
GM x N-Rate	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
GM	NS	NS	NS	NS	NS	NS	NS	*	NS	NS
SH+L	371	257	208	182	160	45.3	47.3	55.3 ab	55.5	52.3
SH	372	257	216	183	163	44.8	45.4	46.2 b	50.4	55.1
L	379	243	223	193	166	43.1	51.6	68.4 a	53.6	52.6
Conv	379	247	214	190	163	41.3	51.2	46.2 b	52.3	50.6
N-Rate	**	*	*	NS	*	***	***	***	***	***
0N	388 a	263 a	241 a	195 a	170 a	39.2 b	35.8 b	35.5 b	42.7 b	42.8 c
67N	375 b	250 ab	202 b	182 b	163 ab	42.7 b	53.4 a	58.2 a	53.5 a	51.4 b
133N	362 c	240 b	203 b	184 b	156 b	49.1 a	57.3 a	68.3 a	62.6 a	63.8 a

WAE: weeks after emergence. NS: means within columns not significantly different to the 0.05 level. *, **, ***: means within columns significantly different to the 0.05, 0.001, and 0.0001 level, respectively. Letters reflect vertical Duncan's Multiple Range Test comparisons at the 0.05 level.

Table C.3. Stem dry weight and nitrogen content by green manure and nitrogen rate, sweet corn, 2002.

	Stem Dry Weight ($kg\ ha^{-1}$)					Stem N Content ($kg\ ha^{-1}$)				
	2WAE	4WAE	6WAE	8WAE	9WAE	2WAE	4WAE	6WAE	8WAE	9WAE
GM x N-Rate	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
GM	NS	*	NS	NS	NS	NS	*	NS	NS	*
SH+L	24 ab	255 a	2203 ab	2374 a	2101 a	0.5	5.9 a	24.1	12.8	11.5 a
SH	28 a	260 a	2265 ab	2279 ab	1990 ab	0.6	5.9 a	21.6	11.2	9.5 a
L	25 ab	216 ab	2244 a	2168 ab	1769 ab	0.5	5.1 ab	24.4	10.2	8.8 a
Conv	19 b	185 b	1976 b	1959 b	1983 b	0.4	4.2 b	21.7	10.3	8.8 b
N-Rate	***	***	***	***	***	***	***	***	***	***
0N	18 b	104 c	804 b	1272 b	1227 c	0.3 c	1.5 c	7.8 c	5.6 c	6.0 c
67N	25 a	257 b	2781 a	2495 a	2044 b	0.5 b	6.0 b	26.4 b	10.9 b	8.7 b
133N	30 a	326 a	2931 a	2819 a	2613 a	0.7 a	8.4 a	34.7 a	16.9 a	14.2 a

WAE: weeks after emergence. NS: means within columns not significantly different to the 0.05 level. *, **, ***: means within columns significantly different to the 0.05, 0.001, and 0.0001 level, respectively. Letters reflect vertical Duncan's Multiple Range Test comparisons at the 0.05 level.

Table C.4. Root dry weight and nitrogen content by green manure and nitrogen rate, sweet corn, 2002.

	Root Dry Weight (kg ha^{-1})					Root N Content (kg ha^{-1})				
	2WAE	4WAE	6WAE	8WAE	9WAE	2WAE	4WAE †	6WAE	8WAE	9WAE
GM x N-Rate	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
GM	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SH+L	16 a	78	348	390	347	0.2	0.9	2.2	1.7	1.3
SH	16 ab	92	344	402	355	0.2	1.0	2.1	1.2	1.2
L	15 ab	79	380	342	298	0.2	0.9	2.5	1.3	1.1
Conv	13 b	70	322	342	314	0.2	0.8	2.2	1.1	1.0
N-Rate	***	***	***	***	***	***	***	***	***	***
0N	11 b	38 b	139 b	174 c	178 c	0.1 c	0.3 c	0.8 c	0.7 c	0.7 c
67N	16 a	95 a	436 a	424 b	359 b	0.2 b	1.0 b	2.5 b	1.2 b	1.1 b
133N	17 a	106 a	470 a	509 a	449 a	0.2 a	1.3 a	3.4 a	2.0 a	1.6 a

WAE: weeks after emergence. NS: means within columns not significantly different to the 0.05 level. *, **, ***: means within columns significantly different to the 0.05, 0.001, and 0.0001 level, respectively. Letters reflect vertical Duncan's Multiple Range Test comparisons at the 0.05 level; † estimated.

Table C.5. Ear dry weight and nitrogen content by green manure and nitrogen rate, sweet corn, 2002.

	Ear Dry Weight (kg ha^{-1})					Ear N Content (kg ha^{-1})				
	2WAE	4WAE	6WAE	8WAE	9WAE	2WAE	4WAE	6WAE	8WAE	9WAE
GM x N-Rate	-	-	NS	NS	NS	-	-	NS	NS	NS
GM	-	-	NS	NS	**	-	-	NS	NS	*
SH+L	-	-	242 ab	1823	1978 a	-	-	4.6	22.2	21.1 a
SH	-	-	350 a	1805	1835 a	-	-	5.9	21.4	18.3 ab
L	-	-	279 ab	1636	1902 a	-	-	5.0	20.2	19.8 a
Conv	-	-	313 b	1597	1597 b	-	-	5.3	19.3	15.7 b
N-Rate	-	-	*	***	***	-	-	***	***	***
0N	-	-	0 b	482 c	437 c	-	-	0.0 c	6.0 c	4.6 c
67N	-	-	309 a	2110 b	2121 b	-	-	5.2 b	24.2 b	19.7 b
133N	-	-	579 a	2552 a	2926 a	-	-	10.3 a	32.1 a	31.9 a

WAE: weeks after emergence. NS: means within columns not significantly different to the 0.05 level. *, **, ***: means within columns significantly different to the 0.05, 0.001, and 0.0001 level, respectively. Letters reflect vertical Duncan's Multiple Range Test comparisons at the 0.05 level.

Table C.6. Stem and root nitrogen concentrations by green manure and nitrogen rate, sweet corn, 2002.

	Stem N Concentration (g kg^{-1})					Root N Concentration (g kg^{-1})				
	2WAE	4WAE	6WAE	8WAE	9WAE	2WAE	4WAE†	6WAE	8WAE	9WAE
GM x N-Rate	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
GM	NS	NS	NS	NS	*	NS	NS	NS	*	NS
SH+L	19.6	21.1	10.4 ab	5.1	5.4 a	10.3	10.3	6.1	4.2 a	3.8 a
SH	19.6	20.5	9.5 b	4.8	4.8 ab	9.9	9.9	6.0	3.2 b	3.6 ab
L	20.3	22.1	10.5 ab	4.7	5.0 ab	10.5	10.5	6.3	3.8 ab	3.7 ab
Conv	19.3	21.8	11.2 a	5.1	4.4 b	11.3	11.3	6.7	3.5 b	3.3 b
N-Rate	***	***	**	**	***	***	***	***	***	***
0N	16.5 b	14.3 c	9.9 b	4.5 b	4.9 b	8.2 c	8.2 c	5.6 b	4.2 a	4.2 a
67N	18.6 b	23.5 b	9.5 b	4.4 b	4.3 c	10.4 b	10.4 b	5.8 b	2.9 b	3.1 c
133N	24.0 a	26.4 a	11.8 a	5.9 a	5.5 a	12.8 a	12.8 a	7.3 a	4.0 a	3.6 b

WAE: weeks after emergence. NS: means within columns not significantly different to the 0.05 level. *, **, ***: means within columns significantly different to the 0.05, 0.001, and 0.0001 level, respectively. Letters reflect vertical Duncan's Multiple Range Test comparisons at the 0.05 level. † Estimated.

Table C.7. Ear and total nitrogen concentrations by green manure and nitrogen rate, sweet corn, 2002.

	Ear N Concentration (g kg^{-1})					Total N Concentration (g kg^{-1})				
	2WAE	4WAE	6WAE	8WAE	9WAE	2WAE	4WAE	6WAE	8WAE	9WAE
GM x N-Rate	-	-	-	NS	NS	NS	NS	NS	NS	NS
GM	-	-	-	NS	NS	NS	NS	NS	NS	*
SH+L	-	-	19.9	12.2	10.4	16.4	14.8	10.5 ab	7.9	7.4 a
SH	-	-	18.3	11.9	9.9	16.3	14.1	9.8 b	7.3	7.0 ab
L	-	-	18.0	12.8	10.6	16.4	15.3	10.6 ab	7.7	7.4 a
Conv	-	-	18.9	12.3	9.6	15.9	14.9	10.8 a	7.9	6.4 b
N-Rate	-	-	-	*	*	***	***	***	***	***
0N	-	-	-	12.8 a	10.3 ab	14.3 c	10.5 c	8.9 c	6.7 c	6.3 b
67N	-	-	17.9	11.4 b	9.3 b	15.7 b	15.9 b	10.1 b	7.5 b	6.7 b
133N	-	-	19.6	12.7 a	10.8 a	18.7 a	17.8 a	12.2 a	9.0 a	8.2 a

WAE: weeks after emergence. NS: means within columns not significantly different to the 0.05 level. *, **, ***: means within columns significantly different to the 0.05, 0.001, and 0.0001 level, respectively. Letters reflect vertical Duncan's Multiple Range Test comparisons at the 0.05 level.

Table C.8. Pairwise contrasts of chlorophyll meter readings and specific leaf area, sweet corn, 2002.

	Chlorophyll Meter Readings (unitless)					Specific Leaf Area ($cm^2\ g^{-1}$)				
	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE
Conv 200N	46.9	45.4	48.7	53.8	53.5	347	240	194	174	149
Conv 267N	42.3	47.8	54.4	53.1	56.1	369	238	192	177	158
SH+L 67N	36.6*	41.0*	47.5	50.3	44.7*†	374*	263	192	171	160
SH 67N	39.7*	41.6*	49.9	50.8	44.1*†	366	260	214	182	153
L 67N	36.5*	42.0*	46.7*	47.4	37.9*†	387*	246	203	189	175*
SH+L 133N	43.8	44.4	48.1	49.8	55.9	367	236	206	181	156
SH 133N	43.3	43.6	49.5	50.8	44.0*†	351	251	181	180	154
L 133N	42.5	42.3*	50.7	51.9	49.3†	362	236	224	195	159

*,† mean of GM treatment significantly different from mean of Conv 200N and Conv 267N, respectively, to the 0.05 level; WAE= weeks after emergence.

Table C.9. Pairwise contrasts of Stem Dry Weight and N Content, sweet corn, 2002.

	Stem Dry Weight ($kg\ ha^{-1}$)					Stem N Content ($kg\ ha^{-1}$)				
	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE
Conv 200N	30	342	3901	2936	2479	0.8	9.7	61.0	21.4†	19.2†
Conv 267N	27	396	2989	3556	2766	0.7	11.3	41.6	34.0*	25.2*
SH+L 67N	24	263†	2674	2898	2037*†	0.4*	6.1*†	26.9*	13.5*†	9.3*†
SH 67N	29	307	2979	2321†	2114††	0.6	6.7*†	22.9*	10.4*†	10.0*†
L 67N	21	234†	2663	2363†	1827*†	0.4*	5.9*†	25.2*	10.5*†	7.7*†
SH+L 133N	30	377	2886	3003	2705	0.7	9.7	36.4	19.6†	17.6†
SH 133N	38	360	3072	2878†	2514	0.9	9.5	34.8*	16.4†	12.1*†
L 133N	31	306	3183	2838†	2430	0.8	7.9†	39.3	14.2*†	13.0*†

*,† mean of GM treatment significantly different from mean of Conv 200N and Conv 267N, respectively, to the 0.05 level; WAE= weeks after emergence.

Table C.10. Pairwise contrasts of root dry weight and nitrogen content, sweet corn, 2002.

	Root Dry Weight (kg ha^{-1})					Root N Content (kg ha^{-1})				
	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE
Conv 200N	17	105	595	526	390	0.2	1.4†	5.6	2.8†	1.7†
Conv 267N	17	127	580	648	479	0.2	1.8*	5.0	4.2*	2.9*
SH+L 67N	17	84†	406*†	477†	340†	0.2	0.9*†	2.4*†	1.5*†	0.9*†
SH 67N	16	116	446*†	388†	428	0.2	1.3†	2.4*†	1.0*†	1.4†
L 67N	16	94	495	400†	334†	0.2	1.1	3.0*†	1.2*†	1.0*†
SH+L 133N	18	112	475*	522	475	0.2	1.5	3.3*†	2.6†	1.8†
SH 133N	18	122	457*†	613	464	0.2	1.5	3.0*†	1.9*†	1.4†
L 133N	17	99	498	465†	410	0.2	1.2†	3.8*†	2.1†	1.6†

*,† mean of GM treatment significantly different from mean of Conv 200N and Conv 267N, respectively, to the 0.05 level; WAE= weeks after emergence.

Table C.11. Pairwise contrasts of ear dry weight and nitrogen content, sweet corn, 2002.

	Ear Dry Weight (kg ha^{-1})					Ear N Content (kg ha^{-1})				
	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE
Conv 200N	-	-	140†	2959	3431†	-	-	12.5	39.2	36.8†
Conv 267N	-	-	889*	3218	3889*	-	-	16.5	43.2	45.2*
SH+L 67N	-	-	270†	2283†	2283*†	-	-	6.1†	27.2*†	21.9*†
SH 67N	-	-	224†	2224†	2219*†	-	-	7.7†	25.9*†	21.2*†
L 67N	-	-	263†	2093†	2111*†	-	-	5.4†	23.0*†	19.3*†
SH+L 133N	-	-	268†	2670	3185†	-	-	7.6†	33.3	36.6†
SH 133N	-	-	512†	2835	2891*†	-	-	10.1	34.0	29.7*†
L 133N	-	-	149†	2277†	2968*†	-	-	9.5	30.8†	32.9†

*,† mean of GM treatment significantly different from mean of Conv 200N and Conv 267N, respectively, to the 0.05 level; WAE= weeks after emergence.

Table C.12. Pairwise contrasts of stem and root nitrogen concentrations, sweet corn, 2002.

	Stem N Concentration (g N kg^{-1})					Root N Concentration (g N kg^{-1})				
	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE
Conv 200N	26.7	288	142	7.4†	7.7	13.3	NA	9.4	5.5	4.3†
Conv 267N	25.2	287	138	9.6*	9.1	14.4	NA	8.6	6.4	6.0*
SH+L 67N	18.0*†	23.5*†	10.0*†	4.7*†	4.6*†	10.4*†	NA	6.0*†	3.2*†	2.8*†
SH 67N	17.8*†	21.6*†	7.8*†	4.5*†	4.7*†	10.6*†	NA	5.4*†	2.6*†	3.4*†
L 67N	18.2*†	25.3	9.5*†	4.5*†	4.2*†	11.2†	NA	6.1*†	3.0*†	3.0*†
SH+L 133N	25.1	25.6	12.8	6.4†	6.6†	13.0	NA	7.2†	4.9†	3.9†
SH 133N	24.1	26.6	11.3*†	5.7†	4.9*†	12.2	NA	6.7*†	3.1*†	3.1*†
L 133N	24.9	26.5	11.7*	4.8*†	5.3*†	12.0	NA	7.6*†	4.4*†	4.0†

*,† mean of GM treatment significantly different from mean of Conv 200N and Conv 267N, respectively, to the 0.05 level; WAE= weeks after emergence.

Table C.13. Pairwise contrasts of ear and total nitrogen concentrations, sweet corn, 2002.

	Ear N Concentration (g N kg^{-1})					Total N Concentration (g N kg^{-1})				
	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE
Conv 200N	-	-	20.0	13.3	10.7	20.1	18.8	14.4	10.4	9.3†
Conv 267N	-	-	18.7	13.5	11.6	19.3	19.7	14.1	11.4	10.5*
SH+L 67N	-	-	19.4	11.9	9.6	15.4*†	16.2*†	10.7*†	8.0*†	7.0*†
SH 67N	-	-	16.4	11.6†	9.5	15.7*†	14.8*†	9.1*†	7.6*†	7.1*†
L 67N	-	-	18.1	11.1*†	9.1†	13.6*†	17.1†	10.3*†	7.6*†	6.7*†
SH+L 133N	-	-	20.3	12.4	11.5	19.1	17.6†	12.9	9.2†	9.0†
SH 133N	-	-	20.3	11.9	10.2	19.0	17.9	11.5*†	8.7*†	7.7*†
L 133N	-	-	17.9	13.7	11.0	19.0	17.7†	12.2*†	8.6*†	8.4†

*,† mean of GM treatment significantly different from mean of Conv 200N and Conv 267N, respectively, to the 0.05 level; WAE= weeks after emergence.

Table C.14. Corn applied nitrogen, unaccounted for applied nitrogen and chlorophyll meter readings by green manure and nitrogen rate, sweet corn, 2003.

	NUE	Corn Applied N	UAN	Total UAN	Chlorophyll meter readings				
	kg kg^{-1}	kg N ha^{-1}	kg N ha^{-1}	kg N ha^{-1}	2WAE	4WAE	6WAE	8WAE	9WAE
GM x N-Rate	NS	NS	NS	NS	NS	NS	NS	NS	NS
GM	NS	***	***	***	NS	NS	NS	*	NS
SH+L	0.22	118 a	92 a	212 a	37.8 ab	41.9	38.8 a	42.4 a	35.5 a
SH	0.22	97 b	72 b	195 a	39.8 a	41.0	35.8 ab	40.3 ab	32.6 ab
L	0.21	88 b	68 b	94 b	36.6 ab	41.3	35.9 ab	40.0 ab	30.3 b
Conv	0.18	71 c	51 c	73 c	34.9 b	41.9	32.0 b	37.2 b	32.9 ab
N-Rate	NS	***	***	***	***	***	***	***	***
0N	-	26 c	18 c	86 c	29.3 c	32.1 c	24.1 c	26.2 c	22.7 c
67N	0.22	91 b	66 b	142 b	38.4 b	44.1 b	38.5 b	41.1 b	33.2 b
133N	0.19	163 a	127 a	204 a	44.1 a	48.4 a	44.3 a	52.6 a	42.6 a

NUE: N use efficiency (calculated without 0N treatments). UAN: Unaccounted for applied N. Total UAN includes N content of sunn hemp and weeds prior to winter decomposition. WAE: weeks after emergence. † Corn Applied N includes contributions from GMs and chemical N (chemical N = 67 kg N ha^{-1}). NS: means within columns not significantly different to the 0.05 level. *, **, ***: means within columns significantly different to the 0.05, 0.001, and 0.0001 level, respectively. Letters reflect vertical Duncan's Multiple Range Test comparisons at the 0.05 level.

Table C.15. Specific leaf area and specific leaf nitrogen by green manure and nitrogen rate, sweet corn, 2003.

	Specific Leaf Area ($cm^2\ g^{-1}$)					Specific Leaf N ($\mu g\ N\ cm^{-2}$)				
	2WAE	4WAE	6WAE	8WAE	9WAE	2WAE	4WAE	6WAE	8WAE	9WAE
GM x N-Rate	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
GM	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SH+L	324	255	200	183	169 b	43.4	20.5	30.7 a	35.0	30.7
SH	311	240	211	184	181 a	46.9	24.2	28.5 ab	33.4	27.0
L	309	259	193	179	177 ab	45.1	22.4	29.5 a	33.3	26.5
Conv	349	245	208	185	177 ab	43.6	21.8	24.7 b	31.2	27.3
N-Rate	NS	NS	NS	NS	*	***	***	***	***	***
0N	358 a	248	212	185	180 a	35.4 c	14.7 b	18.0 c	20.2 c	22.1 c
67N	309 b	247	197	180	169 b	46.6 b	23.6 a	30.2 b	33.2 b	28.1 b
133N	303 b	254	200	183	180 a	52.3 a	28.3 a	36.8 a	46.4 a	33.4 a

WAE: weeks after emergence. NS: means within columns not significantly different to the 0.05 level. *, **, ***: means within columns significantly different to the 0.05, 0.001, and 0.0001 level, respectively. Letters reflect vertical Duncan's Multiple Range Test comparisons at the 0.05 level.

Table C.16. Stem dry weight and nitrogen content by green manure and nitrogen rate, sweet corn, 2003.

	Stem Dry Weight ($kg\ ha^{-1}$)					Stem N Content ($kg\ ha^{-1}$)				
	2WAE	4WAE	6WAE	8WAE	9WAE	2WAE	4WAE	6WAE	8WAE	9WAE
GM x N-Rate	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
GM	NS	*	NS	NS	*	NS	NS	*	NS	NS
SH+L	45	255 a	2937 a	3187 ab	3540 a	0.5	2.0 a	6.0 a	5.6 ab	3.7
SH	46	260 a	3038 a	3874 a	3572 a	0.6	1.9 ab	6.0 a	6.4 a	3.8
L	45	216 ab	2738 ab	3084 b	3521 a	0.5	1.5 ab	5.1 b	4.6 b	3.4
Conv	44	185 b	2414 b	2979 b	2912 b	0.5	1.4 b	4.6 b	4.4 b	3.2
N-Rate	***	***	***	***	***	***	***	***	***	***
0N	35 b	104 c	1365 c	1956 b	2238 b	0.3 c	0.5 c	2.5 c	2.9 b	2.2 c
67N	47 a	257 b	3230 b	4157 a	3981 a	0.5 b	1.8 b	5.6 b	6.4 a	3.6 b
133N	53 a	326 a	3751 a	3730 a	3940 a	0.7 a	2.8 a	8.3 a	6.5 a	4.7 a

WAE: weeks after emergence. NS: means within columns not significantly different to the 0.05 level. *, **, ***: means within columns significantly different to the 0.05, 0.001, and 0.0001 level, respectively. Letters reflect vertical Duncan's Multiple Range Test comparisons at the 0.05 level.

Table C.17. Root dry weight and nitrogen content by green manure and nitrogen rate, sweet corn, 2003.

	Root Dry Weight (kg ha^{-1})					Root N Content (kg ha^{-1})				
	2WAE	4WAE	6WAE	8WAE	9WAE	2WAE	4WAE	6WAE	8WAE	9WAE
GM x N-Rate	NS	NS	NS	NS		NS	NS	NS	NS	NS
GM	NS	NS	*	NS	*	NS	NS	*	*	*
SH+L	27	78	655 ab	640	755 a	0.2	0.4	1.6 a	1.3 ab	1.5 a
SH	29	92	643 ab	677	785 a	0.2	0.4	1.3 ab	1.2 a	1.2 b
L	30	79	760 a	591	627 b	0.2	0.3	1.5 a	1.0 b	1.2 b
Conv	25	70	501 b	577	596 b	0.2	0.3	1.0 b	1.1 b	1.0 b
N-Rate	***	***	***	***	***	**	***	***	***	***
0N	22 c	38 b	282 b	322 b	386 b	0.1 b	0.1 b	0.5 c	0.6 c	0.8 b
67N	29 b	95 a	767 a	793 a	823 a	0.2 a	0.4 a	1.5 b	1.3 b	1.3 a
133N	34 a	106 a	871 a	748 a	863 a	0.2 a	0.5 a	1.9 a	1.6 a	1.6 a

WAE: weeks after emergence. NS: means within columns not significantly different to the 0.05 level. *, **, ***: means within columns significantly different to the 0.05, 0.001, and 0.0001 level, respectively. Letters reflect vertical Duncan's Multiple Range Test comparisons at the 0.05 level.

Table C.18. Ear dry weight and nitrogen content by green manure and nitrogen rate, sweet corn, 2003.

	Ear Dry Weight (kg ha^{-1})					Ear N Content (kg ha^{-1})				
	2WAE	4WAE	6WAE	8WAE	9WAE	2WAE	4WAE	6WAE	8WAE	9WAE
GM x N-Rate	-	-	NS	NS	NS	-	-	NS	NS	NS
GM	-	-	NS	NS	*	-	-	NS	NS	NS
SH+L	-	-	244	1799	2564 a	-	-	2.5	11.3	16.0
SH	-	-	238	1371	2017 ab	-	-	2.6	9.5	12.8
L	-	-	352	1242	2037 ab	-	-	3.0	7.2	13.5
Conv	-	-	162	1281	1892 b	-	-	1.6	8.0	12.5
N-Rate	-	-	**	***	***	-	-	**	***	***
0N	-	-	11 b	192 c	347 c	-	-	0.1 b	1.2 c	2.3 c
67N	-	-	319 a	1575 b	1960 b	-	-	2.9 a	9.5 b	11.6 b
133N	-	-	417 a	2503 a	4075 a	-	-	4.2 a	16.2 a	27.3 a

WAE: weeks after emergence. NS: means within columns not significantly different to the 0.05 level. *, **, ***: means within columns significantly different to the 0.05, 0.001, and 0.0001 level, respectively. Letters reflect vertical Duncan's Multiple Range Test comparisons at the 0.05 level.

Table C.19. Stem and root nitrogen concentrations by green manure and nitrogen rate, sweet corn, 2003.

	Stem N Concentration (g kg^{-1})					Root N Concentration (g kg^{-1})				
	2WAE	4WAE	6WAE	8WAE	9WAE	2WAE	4WAE	6WAE	8WAE	9WAE
GM x N-Rate	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
GM	NS	NS	NS	NS	NS	NS	NS	*	NS	NS
SH+L	10.9	7.1	2.0	1.6	1.0	6.2	4.3	2.4 a	2.1	2.1
SH	12.0	6.7	2.0	1.6	1.1	6.5	4.0	2.0 a	1.9	1.7
L	11.3	6.7	1.9	1.6	1.0	6.4	3.6	2.0 a	1.9	1.9
Conv	11.7	7.3	1.9	1.4	1.1	6.3	3.8	1.9 b	1.9	1.8
N-Rate	***	***	*	*	***	NS	NS	NS	*	***
0N	9.6 c	4.9 c	1.9 ab	1.5 b	1.0 b	5.6	3.2	1.9	2.0 ab	2.3 a
67N	11.5 b	7.2 b	1.7 b	1.5 b	0.9 c	6.6	4.2	2.1	1.7 b	1.6 c
133N	13.3 a	8.7 a	2.2 a	1.8 a	1.2 a	7.0	4.4	2.2	2.1 a	1.9 b

WAE: weeks after emergence. NS: means within columns not significantly different to the 0.05 level. *, **, ***: means within columns significantly different to the 0.05, 0.001, and 0.0001 level, respectively. Letters reflect vertical Duncan's Multiple Range Test comparisons at the 0.05 level.

Table C.20. Ear and total nitrogen concentrations by green manure and nitrogen rate, sweet corn, 2003.

	Ear N Concentration (g kg^{-1})					Total N Concentration (g kg^{-1})				
	2WAE	4WAE	6WAE	8WAE	9WAE	2WAE	4WAE	6WAE	8WAE	9WAE
GM x N-Rate	-	-	-	*	NS	NS	NS	NS	NS	NS
GM	-	-	-	*	*	NS	NS	NS	NS	NS
SH+L	-	-	10.1	6.1 b	6.0 c	11.7	8.3	3.3	3.4	3.2
SH	-	-	10.9	6.7 a	6.3 bc	12.5	7.7	3.2	3.2	3.0
L	-	-	8.3	6.0 b	6.7 ab	11.8	7.8	3.1	3.1	3.0
Conv	-	-	9.6	6.2 b	6.9 a	12.1	8.1	2.9	3.0	3.0
N-Rate	-	-	-	NS	**	***	***	**	***	***
0N	-	-	-	6.3 ab	6.8 a	10.2 c	5.8 c	2.4 c	2.2 c	2.2 c
67N	-	-	9.3	6.0 b	5.9 b	12.2 b	8.5 b	3.0 b	3.1 b	2.8 b
133N	-	-	10.0	6.4 a	6.8 a	13.6 a	9.6 a	3.9 a	4.3 a	4.1 a

WAE: weeks after emergence. NS: means within columns not significantly different to the 0.05 level. *, **, ***: means within columns significantly different to the 0.05, 0.001, and 0.0001 level, respectively. Letters reflect vertical Duncan's Multiple Range Test comparisons at the 0.05 level.

Table C.21. Pairwise contrasts of chlorophyll meter readings and specific leaf area, sweet corn, 2003.

	Chlorophyll Meter Readings (unitless)					Specific Leaf Area ($cm^2\ g^{-1}$)				
	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE
Conv 200N	45.4	54.3	48.5	54.3	51.0	288	255	207	182	182
Conv 267N	46.6	50.2	53.5	55.4	52.5	298	243	197	183	177
SH+L 67N	38.8†	44.6*	38.6*†	44.5*†	33.5*†	326	258	204	180	155*†
SH 67N	37.8*†	41.1*†	36.7*†	42.2*†	33.4*†	309	233	197	181	172
L 67N	41.0	45.9*	42.3†	41.4*†	31.7*†	304	256	188	175	175
SH+L 133N	43.9	47.0*	48.1	54.9	44.9	293	280†	194	182	184
SH 133N	46.5	49.7	45.5	51.2	42.3	296	237	208	183	184
L 133N	45.3	46.9*	41.6†	51.3	38.8*†	320	251	190	184	170

*,† mean of GM treatment significantly different from mean of Conv 200N and Conv 267N, respectively, to the 0.05 level; WAE= weeks after emergence.

Table C.22. Pairwise contrasts of stem dry weight and nitrogen content, sweet corn, 2003.

	Stem Dry Weight (kg ha^{-1})					Stem N Content (kg ha^{-1})				
	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE
Conv 200N	61	342	3302	3616	3468	0.9	3.2	9.2	7.2	5.5
Conv 267N	60	396	2920	3790	3528	1.0	4.0	10.8	9.6	5.6
SH+L 67N	47	263†	3206	3967	4161	0.6*†	2.0*†	5.4*†	6.6	4.0*†
SH 67N	49	307	3444	4519	4356	0.5*†	1.8*†	6.0*†	7.2	4.2*†
L 67N	49	234†	3371	4147	4098	0.5*†	1.8*†	6.1*†	5.3†	3.5*†
SH+L 133N	55	377	3749†	3841	3753	0.7	3.4†	9.4	7.6	4.9
SH 133N	53†	360	4096*†	4070	3710	0.8	3.3†	9.5	7.2	4.4
L 133N	55	306	3663	3428	4394*	0.7	2.4††	7.0*†	6.1†	4.4

*,† mean of GM treatment significantly different from mean of Conv 200N and Conv 267N, respectively, to the 0.05 level; WAE= weeks after emergence.

Table C.23. Pairwise contrasts of root dry weight and nitrogen content, sweet corn, 2003.

	Root Dry Weight (kg ha^{-1})					Root N Content (kg ha^{-1})				
	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE
Conv 200N	33	105	921	791	853	0.2†	0.5	2.9†	1.8†	1.6
Conv 267N	42	127	664	761	848	0.3*	0.7	2.2*	2.3*	1.9
SH+L 67N	32	84†	738	788	921	0.2	0.4	1.9*	1.5†	1.6
SH 67N	24	116	715	800	1066	0.2†	0.5	1.3*†	1.3*†	1.5
L 67N	33†	94	1041†	814	594	0.2	0.4†	2.0*	1.2*†	0.9*†
SH+L 133N	31†	112	837	814	842	0.2	0.6	2.2*	1.9	2.0
SH 133N	39	122	857	727	784	0.3	0.5	1.9*	1.5†	1.3†
L 133N	34	99	989†	680	954	0.2	0.4†	1.8*	1.2*†	1.7

*,† mean of GM treatment significantly different from mean of Conv 200N and Conv 267N, respectively, to the 0.05 level; WAE= weeks after emergence.

Table C.24. Pairwise contrasts of ear dry weight and nitrogen content, sweet corn, 2003.

	Ear Dry Weight (kg ha^{-1})					Ear N Content (kg ha^{-1})				
	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE
Conv 200N	-	-	640	3051	4573	-	-	6.2	19.8	36.2
Conv 267N	-	-	738	2743	4762	-	-	7.5	20.0	37.4
SH+L 67N	-	-	277†	1831*	1926*†	-	-	2.7†	10.8†	10.4*†
SH 67N	-	-	282†	1607*†	2170*†	-	-	2.8†	11.5†	13.0*†
L 67N	-	-	614	1829*	1946*†	-	-	5.3	9.6††	11.8*†
SH+L 133N	-	-	410	3292	4984*†	-	-	4.4	21.4*	32.9
SH 133N	-	-	433	2252	3674	-	-	4.9	15.3	24.2*†
L 133N	-	-	443	1790*	3838	-	-	3.6†	11.1†	26.2*†

*,† mean of GM treatment significantly different from mean of Conv 200N and Conv 267N, respectively, to the 0.05 level; WAE= weeks after emergence.

Table C.25. Pairwise contrasts of stem and root nitrogen concentrations, sweet corn, 2003.

	Stem N Concentration (g N kg^{-1})					Root N Concentration (g N kg^{-1})				
	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE
Conv 200N	15.4	9.1	2.8†	1.9	1.7	5.7	4.4	3.2	2.2†	1.9†
Conv 267N	16.7	9.9	3.7*	2.6	1.6	6.6	5.3	3.3	3.2*	2.4*
SH+L 67N	11.4*†	7.3†	1.7*†	1.6†	1.0*†	6.5	4.6	2.6*	1.9†	1.8†
SH 67N	11.5*†	5.8*†	1.8*†	1.6†	1.0*†	6.7	3.9	2.0*†	1.8†	1.5†
L 67N	10.9*†	8.0†	1.8*†	1.3†	0.9*†	6.7	4.2	1.9*†	1.5†	1.6†
SH+L 133N	13.0†	9.0	2.5†	2.0	1.3*†	6.6	5.3	2.6†	2.4†	2.4
SH 133N	14.5	9.2	2.4†	1.8†	1.2*†	7.3	4.0	2.2*†	2.0†	1.7†
L 133N	12.5*†	7.9†	1.9*†	1.9	1.0*†	6.9	3.7	1.9*†	2.0†	1.8†

*,† mean of GM treatment significantly different from mean of Conv 200N and Conv 267N, respectively, to the 0.05 level; WAE= weeks after emergence.

Table C.26. Pairwise contrasts of ear and total nitrogen concentrations, sweet corn, 2003.

	Ear N Concentration (g N kg^{-1})					Total N Concentration (g N kg^{-1})				
	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE
Conv 200N	-	-	9.7	6.5†	7.8	14.5	9.8	4.7†	4.5	5.3
Conv 267N	-	-	10.2	7.3*	7.9	14.6	10.1	5.9*	5.2	5.4
SH+L 67N	-	-	9.6	5.9†	5.4*†	11.9*†	8.8†	3.1*†	3.4†	2.6*†
SH 67N	-	-	10.0	7.1	5.9*†	12.4*†	7.5*†	3.0*†	3.4†	2.9*†
L 67N	-	-	8.7	5.3*†	6.0*†	12.1*†	8.9	3.3*†	2.9†	2.8*†
SH+L 133N	-	-	10.6	6.5†	6.6*†	13.6	9.8	4.2†	4.6	4.5*†
SH 133N	-	-	11.4	6.7†	6.6*†	14.2	9.9	4.3†	4.1†	4.0*†
L 133N	-	-	8.1	6.2†	6.8*†	12.9*†	9.1	3.3*†	4.1†	3.8*†

*,† mean of GM treatment significantly different from mean of Conv 200N and Conv 267N, respectively, to the 0.05 level; WAE= weeks after emergence.

Table C.27. Leaf nitrogen concentration by green manure and nitrogen rate, 2002 (g N g^{-1})

	Leaf N Concentration (g N kg^{-1})				
	2WAE	4WAE	6WAE	8WAE	9WAE
GM x N-Rate	NS	NS	NS	NS	NS
GM	NS	NS	NS	NS	NS
SH+L	16.7	12.0	11.0	10.0	8.3
SH	16.5	11.5	10.3	9.1	8.7
L	16.3	12.5	11.0	10.2	8.7
Conv	15.5	12.2	11.2	9.8	8.1
N-Rate	**	***	***	***	***
0N	15.1 b	9.4 b	8.7 b	8.2 c	7.2 c
67N	16.0 b	13.1 a	11.7 a	9.7 b	8.2 b
133N	17.7 a	13.7 a	12.3 a	11.4 a	9.9 a

WAE: weeks after emergence. NS: means within columns not significantly different to the 0.05 level. *, **, ***: means within columns significantly different to the 0.05, 0.001, and 0.0001 level, respectively. Letters reflect vertical Duncan's Multiple Range Test comparisons at the 0.05 level.

Table C.28. Pairwise contrasts of leaf nitrogen concentration, sweet corn, 2002.

	Leaf N Concentration (g N kg^{-1})				
	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE
Conv 200N	18.8	13.8	13.6	12.8	10.6
Conv 267N	17.7	15.1	14.4	13.2	11.9
SH+L 67N	16.0*	13.3†	12.0†	10.7*†	7.7*†
SH 67N	16.2*	12.0*†	11.4*†	8.5*†	9.1†
L 67N	15.7*	13.8	11.9†	10.4*†	8.9*†
SH+L 133N	18.0	13.4†	13.4	11.3†	10.4†
SH 133N	18.1	14.1	11.0*†	11.4†	9.3†
L 133N	17.9	13.7	11.8†	11.5	10.4†

*,† mean of GM treatment significantly different from mean of Conv 200N and Conv 267N, respectively, to the 0.05 level; WAE= weeks after emergence.

Table C.29. Leaf nitrogen concentration by green manure and nitrogen rate, 2003 (g N g^{-1})

	Leaf N Concentration (g N kg^{-1})				
	2WAE	4WAE	6WAE	8WAE	9WAE
GM x N-Rate	NS	NS	NS	NS	NS
GM	NS	NS	NS	NS	NS
SH+L	13.8	9.7	6.1 a	6.4	5.2
SH	14.5	9.1	5.8 ab	6.1	4.9
L	13.8	9.4	5.6 ab	6.0	4.6
Conv	13.8	9.6	5.1 b	5.7	4.8
N-Rate	***	***	***	***	***
0N	11.9 c	7.0 c	3.7 c	3.7 c	4.0 c
67N	14.3 b	101 b	5.9 b	5.9 b	4.7 b
133N	15.7 a	112 a	7.3 a	8.5 a	6.0 a

WAE: weeks after emergence. NS: means within columns not significantly different to the 0.05 level. *, **, ***: means within columns significantly different to the 0.05, 0.001, and 0.0001 level, respectively. Letters reflect vertical Duncan's Multiple Range Test comparisons at the 0.05 level.

Table C.30. Pairwise contrasts of leaf nitrogen concentration, sweet corn, 2003.

	Leaf N Concentration (g N kg^{-1})				
	2 WAE	4 WAE	6 WAE	8 WAE	9 WAE
Conv 200N	16.5	11.3	8.3	8.8	9.4
Conv 267N	16.4	11.5	9.6	9.3	11.2
SH+L 67N	13.9*†	10.4	6.1*†	6.4*†	5.3*†
SH 67N	14.3*	9.2*†	6.0*†	6.5*†	6.3*†
L 67N	14.4*	10.6	6.5*†	5.8*†	5.0*†
SH+L 133N	15.9	11.2	7.8†	8.8	8.8*†
SH 133N	16.4	11.5	7.9†	8.1	8.4*†
L 133N	15.0	11.0	6.7*†	8.3	8.1*†

*,† mean of GM treatment significantly different from mean of Conv 200N and Conv 267N, respectively, to the 0.05 level; WAE= weeks after emergence.

APPENDIX D
TABLES OF INTERACTIONS FOR ROOT LENGTH DENSITY BY LOCATION, 8 WEEKS AFTER EMERGENCE, SWEET CORN 2003

Table D.1. Root length density (cm cm^{-3}) interaction between depth and position with green manure and chemical nitrogen rate held constant, 8 weeks after emergence, sweet corn, 2003.

Depth (cm)	Conv 0N			Conv 133N		
	Position			Position		
	IR 0	IR 0.5	BR	IR 0	IR 0.5	BR
0-15	1.30 Aa	0.95 Aab	0.78 Ab	3.57 Aa	2.89 Aa	2.04 Aa
15-30	0.88 Ba	1.06 Aa	0.16 Bb	1.76 Ba	1.84 Ba	0.31 Ab
30-60	0.23 Ca	0.22 Ba	0.08 Bb	0.56 Ca	0.61 Ca	0.17 Bb
	SH+L 0N			SH+L 133N		
	Position			Position		
	IR 0	IR 0.5	BR	IR 0	IR 0.5	BR
0-15	2.58 Aa	1.94 Aab	1.42 Ab	4.73 Aa	3.42 Aab	1.50 Ab
15-30	1.35 Ba	0.90 Bab	0.38 Bb	2.70 Ba	2.00 Ba	0.18 Bb
30-60	0.44 Ca	0.27 Cab	0.16 Bb	0.55 Ca	0.41 Ca	0.13 Bb

Conv = conventional (no green manure); SH+L = sunn hemp plus winter legume green manure; N = kg NH_4NO_3-N ha^{-1} to sweet corn; IR0 = in-row next to plant; IR0.5 = in-row and half-way between plants; BR = between row; capital and lower-case letters reflect vertical and horizontal groupings, respectively, by Duncan's Multiple Range Test at $\alpha = 0.05$.

Table D.2. Root length density (cm cm^{-3}) interaction between depth and chemical nitrogen rate with green manure and position held constant, 8 weeks after emergence, sweet corn, 2003.

Depth (cm)	IR0, Conv		IR0.5, Conv		BR, Conv	
	Chemical N-rate		Chemical N-rate		Chemical N-rate	
	0N	133N	0N	133N	0N	133N
0-15	1.30 Ab	3.57 Aa	0.95 Ab	2.89 Aa	0.78 Ab	2.04 Aa
15-30	0.88 Bb	1.76 Ba	1.06 Aa	1.84 Ba	0.16 Bb	0.31 Ba
30-60	0.23 Cb	0.56 Ca	0.22 Ba	0.61 Ca	0.08 Bb	0.17 Ba
	IR0, SH+L		IR0.5, SH+L		BR, SH+L	
	Chemical N-rate		Chemical N-rate		Chemical N-rate	
	0N	133N	0N	133N	0N	133N
0-15	2.58 Ab	4.73 Aa	1.94 Ab	3.42 Aa	1.42 Aa	1.50 Aa
15-30	1.35 Ba	2.70 Ba	0.90 Bb	2.00 Ba	0.38 Ba	0.18 Ba
30-60	0.44 Ca	0.55 Ca	0.27 Ca	0.41 Ca	0.16 Ba	0.13 Ba

Conv = conventional (no green manure); SH+L = sunn hemp plus winter legume green manure; N = kg NH_4NO_3-N ha^{-1} to sweet corn; IR0 = in-row next to plant; IR0.5 = in-row and half-way between plants; BR = between row; capital and lower-case letters reflect vertical and horizontal groupings, respectively, by Duncan's Multiple Range Test at $\alpha = 0.05$.

Table D.3. Root length density (cm cm^{-3}) interaction between depth and green manure with position and chemical nitrogen rate held constant, 8 weeks after emergence, sweet corn, 2003.

Depth (cm)	IR0, 0N		IR0.5, 0N		BR, 0N	
	Green Manure		Green Manure		Green Manure	
	Conv	SH+L	Conv	SH+L	Conv	SH+L
0-15	1.30 Aa	2.58 Aa	0.95 Ab	1.94 Aa	0.78 Ab	1.42 Aa
15-30	0.88 Ba	1.35 Ba	1.06 Aa	0.90 Bb	0.16 Ba	0.38 Ba
30-60	0.23 Ca	0.44 Ca	0.22 Bb	0.27 Ca	0.08 Bb	0.16 Ba
	IR0, 133N		IR0.5, 133N		BR, 133N	
	Green Manure		Green Manure		Green Manure	
	Conv	SH+L	Conv	SH+L	Conv	SH+L
0-15	3.57 Aa	4.73 Aa	2.89 Aa	3.42 Aa	2.04 Aa	1.50 Aa
15-30	1.76 Ba	2.70 Ba	1.84 Ba	2.00 Ba	0.31 Ba	0.18 Bb
30-60	0.56 Ca	0.55 Ca	0.61 Ca	0.41 Ca	0.17 Ba	0.13 Ba

Conv = conventional (no green manure); SH+L = sunn hemp plus winter legume green manure; N = kg NH_4NO_3-N ha^{-1} to sweet corn; IR0 = in-row next to plant; IR0.5 = in-row and half-way between plants; BR = between row; capital and lower-case letters reflect vertical and horizontal groupings, respectively, by Duncan's Multiple Range Test at $\alpha = 0.05$.

Table D.4. Root length density (cm cm^{-3}) interaction between position and chemical nitrogen rate with green manure and depth held constant, 8 weeks after emergence, sweet corn, 2003.

Position	0-15 cm, Conv		15-30 cm, Conv		30-60 cm, Conv	
	Chemical N-rate		Chemical N-rate		Chemical N-rate	
	0N	133N	0N	133N	0N	133N
IR0	1.30 Ab	3.57 Aa	0.88 Ab	1.76 Aa	0.23 Ab	0.56 Aa
IR0.5	0.95 ABb	2.89 Aa	1.06 Aa	1.84 Aa	0.22 Aa	0.61 Aa
BR	0.78 Bb	2.04 Aa	0.16 Bb	0.31 Ba	0.08 Bb	0.17 Ba
	0-15 cm, SH+L		15-30 cm, SH+L		30-60 cm, SH+L	
	Chemical N-rate		Chemical N-rate		Chemical N-rate	
	0N	133N	0N	133N	0N	133N
IR0	2.58 Ab	4.73 Aa	1.35 Ab	2.70 Aa	0.44 Aa	0.55 Aa
IR0.5	1.94 ABb	3.42 Aa	0.90 ABa	2.00 Aa	0.27 ABa	0.41 Aa
BR	1.42 Ba	1.50 Ba	0.38 Ba	0.18 Ba	0.16 Ba	0.13 Ba

Conv = conventional (no green manure); SH+L = sunn hemp plus winter legume green manure; N = kg NH_4NO_3-N ha^{-1} to sweet corn; IR0 = in-row next to plant; IR0.5 = in-row and half-way between plants; BR = between row; capital and lower-case letters reflect vertical and horizontal groupings, respectively, by Duncan's Multiple Range Test at $\alpha = 0.05$.

Table D.5. Root length density (cm cm^{-3}) interaction between position and green manure with chemical nitrogen rate and depth held constant, 8 weeks after emergence, sweet corn, 2003.

Position	0-15 cm, 0N		15-30 cm, 0N		30-60 cm, 0N	
	Green Manure		Green Manure		Green Manure	
	Conv	SH+L	Conv	SH+L	Conv	SH+L
IR0	1.30 Aa	2.58 Aa	0.88 Aa	1.35 Aa	0.23 Aa	0.44 Aa
IR0.5	0.95 ABb	1.94 ABa	1.06 Aa	0.90 ABb	0.22 Ab	0.27 ABa
BR	0.78 Bb	1.42 Ba	0.16 Ba	0.38 Ba	0.08 Bb	0.16 Ba
	0-15 cm, 133N		15-30 cm, 133N		30-60 cm, 133N	
	Green Manure		Green Manure		Green Manure	
	Conv	SH+L	Conv	SH+L	Conv	SH+L
IR0	3.57 Aa	4.73 Aa	1.76 Aa	2.70 Aa	0.56 Aa	0.55 Aa
IR0.5	2.89 Aa	3.42 Aa	1.84 Aa	2.00 Aa	0.61 Aa	0.41 Aa
BR	2.04 Aa	1.50 Ba	0.31 Ba	0.18 Bb	0.17 Ba	0.13 Ba

Conv = conventional (no green manure); SH+L = sunn hemp plus winter legume green manure; N = kg NH_4NO_3-N ha^{-1} to sweet corn; IR0 = in-row next to plant; IR0.5 = in-row and half-way between plants; BR = between row; capital and lower-case letters reflect vertical and horizontal groupings, respectively, by Duncan's Multiple Range Test at $\alpha = 0.05$.

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BIOGRAPHICAL SKETCH

Corey Cherr was born on October 7, 1977 in Tallahassee, Florida. Like his mother and father, he developed an interest in the living world and its simultaneous complexity and simplicity. He earned his BS in physics from Florida State University, and while attending the University of Florida helped manage the student-run Collegiate Living Organization and the Graduate Student Council in addition to his professional research responsibilities. During this time, Corey met Aisha Goodman, a kindred soul in the journey of life. They were married on May 22, 2004, and happily expect their first child near Corey's 27th birthday.