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Sue Ellen Johnson

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Major professor

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ON-FARM AND SMALL PLOT STUDIES OF THE GROWTH AND PERFORMANCE OF COVER CROPS INTERSEEDED INTO CORN

Sue Ellen Johnson

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
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ABSTRACT

ON-FARM AND SMALL PLOT STUDIES OF THE GROWTH AND PERFORMANCE OF COVER CROPS INTERSEEDED INTO CORN

By

Sue Ellen Johnson

Interseeded cover cropping systems may be compatible with farming operations and objectives in northern temperate regions. Ecophysiological parameters influencing cover crop performance need to be determined to optimize these systems. Exploratory field studies were conducted at two locations to better understand the performance and ecophysiology of interseeded corn systems.

Eight cover crop species were interseeded into corn at cultivation in small plot, and on-farm field-scale trials. Growth and development, N, and biomass (dry matter) contribution to the cropping system were characterized for the cover species. Variability of cover crop growth and N accumulation across the field were performance criteria generated by farm discussions. Spatial distribution of cover biomass and N were surveyed for the field scale trial.

In the fall of the seeding season, crimson clover had the greatest total biomass, and biomass N. Crimson clover had a different growth pattern than other species. It exhibited stress at a later period following corn canopy closure, and made rapid growth in late fall. However, no particular growth parameter was clearly associated with relative species performance. Throughout the study, soil nitrogen was not statistically effected by treatment. In spring, red clover provided the greatest amount of available N (plant +soil N = 106 kg ha^{-1} (96 lb a^{-1})) for the subsequent crop. In spring, winter-killed species were associated with less available N, but greater soil nitrate, than species that overwintered successfully. Biomass variability did not necessarily correspond to N variability over the field. Adequate winter cover was provided by most species, although alsike and sweet

clovers provided less cover than other species. Results were similar across the small plot, and field scale trials.

Although cover species responded similarly to the dynamics of the interseeded environment, individual species responses apparently determine agronomic and economic efficacy of interseeding cover crops into corn. Exploratory field scale trials, combining on-farm production and process research, allowed effective assessment of the potential productivity, and the ecophysiological aspects of cover crop growth and productivity in the interseeded corn system.

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I wish the many student friends who have encouraged me through this process, especially Gaye Burpee, personal happiness and fulfillment in their careers. Last, I affectionately thank Bob and Lois Lichtsinn for their interest, and my parents for their good humor and support.

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a	acre
AC	alsike clover
ARG	annual ryegrass
BKWT	buckwheat
bu	bushel (for corn approximately 52-6 lbs)
CC	crimson clover
CGR	crop growth rate
CF	chlorophyll fluorescence
CV	coefficient of variation
DAP	days after planting
EL	East Lansing field location; small plot trial
GA	growth analysis
ha	hectare
HV	hairy vetch
LAI	leaf area index (m^2 leaf surface per m^2 ground surface)
LAR	leaf area ratio (plant leaf surface area divided by plant biomass)
LI	light interception (% of sunlight intercepted by plant canopy)
LS	leaf stem ratio (leaf mass divided by stem mass)
LSD	least significant difference
m	meter
MDC	annual medic cv. Cyprus
N	nitrogen
NAR	net assimilation rate
NCCO	no cover-corn only treatment
OM	Omega Farms field location; field scale trial
PPFD	photosynthetic photon flux density (umoles m^2 s^{-1} at wavelengths of 400-700 nm)
r^2	coefficient of determination
RC	red clover
R-G	red clover-annual ryegrass mixture
RM	root mass
RSA	root surface area
RSm	root shoot ratio (root mass divided by shoot mass)
SD	standard deviation
SLA	specific leaf area (leaf area divided by leaf mass)
SWT	sweet clover
ULR	unit leaf rate (net biomass assimilated per unit leaf area per day)
vLAR	vegetative leaf area ratio (leaf area divided by shoot mass)
V-G	hairy vetch-annual ryegrass mixture
V#	vegetative stage

Introduction

Economic and environmental concerns have prompted renewed interest in ecologically based farming practices such as cover cropping. In the northern temperate region of the USA, relaying cover crops into an established cash crop, the practice known as interseeding or overseeding, has the potential to serve both environmental and economic objectives.

Cover cropping and green manuring are fundamental, nearly universal sustainable agricultural practices. Cover cropping encompasses practices provide for live vegetative plant growth and carbon and nutrient accumulation (generally without a direct economic yield) in fields or areas of fields that are not currently actively cropped. Cover cropping benefits are related to soil biophysical characteristics such as erosion control, soil tilth, and water holding capacity. Other cover cropping objectives include nutrient conservation and cycling, substitution of off-farm nutrient sources, and especially nutrient (N) accumulation, holding and recycling (Hargrove, 1988). Cover crops are increasingly being evaluated to reduce production costs, especially fossil fuel inputs (N), and decrease health and environmental impacts from chemical runoff and leaching (on- and off-farm) (Frye et al., 1985; Frye and Blevins, 1989).

On-farm research has conventionally been a terminal or conclusive step in the formal research process, usually for the purposes of technology validation or demonstration. Farmers, of course, are continually conducting informal research, technology assessment and adaptation, usually through observation or trial and error, and comparison with their own farm experience. Farmers have to evaluate, integrate, and adapt varied technology or recommendations to their specific farming situations and conditions. This generalized synthesis and systemization of diverse information sources and biophysical (and economic resources) for actual decision making and operations is one of the central, essential processes and challenges of contemporary farming and agriculture. Scientists need to become more involved in this systemization task, at the farm and experimental level. Information and understanding generated through formal scientific study can accelerate and optimize systemization. Research needs to be designed and executed to generate understanding and information that supports farm level systemization. Underlying paradigms and philosophies (and scientific principles) driving technological recommendations are often not understood or articulated. If conducted in the preliminary early stages of the technology generation process, on-farm research can enhance the definition of technical options, research criteria, and the clarification of research questions and assumptions, and overall technology systemization. On-farm "exploratory" research can provide information on the economic and operational feasibility of interseeding row crops, and opportunities to understand the agroecology of the system so that productivity and environmental benefits can be optimized.

Although the literature indicates minimal basic research of cover cropping systems, the study and comparison of cover crop species growth and development in the interseeded system is a prerequisite for development of sustainable cover crop systems. In the dynamic resource environment created by the interseeding system, cover crops must succeed in a spatially and especially a temporally variable environments. Production in systematically, inherently marginal growth microclimate may be accomplished by plant physiological adaptation and morphological plasticity.

One study was initiated on-farm to enhance the systemization and synthesis of agricultural ecology for technology development and evaluation. Exploratory studies combining assessment of performance potential, and farm feasibility with ecophysiological characterization are an effective, efficient research strategy. By reordering the processes of technology adaptation and optimization to a farm-field scale, and relocating preliminary research from the station to the farm overall research process can be accelerated.

This dissertation evaluates a sustainable agricultural production system utilizing cover crops from an agroecological perspective. Following the literature review, our field design and experimental methods are presented, including a description of the understory environment of interseeded cover crops. Performance, in terms of biomass and N accumulation and distribution of the cover species is reviewed in chapter 5. This is followed by the ecophysiological analyses of cover growth in chapter 6. The summary and recommendations are followed by several appendices.

Problem Statement and Justification

Farmers and researchers need a more comprehensive understanding of the ecology of cropping systems to make intelligent farm management decisions (Figure 1). Conventional cash grain row cropping practices contribute to the deterioration of soil and environmental quality in mid-Michigan. Inorganic chemical fertilizers may become uneconomical in the future. Nutrient cycling is currently not a management strategy on mid-Michigan farms. Interseeded corn cover cropping systems have undetermined potential to enhance the sustainability of cash grain cropping systems in mid-Michigan. However, as reported, the survival and performance of cover crops in interseeded systems is inconsistent. The integration of ecological theory and methods into agronomic research is vital for development of productive sustainable agricultural systems.

Current research systems require extensive time frames to produce implementable technologies for farm practice. Agricultural research and education have primarily focused on chemical and mechanical management tactics and their underlying principles.

Understanding successful cover species growth and development responses in real field conditions and scales is imperative to accelerate the development of cover cropping systems. The approach was a combination of performance and morphological mechanistic studies to quantify and understand cover crop responses and attributes in the interseeded system performance so that this system and practice may be ecologically and agronomically optimized.

Literature Review

In this overview I first discuss the premise of sustainable agriculture, and the sciences of agroecology and physiological ecology. These discussions lead into brief reviews of the methodological approaches to the study of agroecology, specifically the concepts and literature for cropping systems, farming systems, on-farm and field-scale research. Finally, there is a summary of the cover crop literature, with a section specifically addressing the overseeding of temperate row crops.

In this document, the term cover crop is used to represent cover crops, green manures and catch crops. Although the primary purpose and evaluation criteria of "success" differ, the ecophysiology of a species will be specific to the system in which it is grown.

Sustainable Agriculture

In the best context, the term sustainability encompasses maintenance of society's potential, which is dependent on the natural resource base, the technology with which it is used, and implicitly, the value systems of that society. Values are influenced by resource and technology options, but culture mediates the interaction of technology and resources.

This interaction is central to the set of farm practices and management strategies which often define agricultural sustainability. Sustainable agriculture is a more comprehensive concept than environmentally sound farming practices or farm and rural community economic viability. Agricultural systems have roles other than production, and produce more than food or fiber and sustenance, i.e., industrial precursors, rural employment, urban labor, and speculative opportunities. Economics is the study of the mechanisms linking the individual (scientist, farmer, producer, consumer) to the society, and relate sociological and political values/decisions (including technology) to agricultural resources.

Famine, the failure of the food system, has sociological, political, and ecological origins, and has destabilizing ecological, political, and social consequences. The food system is comprised of production, processing, distribution, consumption (and disposal) systems. These reflect the natural resources, technology, and culture/values of a society. A society's food system regulates population, nutrition, health, and productivity of the human resource. The productivity of the agricultural system is influenced by the quality and organization of natural and human resources. The sustainability of a food system fundamentally depends on values, which define relevant objectives, time frames, and priorities. The relationship of quality of life to natural resource quality, utilization, and productivity is the central issue of sustainability.

As population increases, and industrial development reduces arable land, technologies that enhance the maintenance and productivity of agricultural resources of both prime and marginal lands become increasingly important. Technology influences natural and human resource efficiency in both economic and absolute contexts. Technology is dependent on understanding the natural and human systems. Understanding and knowledge are the outcome of science and experience. Science is the organization of knowledge, while research is a process for the acquisition of knowledge and exploration of nature.

<u>Agroecology</u>

Agroecology is the study of agricultural field systems in a systematic framework. Ecology focuses on the patterns, cycles, and interactions (balance and synergy) of the biological and physical components of a system. Integrating these cycles and optimizing interactions for production or other objectives is the goal of agroecological research and management. In contrast with agronomic research which focuses on human (farmer) actions and biophysical outcomes usually in a monocultural system, agroecology focuses on processes, and resource transformations, species interactions, and elemental flows or cycles.

Current research seeks to apply the principles of population, community, ecosystem and landscape ecology to agricultural systems (Lowrance et al., 1981; Carroll et al. 1990). Agroecological study results in spatial and temporal redefinition of the system; units of analysis differ from the production/agronomic management units (Odum, 1981). Scales vary to fit biophysical processes, cycles and technological practices within a system and their effects on related systems (Levins and Vandermeer, 1990).

A crop's genetic composition, expression and immediate environment interact with management to determine gross and net primary (and agricultural) productivity: biomass and yield (Mitchell, 1981; Hall, 1990). Interactions within the system of the organic and inorganic constituents, temporally and spatially, and their influence on productivity are the basis of agroecology. Diversity and integration are characteristics associated with both the technological and biological components of sustainable agriculture systems (and sustainable societies). Agroecological diversity within a system confers resilience and greater resource niche exploitation, and higher overall resource capture (Mitchell, 1981). Integration influences resource use efficiency. Resource cycling and capture are naturally accomplished by systems with a diversity of species.

Agroecosystems

Many temperate agricultural systems represent disturbed, imbalanced natural systems. Agricultural management can attempt to influence primary productivity levels, and/or the percentage of primary productivity (and soil elements) that reaches one (the human) consumer level or that is transferred out of the community or ecosystem (Mitchell, 1981). Inputs or other disturbances/practices (and species introductions) maintain successional states and resource forms/availability at points that, theoretically, optimize desired forms of productivity. Management seeks to shift productivity towards an economic objective (Aldag, 1987). High resource intensity/application per unit product is characteristic of contemporary, conventional agriculture, yet these systems have low rates of resource capture, accumulation, and turnover. Managed agricultural systems can potentially increase resource capture or resource conservation without losing productivity. Management seeks to maintain an inherently unstable ecosystem and a non-successional objective (production). Agroecological research has focused on the diversified cropping systems of the tropics, and this research has focused on "basic" resource cycles (Carroll, 1990). One agroecological perspective considers the closer the system is to a natural ecosystem the potentially more efficient and sustainable the agricultural system (Ewel, 1986).

Ecophysiology

The basic cycles of nitrogen, carbon, mineral elements, and energy or matter transformations are integrated through the physiological cycles of individual organisms, populations, and communities of organisms (the interaction of species) through space and time. Plant-plant, plant-animal, plant-animal-microbial associations synchronously or synchronously accomplish these transformations.

From an ecological perspective, the conversion and redistribution of elemental resources is based on organism's physiological function or resource flows through a community. (At the basis of this are solar--carbon fixation, and hydrological cycles). Species metabolism, ontogeny, and community succession are essential to energy transformations (chemical-thermal forms) and matter conversions (solid-gas-liquid states). Physiology is the link between inorganic and organic constituents of ecosystems. The key processes in the cycling of organic and inorganic resources are physiological (ultimately biochemical).

Webs of interacting autotrophs, heterotrophs, saprotrophs, and sessile and mobile organisms determine ecosystem "efficiency" or "integrity"; and shape long term patterns of a system's resource accumulation, loss, and productivity along with climatic and geological events.

On an agricultural scale, organisms (species), populations and communities (and increasingly landscapes) are more "manageable" than is an organism's biochemical-physiological pathways directly. Species and associations (communities) of species are increasingly being recognized as tools for the management of mineral element, and energy (and input) cycles in agricultural systems. Agroecology focuses on the management of the cropping cycles, and the potential for integrated C, N, and mineral cycling. Synchronous cycles via organism or population growth, and decomposition are enhanced by increased levels biodiversity and integration. A simplistic example of an integrated system is the interseeding of legumes species with field corn (Zea mays).

Agroecosystems are designed primarily for maximal/optimal harvest of specific configurations of carbon and nitrogen. A concurrent objective is minimal physical and chemical disturbance of the surrounding systems by optimization of input:output ratios of biotic and mineral resources. Understanding the underlying principles linking the biological and physical components of production systems is still a challenge. Since carbon, nitrogen, mineral, and hydrological cycles are integrated and mediated by the physiology of organisms and communities of organisms, ecophysiology is key to understanding and designing ecologically efficient cropping systems.

Cropping Systems

Common components of all cropping systems include the soil (or rooting and support medium), inorganic nutrients, carbon, water, primary producers (crop plants), plant residues of previous crops, perhaps secondary crops, and perhaps animals (or manures). The system may include intermediate predators, consumers as well as producers occupying resource niches.

The components are organized and managed to meet an economic objective (Spedding, 1979). Cropping systems research tends to have a limited temporal focus, although interactions are considered and measured as functions of time, often seasonally. Climatic-economic regions tend to define cropping systems geographically. The focus is on a commodity/primary "crop" or rotation (as in corn-bean-wheat or rice based systems), not the composite of organisms comprising the system.

Temperate cropping systems are frequently characterized by sole cropping and simple rotations, and less frequently, monocultures. Yield per unit land area is typically reported attribute. There is an applied research emphasis, which centers on either genetic and cultural manipulation (and landscape), especially technology. The operational and economic unit tends to be a 'field'. Cover crops can be developed as management tools (as are tillage, fertilization practices, etc.) for soils and nutrient cycles. Similarly, cropping sequences or "rotations" effect farm economics, but are also ecologically influential within a particular field.

Farming Systems

The Farming Systems Research (FSR) approach seeks to understand and include economic, sociological, and anthropological aspects of farm household level decisions and activities, in the study of technology development and adoption. Initially the approach was developed to improve applied crop breeding for tropical cropping systems. Technology assessment with farmer consultation was expected to improve the efficacy of the extension and research process. The link of agronomic production decisions and technology development to "non-technical" factors affecting farm decision making (i.e., technology adoption), by incorporating whole farm economics (beyond operational level economics), whole farm logistics, labor and input-output markets, farm sociological issues, intra-household labor and benefit patterns, tenure, and cultural preferences were expected to make agricultural research more effective at the farm level. Interdisciplinary methodologies were developed to implement FSR (Hildebrand, 1993).

Farming systems research encompasses all activities on a farm (commercial and sustenance), including annual and perennial crop systems, livestock systems, as well as processing or retail enterprises. Farming systems have multiple operational units. The whole farm system (in practice representing a collection of similar farms) is the research unit. The interdependence of multiple operational units is an important consideration of FSR. Interdisciplinary "teams" of researchers conduct systems appraisals in consultation with farmers to understand the system, and its constraints. Farming systems research focused attention on the decision frameworks of farmers and farm households.

The field research process was extended to real farm environments, with, ideally, farmer participation. Farming systems research has tended to focus on problem identification, and technology assessment and adaptation, more than technology development.

Participatory research paradigms and methodologies paralleled initiatives in international participatory community development and empowerment (Chambers, 1992; Rhoades, 1994). Issues of the control, pace and direction of "development" became paramount. The perspectives of farmers (and rural people) as research partners, "stakeholders" with unique intellectual contributions to the research process, have continued to influence other research approaches.

Land grant university research has been criticized for its lack of responsiveness to farmer needs. A gap is perceived to exist between basic and applied research and station research and farm practice. Farmers generally (and necessarily) are left to be the integrators of innovations and technologies in their own farming systems. The narrow specialization of scientists contrasts with the systematic requirements of farmers. The conventional research system and research process do not accommodate these dichotomies. The need for accelerated, more effective research process exists. The synthesis of basic and empirical (research and farm) knowledge, and methodologies of the disciplines (ecology, agronomy, physiology) is imperative to develop better biologically integrated agricultural systems which maximize natural resource use efficiency (acquisition and recycling), and long and near term productivity.

On-Farm Research

On-farm research implies communication and collaboration between farmers and researchers. All agricultural progress eventually depends on the farmer. On-farm research objectives are broader, but not necessarily less specific than station research. A different learning process/opportunity exists on-farm. Indigenous (farmer) knowledge, experience, objectives and interpretation of results can hone the research process (Gardner, 1990). Lockeretz (1993) has emphasized the importance of "good" science in on-farm research, though this is not necessarily confined to conventional design and analysis.

Originally all agricultural research was conducted on farm, by farmers. Farmer innovation still drives farm technology. With formalization of the land grant research system, applied research was frequently conducted on-farm with multiple farmer collaborators. Concurrent with the "invention" of statistical theory regarding controlled variance (Neilsen and Alemi, 1989) agricultural research moved to research stations and small plots. Currently, on-farm research is typically conducted through county agents (Copeland and Ward, 1994). Farmers are selected to implement researcher specified practices.

On-farm research configurations are typically categorized:

--farmer designed -- farmer managed

--researcher designed -- farmer managed

--researcher designed -- researcher managed

--joint design -- joint management

On-farm research should emphasize the importance of problem identification, definition of research objectives, division of research activities, and evaluation of outcomes. Tripp (1989) indicated that joint participation of farmers and reearchers in the research decision-process was the distinguishing feature of true on-farm research. Alternative, especially basic ecological, questions are rarely addressed in on-farm research, despite the opportunities it provides. In addition to research benefits, Norman and Freyenberger (1993) emphasized the "multiplier" extension effects of on-farm trials due to farmer to farmer communication, based on a survey of Kansas farmers.

Integration of agricultural systems on the farm (among fields and crops, and livestock), within the research system, and between farming and research systems is necessary. More efficient and effective production and research systems are needed for both temperate and tropical agriculture.

Field Scale Research

For many farm decisions and operations, the management unit is the field. The "field" is the operational technical decision unit of farming. The field is a composite of soil types, and topographic sites. The economic unit is usually a composite of fields (crops and technologies), and may be managed with or separately from livestock operations. The tactical decisions of individual fields' management are integrated into the strategic management of whole farm operations and economics by the farmer.

Increasingly, there are resource flows between these field-decision (operational) units. The driver of this activity is primarily economic strategy. In the case of livestock, adding value (by feeding out crops) or altering/synchronizing labor use (as well as manure management) integrates the farm economically and biophysically. Farm fields are most directly linked by management of organic resource flows. These linkages are central to sustainable management.

Field scale research provides opportunities for ecological questions to be answered, for example the effects of soil variability or landscape (hedgerows). While variability is controlled in small plots, in farm field scale studies variability is encompassed and quantified (in a regular pattern through/across the treatment replicates, if possible). A different suite of conditions and questions are introduced.

Agroecosystems development and adaptation needs to be conducted at field scales because of the variability and patterns of the organic and inorganic field components. The variability that can be examined in field scale research makes it an appropriate approach for exploratory research for economic as well as scientific reasons.

The movement to field-scale research has involved a scaling up rather than a rethinking and redesign of small plot research techniques and statistics (Rzewnicki, 1988; Thompson, 1990). Research design and statistical techniques will have to be developed to deal with the challenges of performance assessment and understanding of field scale phenomena and management. Farmers and researchers will have to create and learn new ways of answering old and new questions.

For economic reasons applied mean "performance" research will increasingly be conducted and focused on-farm at field scales, reflecting heterogeneous soils and a range of management levels. Field scale research allows for study of community, population, ecosystem or landscape parameters in the ecologically simplified agricultural system.

The Practical Farmers of Iowa generally advocate field strips for paired treatment comparisons (Thompson, 1990). Designs prioritize simplicity of operations and farmer credibility (for farmer designed and managed trials), and large numbers of replicates of field length plots (Thompson, 1990). For mean yield treatment comparisons, field strip and small plot trials produce similar results, when field station soils, resources and management practices represent farm conditions (Christenson and Poindexter, 1992; Rzewnicki, 1988). This method may be appropriate for empirical, terminal, and validation experiments. Walter (1993) conducted a study of how Illinois farmers evaluate research reports. Thirty-nine percent of the farmers indicated field size of a trial was important to their evaluation of the validity of research results. A similar conclusion was reached by Lockeretz and Anderson (1991) after a workshop with practitioners of on-farm research. Stucker and Hicks (1992) challenge this with a statistical and theoretical critique of on-farm research, and distinguished preliminary and "critical" experimental design and objectives.

Field-scale designs should follow some generalizable research principles for "scientific" validity, but the primary objective should be to encompass (and understand) variability, rather than control variability. Experimental variance is reduced with increasing length of field strips (Wuest et al., 1994). Field site selection for specific patterns or patches of heterogeneity and strategic designs to incorporate or distribute variable fields among treatments or replicates can effectively enhance on-farm research (Wuest et al., 1994; Anderson and Lockeretz, 1991). Replication should reflect the magnitude of expected treatment differences, and the field itself (variability encompassed or blocked) (Anderson and Lockeretz, 1991). Appropriate field selection and design can increase and enhance the information gained from a particular trial.

Exploratory field scale research should include basic and applied components, and focus on technology development. On-farm research provides real economic and logistical checks. An ideal study can generate conclusive results for the farmer, potentially some mechanistic understanding of responses, and perhaps information to guide further field scale or controlled factor research (Stucker and Hicks, 1992). Ecology is essential to understanding basic field scale processes. Ecological understanding of ecosystem processes is necessary for the design of systems with optimal integration of biological components for conservation and improved resource use efficiency.

Cover Crops

Utilization of cover crops in the cropping system of cash grain farms is encouraged by advocates of "sustainable, low-input" agriculture (USDA, 1992).

Management of the primary crop creates a resource (and stress) framework within which cover crops must succeed (specifically interrow space, full field post harvest and off-season or fallowed fields). These resources are solar radiation, soil mineral nutrients, and moisture as well as physical space (Vandemeer, 1990). Introduction of cover crops into a highly simplified system for which they have not evolved nor been selected, tests the underseeded species inherent stress tolerance and environmental plasticity.

Cover cropping represents a form of multiple cropping. Species may be relay cropped (overseeding), double cropped (post-harvest seeding), but rarely are true intercrops, when crops are planted and harvested simultaneously. Cover crops can be sole fallow or double crops, but in the north central U.S. many cover cropping systems involve interseeding of small grains (frost seeding) or row crops, because of short seasons and high costs of fallowing (land costs).

On mid-Michigan farms cover crops are managed as secondary crops, which complement the cash-row-primary crops. Conventional, contemporary temperate farming practices create temporal and spatial habitats, with unutilized resource niches available for colonization and exploitation by weeds. These areas/habitats are conventionally managed with an array of chemical or mechanical technologies. By comparison, cover crops are biological tools, employed in an ecological context, which can use the under utilized resources, increasing overall (C harvest). To some extent cover crops actually contribute to the primary crop system via weed control, erosion control, enhancing soil tilth or biological activity, nutrient cycling or nitrogen accretion. Implementation of cover crop strategies is important environmentally, improving resource harvest/use efficiency, and increasingly, farm energetic and economic efficiency.

Cover cropping systems and species, compatible with current agricultural practice, need to be developed concomitantly with development of entirely "new" diversely structured farming systems. Cover crop benefits (reduced erosion, nutrient catchment, N and OM contributions) have been enumerated and validated in numerous cover crop research trials (Power, 1990). However, the research approach to cover cropping has tended to focus on empirical, random species "performance" evaluations, rather than systematic, process-level, mechanistic understanding of species responses and characteristics in an agroecological or production systems context. Power et al. (1983) stated the need for cover crops research to focus on the interrelationships of components as part of integrated management systems.

Land-Grant research in cover cropping dates from the turn of the century (Crozier, 1895). Annual and biennial species, especially forage legumes, have been investigated over a range of environments. Research has tended to focus on cover crop species trials in terms of establishment practices, seeding dates and rates, competitive effects on the commodity/host species, erosion control, percent surface cover, tillage/incorporation management effects, and fertilizer replacement value. Power and Zachariessen (1991) have studied the effects of soil temperature on growth and decomposition. Work in North Carolina has focused on tissue decomposition, mineralization, and nutrient synchrony (Wagger, 1989).

Success (and economic value) of a cover crop species is commonly based on yield response of the following crop(s), and related to cover species yield. Cover species evaluation and comparison has been on the basis of commodity crop yield or soil or nutrient loss depending on whether cover crops are employed to stabilize the system or replace or supplement inputs to the system.

Cover crop system failures (reduced yield of the commodity crop or lack of survival of the cover crop) have frequently been attributed to competition for light or soil moisture between the cover and primary crop (Scott, 1981; Exner, 1993). Yet, research on interseeded species interactions and response of the complex to environmental stress is limited. Information on relay cropping is scarce (Vandemeer, 1989). Application of systematic, functional approaches to the study of temperate intercrops is needed to more rapidly and effectively assess cover crop species, and to design and fine tune sustainable cropping systems with cover crops.

OVERSEEDED TEMPERATE ROW CROP SYSTEMS

The principle of all cover cropping is to grow some species (usually forage or small grain) in the space or time (and capturing/utilizing resources) when other (cash) crops are not growing in the field. In interseeding, the primary (commodity) crop is planted some time before the cover crop is planted into it (between the rows or plants). With the headstart, the commodity crop is already established and it is able to outcompete the cover crop. Relay-interseeded crops are not usually reported to have adverse (or any) effects on the primary crop (Exner, 1993; Thomas and Bennett, 1975). The cover crop is seeded when there is still enough light for it to establish, but not enough for it to compete with the primary crop. In addition the corn overstory "delays" the development of some species, allowing annual crops to be managed as biennials. When the commodity crop is harvested the cover crop already has roots and leaf area established and is able to make rapid growth. The cover crop is expected to provide benefits to the subsequent crops directly or to maintain good soil properties. Ideally, interseeded cover crop practices should "fit" the existing cropping system with minimal impact on yield or operations. The perfect system would have continuous cover at all times.

Several agronomic studies have reported the results of overseeding of row crops in the temperate United States. In a series of small plot studies in upstate N.Y., Scott et al.(1981) measured differences for dry matter, N and % cover for species interseeded in small plot studies (including alsike, sweet, red, vetch, and ryegrass). All species provided adequate cover when interseeded at cultivation: the perennial ryegrass-red clover mixture provided the highest fall cover over 4 years.

Perennial ryegrass, red clover, and hairy vetch sole crops also provided high cover. Cover did not differ with species with fall seeding. Spring cover results varied with year. Medium red and sweet clovers each had the highest cover for one year, and perennial ryegrass in sole and mixed plots provided good cover both years. There appeared to be correlation between fall and spring cover. The highest biomass and N contribution (interseeding at cultivation) came from medium red clover-perennial ryegrass mixture and medium red sole crop in year one. In the second year sweet clover DM and N yields were greater than in the other treatments. In Scott's studies hairy vetch winterkilled.

During the fifties, several studies investigated the effect of row width and corn population density on cover cropping. In central Michigan, Hayes (1958) studied the effects of corn row width, seeding date and technique for red clover, hairy vetch, sweet clover, and a mixture of annual and perennial ryegrass overseeded into corn at cultivation. He reported better growth of covers in wide (56") rows (to the detriment of corn), and weaker seedlings nearer the corn row. Interestingly, he reported that red clover performance was better in narrow rows than in wide rows, which he attributed to adverse effects of high light intensity. He concluded that ryegrass provided a much higher percent 'winter' ground cover (this evaluation was made in late September), and better early season weed competition than the legumes. Ryegrass performed well in both 42 and 56" interrows. Hairy vetch did not perform as well as red clover. Results suggest that planting to coincide with good soil moisture conditions resulted in the best stands (especially hairy vetch). Sweet clover stands failed, possibly due to sweet clover weevil. Triplett (1961) concluded that continuous ryegrass interseeding reduced continuous corn (60" rows) by 5 bu a^{-1}, but benefitted soybeans in a rotation.

Exner and Cruse (1993) found that sweet clover tended to establish better than red or alsike clovers when interseeded at corn cultivation in Iowa. Palada et al. (1981) indicated that interseeding into corn at first cultivation resulted in better cover crop germination and establishment then interseeding at second cultivation for a single year study in Pennsylvania. Establishment differed slightly for two corn population densities. Early-fall ground cover estimates ranged between 50 and 60% for medium red clover, crimson clover, and hairy vetch. Hofstetter (1984) also reported better germination and establishment for interseeding at cultivation, than for later interseeding. For both years of that Pennsylvania study, the highest yields of subsequent season corn followed spring plowdown of hairy vetch, regardless of N rate. Hairy vetch and red clover substituted between 34-41 and 10-26 lbs N a^{-1} in each of two years, respectively, total N was directly related to biomass. "Very good" germination, biomass and ground cover were reported for crimson clover (Hofstetter, 1984).

In Kentucky, Frye and Blevins (1989) and Elbehar et al. (1984) reported positive results from broadcast overseeding of legumes into standing corn in early September, shortly before corn harvest. Over a 4 year study, corn yields and soil nitrogen increased in response to hairy vetch cover crop. Soil organic matter increased with hairy vetch in a no-till treatment. They also calculated yield benefits beyond N replacement. Crimson clover apparently performed less well than hairy vetch in this study. Tomar et.al. (1988) found corn yields depressed by the simultaneous interseeding of a hairy vetch, red clover and alfalfa mixture. They found differences among legume treatments (seeding year). All of the above studies report the important influence of rainfall and soil moisture on timely germination and establishment of cover species.

Several studies have quantified the benefit of repeated interseeding of cover crops over extended research periods (4 years) (as a regular cropping practice) (Frye and Blevins, 1989; Scott et al., 1981). Benefits have usually been attributed to improved soil organic matter and tilth, as well as nitrogen cycling.

Based on the literature, interseeding at cultivation of corn seems effective for establishment of legume and ryegrass cover crops. Nitrogen contribution and corn yields from interseeded cover crops tend to be greatest following hairy vetch, but in some studies hairy vetch does poorly or fails, while red or sweet clover perform more reliably. Alsike clover also tends to be a reliable species. Results are not consistent across years, locations or experiments. Limited interseeding research has been conducted in climates comparable to mid-Michigan.

Numerous studies have evaluated maize-legume intercropping in tropical systems (Hulugalle, 1989; Agboola and Fayemi, 1971; Thomas and Bennett, 1975). There is abundant agronomic and ecological literature regarding intercropping in tropical cropping systems. These studies generally focus on physiological, ecological and farming systems as well as production aspects (Singh et al., 1986; Azam-ali et al., 1990) Such studies evaluate agronomic parameters such as yields, but also ecological interactions, resource use and competition (especially moisture), nutrient, population, and pest dynamics (Ingram and Swift, 1989; Altieri, 1990).

In summary, cover crop and interseeding research have been characterized by empirical performance assessments. Ecophysiological understanding of these systems would contribute to cropping system and agricultural resource optimization. Generally, cover crops have been studied in small plot trials with restricted variability.

The research reported here combines performance and ecophysiological analyses to investigate the feasibility of interseeding for mid-Michigan. Description of the growth of interseeded cover species through the season as integral parts of the cropping system provided research direction by defining important physiological patterns, and clarification of the critical periods for species growth. Introduction of ecophysiological micro-site studies into performance studies to understand the basis for performance and differences in performance on-farm generated a basic data base previously unavailable for cover cropping systems design. The synthesis of ecology, agronomy and real farm conditions is vital for understanding and optimization of cover cropping as a strategy for more sustainable cropping systems.

AGRICULTURAL KNOWLEDGE BASE(s)

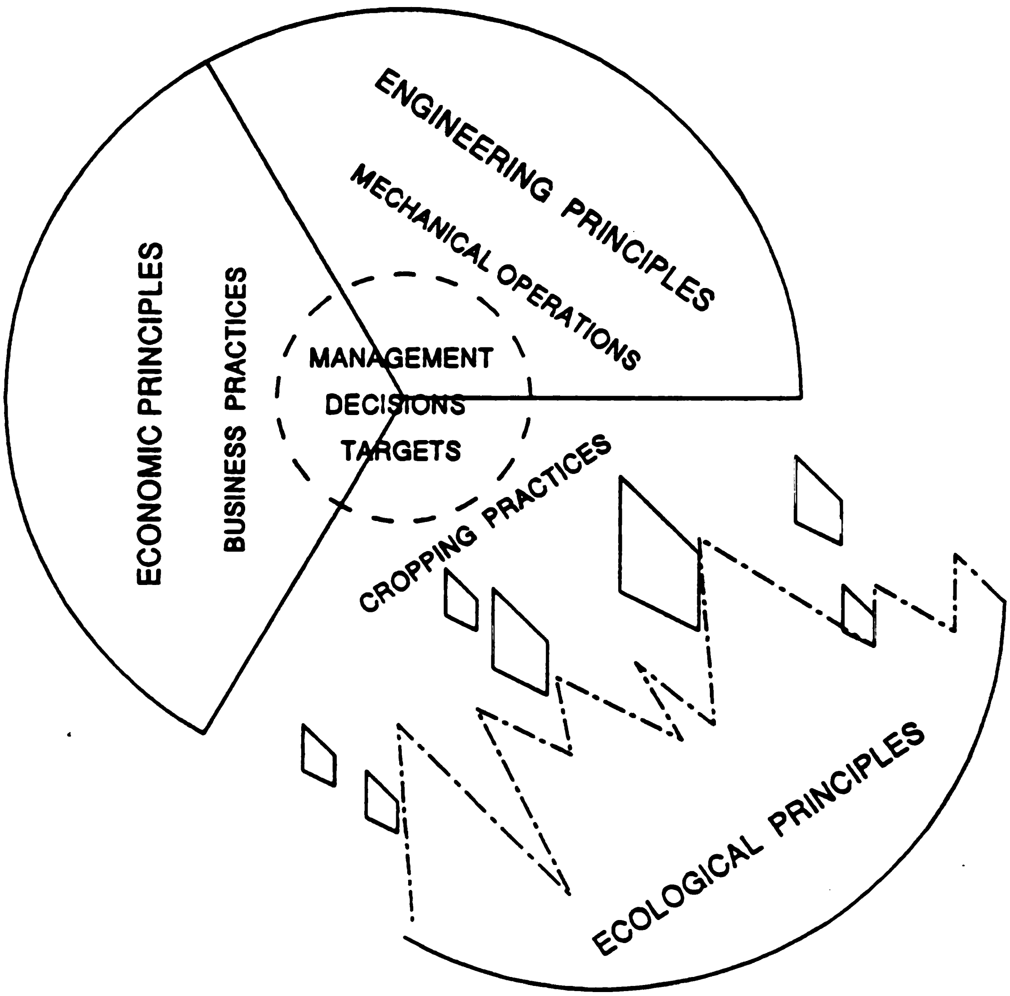


Figure 1. Schematic view of the relationship between agricultural principles and practice in North America.

Research Objectives

The primary objective of this work was to develop and understand the ecophysiological dynamics of incorporating cover crops into a row crop system. The model system was corn. In addition to a small plot trial, a study was conducted on-farm at field scale to improve and accelerate the research process, especially in terms of farm evaluation and systemization. Specific objectives follow:

Performance:

1. Measure and evaluate the performance and contribution of 7 interseeded cover crop species to the central Michigan cropping/farming system.

2. Describe the uniformity of distribution of individual species over a "typical" field, and the relationship to N availability (at spring kill) to the subsequent crop. Describe the variance of productivity of cover crop species through a field.

- **2a.** Determine if grass-legume mixtures result in more uniform cover than do sole-cropped cover species over a field.

Mechanistic:

3. To understand the growth and development of 7 cover crop species in an interseeded cropping system through a field (space) and a season (time).

4. Describe patterns of growth for cover crops interseeded into corn.

- **4a.** Determine if growth patterns are related to species and magnitudes of growth in corn interseeded systems.

5. Identify critical points or periods of growth for cover crops interseeded into corn.

6. Test hypotheses to determine whether relative performance can be related to morphological partitioning and plasticity of 7 cover species in an interseeded system.

Methodological:

7. Demonstrate the utility of an exploratory on-farm research approach for preliminary understanding of an agricultural system prior to the formulation, and design of mechanistic experiments.

8. Assess the potential of farmer participatory, exploratory, on-farm research for description and understanding of an agroecosystem, while generating practical farm information about cover crop performance and contribution to the cropping system.

9. Contribute to the methodology for on-farm field scale research, and designs to link applied and basic research, and assess the relative efficacy of field scale and more controlled, small plot research approaches.

Study Background

Omega Farms is a 4000 thousand acre cash grain farm located in central Michigan, in eastern Ingham County. The owners of Omega Farms approached Michigan State University's Department of Crop and Soil Sciences in fall 1990 for assistance with increasing their farm's overall sustainability. The role of cattle in the farm was under evaluation, as was the sustainability of the cropping system. At that time field operations were supervised by a hired manager. The 1991 research field season addressed the potential for the integration of livestock into the cropping system. Our studies were evaluated the potential of brassicas and cover crop grazing for enhancement of crop production and whole farm economics. Due to commodity pricing, management turnovers, and changing priorities, the 1992 field research season was redirected towards cropping systems only. The farm was involved in an overall reorganization, with field management being under the direct management of family members. Dynamic changes occurred over all the farm in 1992, the most significant of which were the conversion to no-till planting, the increased role of a "conventional" crop consultant, and the allocation of crop acreage to alternative crops. In 1993 the shift in base government program payment acreage (influencing rotations) resulted in 50:50 allocation of acreage to field corn and soybeans, and exploration of site specific management. In 1992, the economics of several cropping system options (with and without cover crops) were evaluated with the Planetor model using soil and yield data from several Omega Farms fields (Irwin and Lohr, 1993). The relative roles of family members were also changing, with the son having increasing responsibility for day to day management decisions. In late 1993 the utility of livestock on the farm was again reassessed, and increased via feedlot development in an effort to add value to crop production (in comparison to the initial research concept of using livestock to enhance crop productivity).

The research program attempted to adapt to changing interests and priorities of the farm, yet also pursue some consistent objectives. In this dynamic context, cover cropping, specifically row crop interseeding was identified as a fundamental sustainable practice. At the planning stage was viewed as feasible and compatible with the farm's resources and operations, and in need of further investigation and development for mid-Michigan.

Methods Overview

Locations

Cover crops were interseeded into corn for research at two locations. Field scale and small plot trials were conducted in both 1992 and 1993. See appendix for discussion of 1992 research.

The on-farm research location, Omega Farms, is in Williamston, Michigan, 15 miles east of Michigan State University. The field used in 1993 was 0.25 mile east of highway M-52 to the north of Bell Oak Road in Williamston, Michigan. The field is owned and farmed by Omega Farms and is located between the farm's mechanical shop and feedlot. It runs from the power poles north to a large pond supporting a diverse range of waterfowl and wildlife. The operative management unit is approximately 49 ha (120 acres). The designated research area within this field was approximately 6 ha (15 a). There is considerable surface water, qualified as wetlands, in the vicinity of the research site. The field was in corn in 1992, and soybeans in 1991.

The USDA soil survey types the entire field area used as Marlette fine sandy loam (MaB), with "broad complex" 2-6% slopes, moderately well-drained, but with a shallow water table, and tilth and erosion hazards (all of which were evident during the course of this study). A plowpan was evident, especially in the center block. Cover cropping and no-till cropping systems are explicitly recommended for this soil type. Surface soil variation was apparent, with soils becoming sandier with increasing elevation, and changing with regard to moisture and drainage characteristics. Elevation changed approximately 60' from the base of slope in the south to the ridge top bounding the field site to the north.

A complementary, parallel trial was implemented in 1993 at the Michigan State University campus soils farm, northwest of the junction of College and Jolly roads in East Lansing, Michigan. The experiment occupied the northern half of soils farm ranges F4 and F5. This field is on a Capac loam (fine-loamy, mixed, mesic, aeric Ochraqualf), a moderately well-drained soil. This location was in soybeans in 1992. The dimensions of the area were 78x53 m (240x130').

Agronomic Operations

At Omega Farms (OM) in 1993, a randomized complete block design with 10 treatments and 3 blocks was imposed on a 6 ha (15 a) area. Blocking coincided with topography (slope). The 1993 corn yields validated the statistical blocking strategy.

The field was disced once to break up corn stalks prior to planting. Corn was planted with a 103 day variety, Pioneer 3217, at a population of 72,900 plants per ha (29,500 a^{-1}) in 76 cm (30") rows at a depth of 6 cm (2") on May 27 with an 8 row no-till planter operated by the farmer as part of normal farm operations. No starter fertilizer was applied.

Two days following planting, the area was band sprayed (25 cm (10") band over the row) with a pre-emergence herbicide mixture of 0.75 qt atrazine, 1.5 qt Bladex, and 2 qt Lasso per acre (1.9, 3.8 and 5 l ha^{-1}) to control weed pressure in the corn row. Banding of herbicide resulted in a 66% reduction of total herbicide used in the field area. A single cultivation controlled weeds in the interrow immediately prior to interseeding. Weed pressure in the field at discing was low, due to timely Round-up (glyphosate) application the previous year at the rate of 2 qt per acre (5 l ha^{-1}). Liquid N fertilizer (28 %) was knifed in at a rate of 150 lbs actual N per acre (168 kg ha^{-1}) on July 3.

Corn population at interseeding was 28,000 a^{-1} (69,200 ha^{-1}). Corn was between 4 and 30" tall and had between 3 and 11 leaves. On July 14, cover crop legume species were broadcast with a single pass. Annual ryegrass required 2 passes for coverage of over 2/3 of the plot width (at least 30'). Seeds were broadcast with a Vicon seeder with an oscillating throw mechanism, mounted approximately 1 m above the ground. The north block had a perpendicular pass (3 m wide) of annual ryegrass (going east-west) to screen legume-ryegrass mixtures.

The **East Lansing** (EL) location was chisel-plowed, disced, then field cultivated prior to planting. A 97 day corn variety, Pioneer 3751, was planted on May 11 at a population of 60,000 plants per hectare (24,200 a^{-1}) at a depth of 5 cm (2"), with a conventional 4 row planter. Corn emergence was uneven in the EL plots, perhaps due to cool temperatures, and the planting date. The plots were rotary-hoed on May 25. Row gaps exceeding 45 cm were hand planted on May 28, to a depth of approximately 4 cm (1.5"). Unfortunately, mechanical tillage sometimes buried smaller corn plants and they had to be manually uncovered; this may have contributed to the stand variability. At EL, additional weed control was required. A mixture of atrazine and basagran was band sprayed over the row on June 11 and plots were cultivated June 13, then hand weeded on June 16-18. Granular ammonium nitrate fertilizer (34% NH_4 NO_3) was broadcast beside the row with a Gandy spreader on June 10 at a rate of 101 kg actual N per ha (90 lbs a^{-1}). This rate was considered adequate for formation of a full corn canopy according to the soil tests taken at corn planting. Corn populations per hectare at interseeding ranged from 65,000 in rep 1 to 60,000 in rep 3 (27,000 to 24,000 a^{-1}). A second cultivation preceded interseeding.

Corn was in the V3 stage at interseeding on June 23. Cover crop seed, which had been weighed out for each interrow, was hand broadcast into the interrows. A 2.6 by 1.5 m (10x5') subplot was oversown with ryegrass at one end of each plot, leaving a sampling area approximately 30 m^2 (10x30'). Data were collected from the three interrows of the small plots. Soil was dry at cultivation, resulting in an uneven seedbed, and seed wash into the cultivation furrow. There was gentle precipitation (6 mm) the day following interseeding.

Plot Designs

Rapid redesign of the OM field study in May 1993 was made necessary by inadvertent spraying of the planned experimental field site. Reassignment of the study to another field resulted in a loss of replication along a slope gradient. Instead, replication and blocking within the gradient (the conventional approach to RCBD small plot design 'restricting' variation) was necessary. Within each block 'environment', and over the field each treatment's sites followed the slope gradient, but this was not a replication of the gradient.

This re-randomization within distinct block "environments" somewhat precluded the expected spatial analysis. The analysis considered each site unique and unrelated, in addition to calculating conventional plot and rep means (of three subsites) analysis.

Three replicates divided the OM field form north to south. Blocks boundaries were arranged E-W. Because of field use constraints, replicates were blocked across the slope, and soil texture rather than encompassing the range of field variability, along the slope. Each plot was 16 rows (two planting passes 12.3 m each) wide, (one round with an eight row corn planter, set for 30" rows) and 154 m (500' ft long) for a plot area of 1894 m^2. Plots ran north-south with the corn rows. The entire research area within this field was 5.93 ha or 14.64 a (1560 by 400 ft). See figure 2.

At OM each 12.5 by 160 m (40 by 500') plot had 3 sampling sites located 25, 80, and 135 m (80, 250, 420 ft) along the center axis (or guess row) of each individual plot. This resulted in sampling sites forming a grid of approximately 52.5 by 12.5 m (170' by 40'). Sampling sites were 6 m^2. Data were randomly collected in a 3 m radius of the site's central point. Data were not collected from the 'guess' interrow, which was used for travel and access, but from the three interrow areas either side (east and west) of the guess row. See figure 2.

The EL research area (was divided into four replicates (NE, NW, SE, and SW) with 12 plots each. Treatments were randomly assigned to the most uniform 9 plots in each rep (see figure 3). This location was blocked on corn stand vigor (which appeared to be related to soil tilth and moisture). Rows and plots ran north-south. Plots were 10 by 40' (3.3x12.3 m). The center N-S (30 ft) was used for an access alley and border plots as it had been used as an alleyway within the last 6 years.

Summary

The two research locations differed in soils and management. Planting dates and operations were earlier, tillage was more intensive, and weed pressure was initially higher at EL. Fertilizer rate and form also differed between locations (see above). At both sites corn was planted in 76 cm (30") rows. Populations at interseeding were slightly lower at EL. Chemical weed control was similar at both locations.

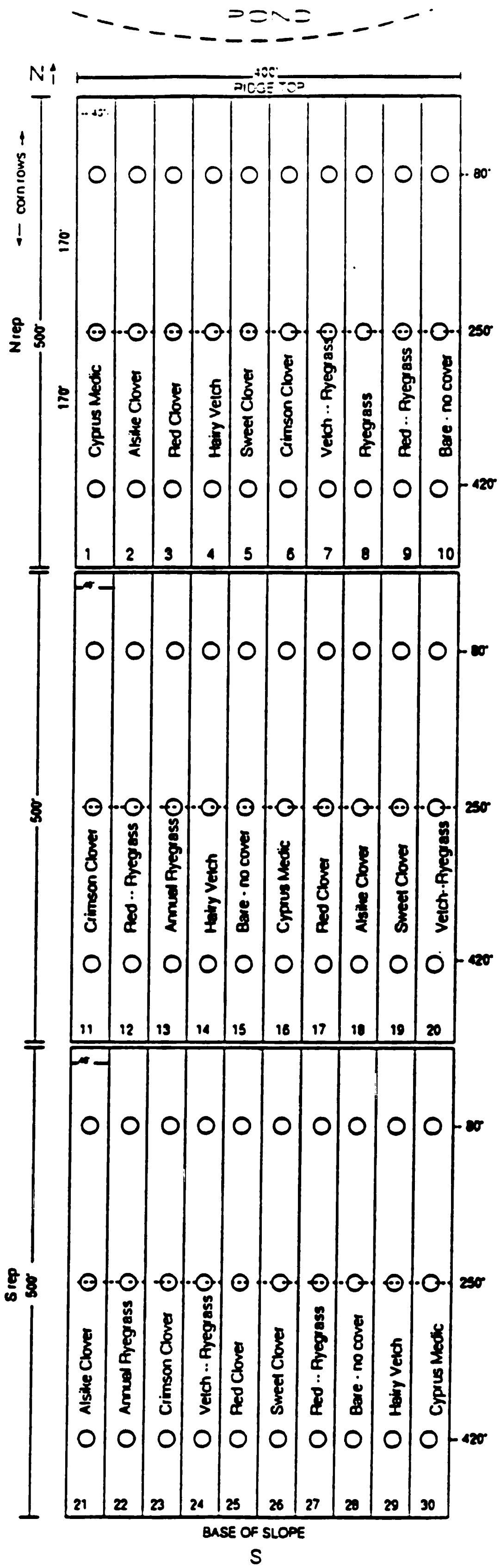


Figure 2. Omega Farms field plot design 1993. Research area was approximately 6 ha. Small circles are sampling sites.

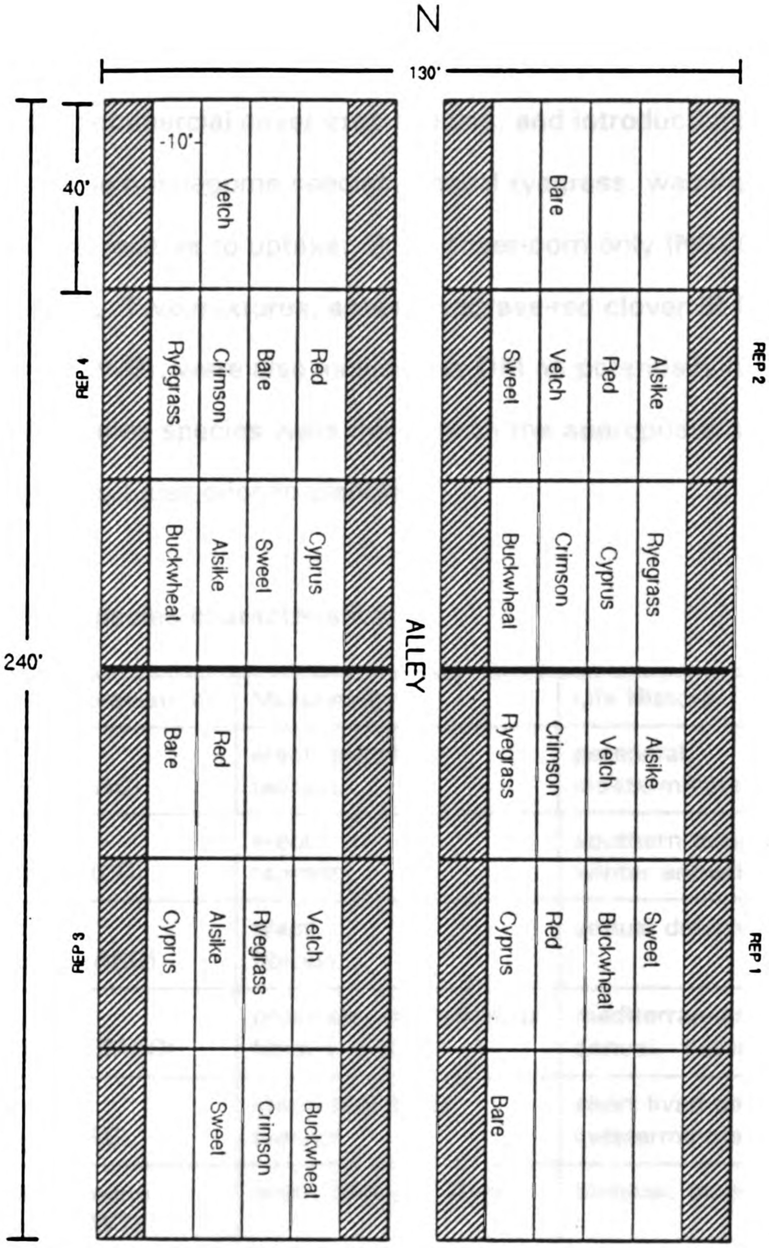


Figure 3. East Lansing Soils Farm small plot design 1993. Research area covered 0.4 ha.

Cover Crop Species: Treatments

Cover crop species were selected to represent a range of growth habits, and life cycles, and included species which have traditionally been used or have potential for interseeding into corn in central Michigan (Table 1). Species evaluated included traditional, commercial cover crop species, and introductions successful in southern, regions. The non-legume species, annual ryegrass, was included to better assess N contribution relative to uptake. A no cover-corn only (NCCO) treatment served as control plot. Two mixtures, annual ryegrass-red clover (R-G) and annual ryegrass-hairy vetch (V-G), were also included at OM as potentially effective cover crop strategies. Legumes species were mixed with the appropriate commercial inoculant (Rhizobia spp.) just prior to planting.

Table 1. Cover crop species characteristics.

Species (abbreviation)	Morphology	Life History	kg ha^{-1}
Alsike Clover Trifolium hybridum (AC)	erect, bunching taproot	perennial, indeterminate	10
Crimson Clover Trifolium incarnatum (CC)	erect taproot	southern temperate winter annual	18
Annual Ryegrass Lolium multiflorum (ARG)	erect fibrous	annual determinate	EL:25 OM:45
Annual Medic (Cyprus) Medicago truncatula (MDC)	prostrate, stoloniferous fibrous root	mediterranean annual, determinate	10
Red Clover (Medium red) Trifolium pratense (RC)	erect, bunching taproot	short lived perennial, indeterminate	15
Sweet Clover Yellow Blossom Melilotus officinalis (SWT)	erect, then prostrate	biennial, determinate	20
Hairy Vetch Vicia villosa Roth. (HV)	vining prostrate fibrous root system	annual determinate	30
*Buckwheat Fagopyrum sagittatum (BKWT)	erect, then prostrate	short, warm season annual, determinate	50

* = EL only

Weather

In 1993, conditions were good for plant growth, though the spring was wet and cool (Figure 4). Moisture was not apparently limiting throughout the season, however periodic flooding (accumulation of surface water more than 24 hrs following the cessation of rainfall occurred in large areas of the OM field). Both EL and OM soils were saturated much of the season. There may have been low soil moisture availability for a few days in late July. Temperature and radiation were within normal ranges. Temperature may have varied with topographic microsites in OM. January and February temperatures (1994) were extremely cold.

Weather data were collected within 1 km of each experimental location, with LICOR 1200 data loggers, radiometers, thermal sensors, and tipping bucket rain gauges. Precipitation data from Omega may occasionally be inaccurate (underestimated) due to recurrent residence of mice and spiders in the rain gauge.

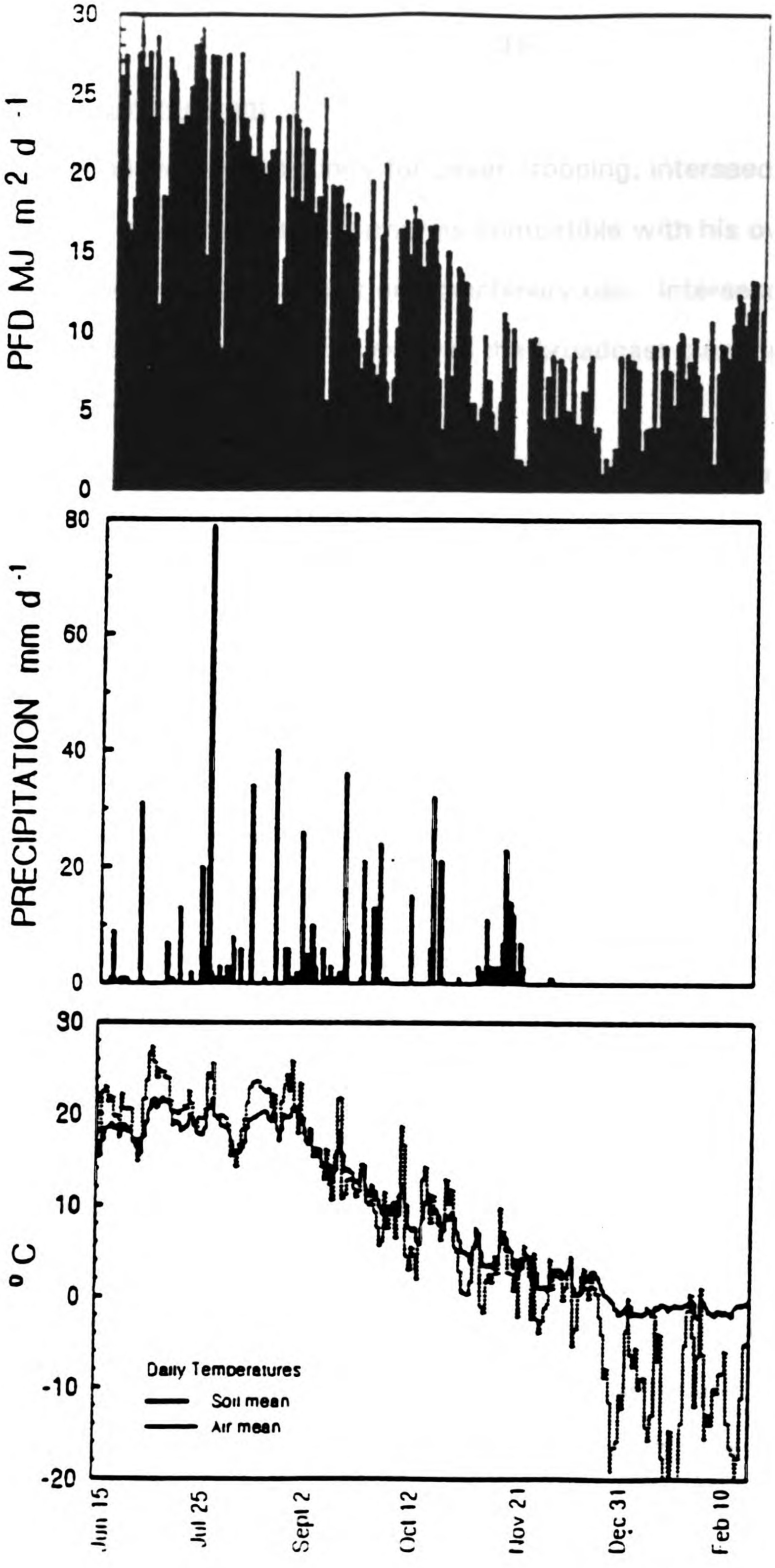


Figure 4. Omega Farms (Williamston, MI) climatic data for 1993. Daily photon flux density (PFD) at top; daily precipitation in middle; daily minimum and maximum air temperature, and mean soil temperature at bottom.

Understory Environment

A window of opportunity for cover cropping, interseeding at cultivation, was identified by the cooperating farmer as compatible with his overall cropping system, particularly with regard to labor and machinery use. Interseeding (overseeding) is an old agronomic practice that involves the broadcast planting of the cover species into an established corn stand.

Interseeding coincides with "layby", cultivation, or nitrogen side-dressing, usually when corn is approximately 25 cm tall (V3-V4 stage of growth). Growth of the cover species is expected to be primarily in the interrow spaces. Since the corn stand and canopy are already established, and the corn root system is thought to be adequately developed to compete effectively for nutrients and water, the interseeded species are not expected to interfere with field corn at populations over 20,000 plants a^{-1}) growth or yields (Scott, 1981; Hofstetter, 1984).

The corn canopy is both an index (of soil) and determinant (of light) of microsite soil and light environment. Corn is the integrator of soil moisture, chemical, and physical properties, management and climate (Chapin et al., 1987); the "quality" and interactions of these factors are expressed by the corn canopy (light interception) and yield. Paradoxically, the more optimal nutrient and moisture conditions are, corn canopy will be more developed, and less photosynthetic photon flux density (PPFD) is available to the understory. In interseeded corn, given good management, light is the inherently limiting resource of the understory.

The light environment of the understory is described by intensity of PPFD, the duration of a given intensity of PPFD, wavelength, and photoperiod. Most importantly the light environment is inherently dynamic; fluctuating seasonally as well as diurnally with the development and senescence of the corn canopy. The light environment is influenced by the natural solar progression of the seasons (solar angle and photoperiod) at 45 latitude N.

Understory light quality is altered by passage through a vegetative overstory. Red:far red wavelengths (R:FR) may have differential effects on plant species (Smith, 1982). In these studies, light measurements only considered PPFD. The influence of R:FR ratio on species responses should be addressed in other experiments.

The effects of soil factors on performance contrast with that of light which is universally limiting cover crop growth throughout the corn field. Shade provided by the corn canopy may alleviate moisture stress experienced by some understory species (Johnson et al., 1994; Hayes, 1958). Soil moisture, though it might be limiting for a given year or soil type, was assumed to be less intrinsically limiting to interseeded species, with the exception of some microsites.

Corre (1983) demonstrated an interaction of light intensity and NO_3 supply on morphological responses which were similar across species. Fertility practices and soil types associated with midwest corn production should provide adequate nutrients for understory species. Atmospheric temperature and humidity, CO_2, and soil temperature may vary through the field with corn and cover presence (Monteith et al.,1985), but these parameters were not measured in this study. However, the "layering" of stresses such as moisture, nutrients (and herbivory or disease) alters the stress environment and response of interseeded cover species (Osmond et al., 1988).

In this study, precipitation and soil moisture were adequate throughout 1993, so plant water stress was not observed. Evaluation of soil saturation and flooding tolerance would have been appropriate for some sites, but the opportunity was missed. In retrospect, field hydrology (and associated soil textural differences) probably influenced corn light interception, yield and sampling site differences as much or more than soil chemistry at OM. Field hydrology appeared to influence the variability of the corn stand. At EL, corn stand also seemed to differ with soil physical characteristics.

Light Environment

Methods

Given that available solar radiation is systematically limiting for interseeded understories, seasonal corn light interception patterns were expected to elicit differential responses from cover species. Light interception was measured to quantify the rate of corn canopy closure, understory light intensity, the duration of full corn canopy, and dry-down light dynamics.

Cover canopy level PPFD was measured with a LICOR (1 m) integrating radiometer, sensitive to photosynthetically active wavelengths (400-700 nm). Measurements were usually under conditions of "full" ambient irradiance >1400 umol m^2 s^{-1}, 2 hrs $\pm$ solar noon (11-3:00 pm EST). Measurements were made within 1 hour of solar noon in EL.

Light interception of the corn canopy was measured as conditions permitted, 5 or 10 times (OM and EL respectively) during the season. Four measurements were taken per site or plot, and used to calculate means for each plot or site. The radiometer was placed diagonally across the interrow, measuring light penetration of the corn canopy to the interrow zone, approximately 4-6" from either corn row. This gave an approximate measure of light available to cover crops in the interrow. The radiometer was held on either a NE-SW or NW-SE axis and then on the opposite axis in the adjacent interrow to eliminate bias. The light bar was held above the cover crop canopy, but below the corn canopy early in the season; later in the season full sun measurements had to be made in clear areas adjacent to the plots.

Results

At EL, light interception (LI), and available PPFD differences with rep were detectable on some dates, there were no treatment differences. Rep 3 (SW) tended to have poorer corn growth and lower LI than the other reps.

Initially, at interseeding, there were no differences in LI. Canopy closure rate did differ with rep, but understory ambient light did not differ during the "full canopy" period. Light interception again differed with rep as canopies dried down, resulting in slightly variable fall light environments (figure 5). Time was significant as was the time by rep interaction, there were no time by treatment interactions. Biologically these differences appeared to influence absolute performance, and may have influenced relative performance of the understory species.

Although the pattern of understory ambient light may have effected cover species differently, LI over EL plots represented a natural range of light variability, and was considered a uniform environment. Mean light interception at EL over the season was best described by a cubic function (figure 5).

In 1993, weather and topography combined to result in a visibly irregular corn stand at OM. OM light interception did not differ with treatment, but was statistically associated with rep and slope/gradient position. Reps did not consistently differ over the five LI measurements. Seasonal curves of mean OM LI by rep are presented in figure 6. Even within reps (and plots) extreme variability of corn light interception was apparent after interseeding, and throughout 1993.

To better understand the variability of ambient light in the understory, cluster analysis (Ward's minimum variance) was used to classify the actual range and variability of light environment (Golden, 1981; SAS, 1990). Cluster analysis of the LI values for each site grouped sites with similar light interception parameters together. Three to six clusters could be distinguished. The coefficients of determination (r-squared) associated with the Ward clustering were between 0.63 and 0.84. Cluster analysis of the light interception data for four clusters (or light environment types) is presented diagrammatically (figure 7b). Figure 7a presents the mean light interception of each of these light environments. Clusters 1 and 2 were more similar to each other then to the other clusters. Cluster 3 grouped sites that were far ahead in corn canopy development, relative to other sites, were more vigorous, had higher corn yields and created the most limited light environment, with instantaneous ambient light values under 250 umoles m^{-2} s^{-1} for several weeks.

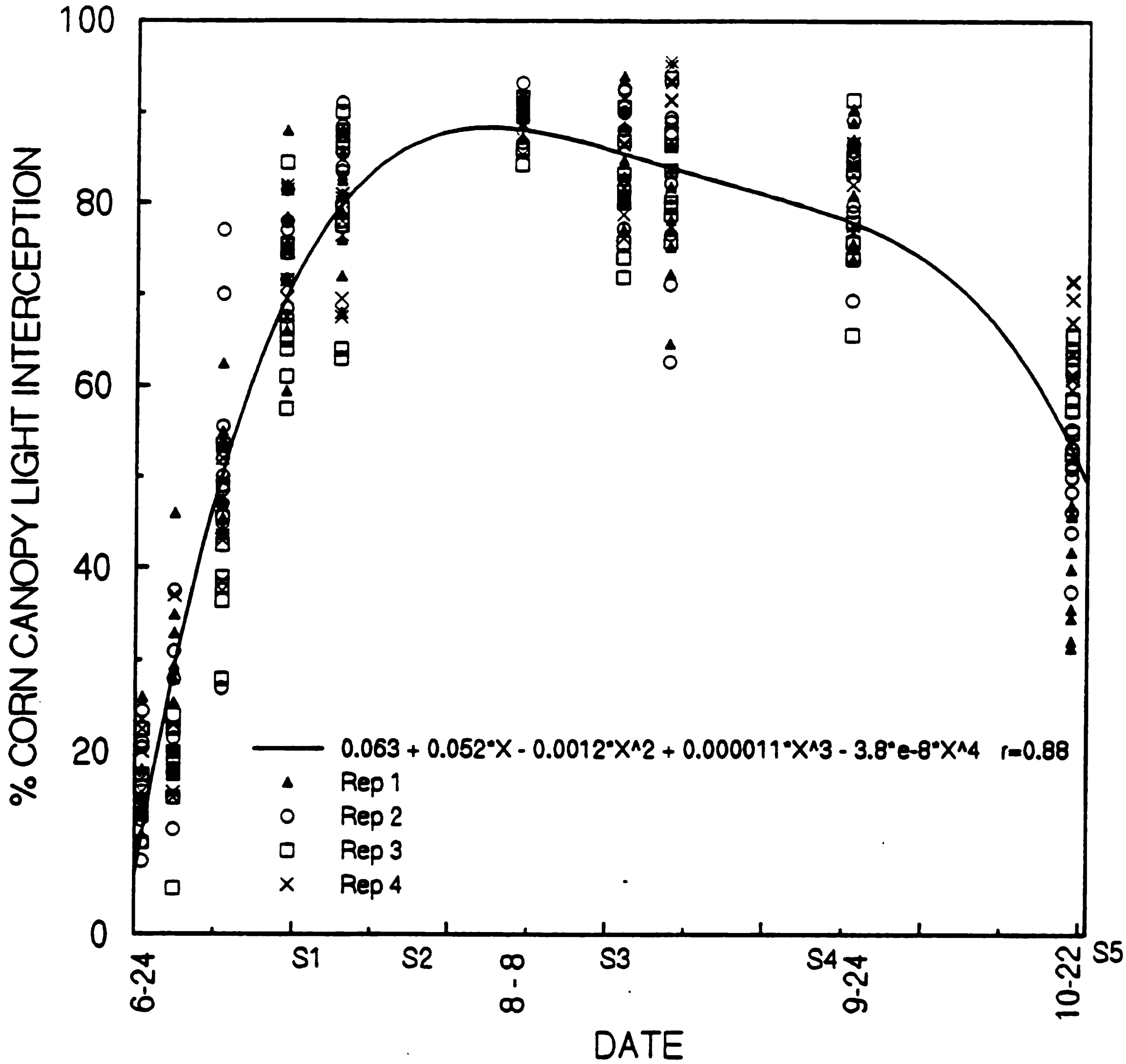
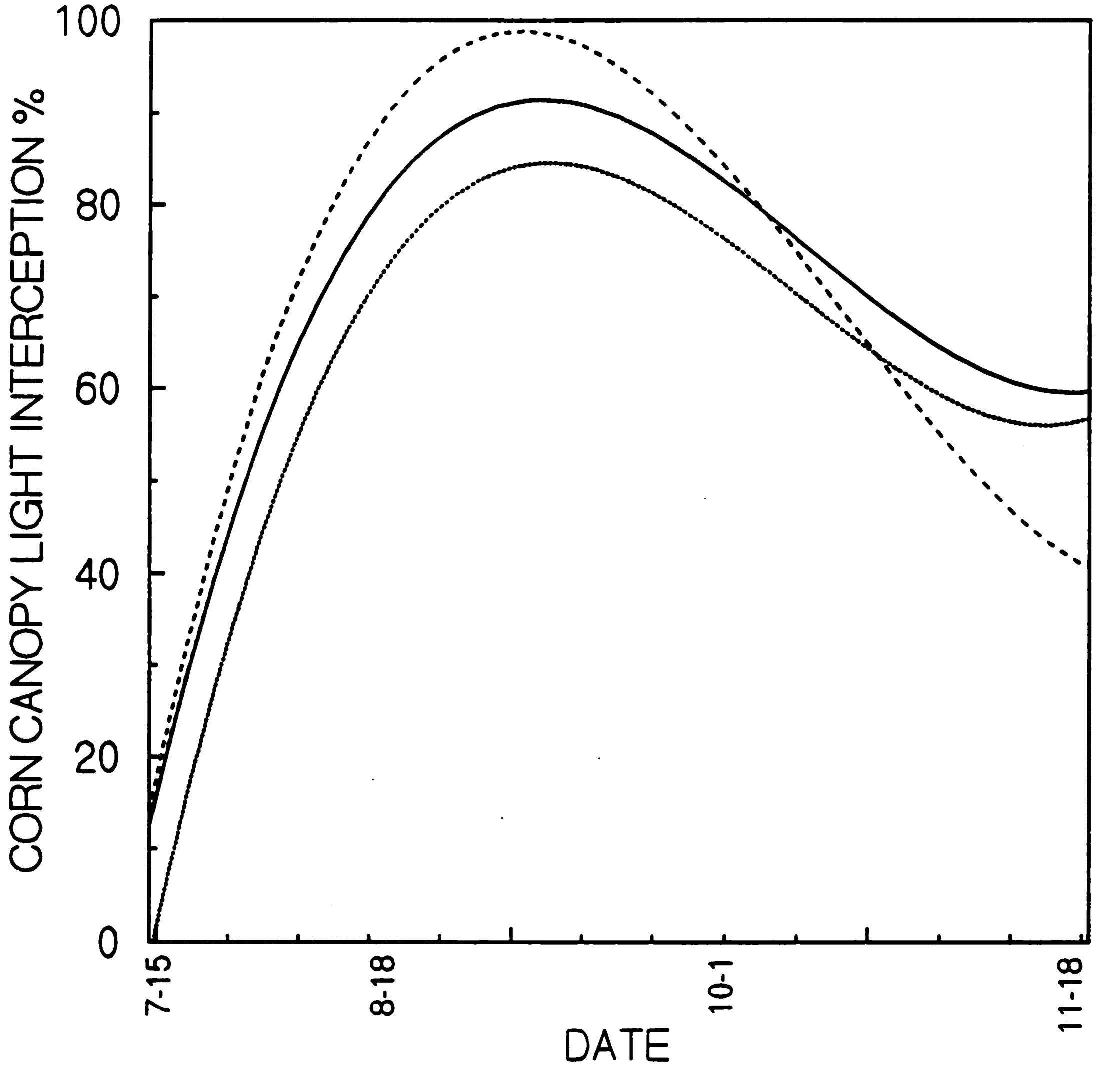


Figure 5. Corn canopy light interception for EL, 1993. LI measurement dates and means: Jun 24-16.7%, Jun 29-22.6%, Jul 5-48.2%, Jul 13-73.1%, Jul 20-80.1%, Aug 12-89.8%, Aug 25-83.8%, Sept 1-82.8%, Sept 24-79.5%, Oct 22-53.5%. [s=cover crop sampling].



——— REP 1 = 0.158047 + 0.032466*X - 0.000426*X^2 + 0.000001555*X^3 r=0.82

········ REP 2 = 0.017659 + 0.03515*X - 0.000459*X^2 + 0.0000017*X^3 r=0.88

------- REP 3 = 0.177905 + 0.035987*X - 0.000479*X^2 + 0.000001661*X^3 r= 0.83

Figure 6. Corn canopy light interception for OM by rep, 1993. LI measurement dates: Jul 15, Jul 30, Aug 18, Oct 1, Nov 18. See figure 7 for further description of OM LI.

The most pronounced division separated cluster 4. The other clusters had less distinct divisions. Cluster 4 provided the most "generous" light environment for the covers through most of the season. Mid-day ambient light values for sites in this cluster were generally above 300 umoles m^{-2} s^{-1}. The high late season light availability of cluster 2 (only in the third rep), is difficult to explain, but leaf areas and plant weights were slightly higher (within spp) for these sites at the final sampling.

Interpretations of field variability of LI indicated the center second rep (cluster 4) had the most uniform light environment (numerous sites in the other reps also belonged to this cluster). The south rep had sites from all 4 clusters, but the majority of its sites (25) were segregated by the smallest division. The north rep had a more mottled light environment than did the other reps. Rows of sites (east-west) tended to be more similar (belonged to the same clusters) than sites within a plot (patterns were more detectable and associated with site position across the slope (E-W) than along the slope (N-S). Trends in site similarity were apparent in all reps. Only plots 11, 14, 16, 17, 18, 19, 20 had consistent light environments (all 3 sites of these plots belonged to the same cluster) (figure 7). Most of these were in the center replicate, and each represented a different cover treatment. No treatment was associated with any specific pattern of LI or LI variability except for two of the MDC sites which were in the LI cluster (3). The remaining 3 sites of this cluster were distributed among AC, HV, and NCCO. Cluster patterns of light environment by treatment are also presented in figure 7. Only the AC and MDC treatments had the sites in all four clusters, i.e., the most uniform exposure to the possible light environments. Vetch-grass plots tended to be skewed to the largest cluster.

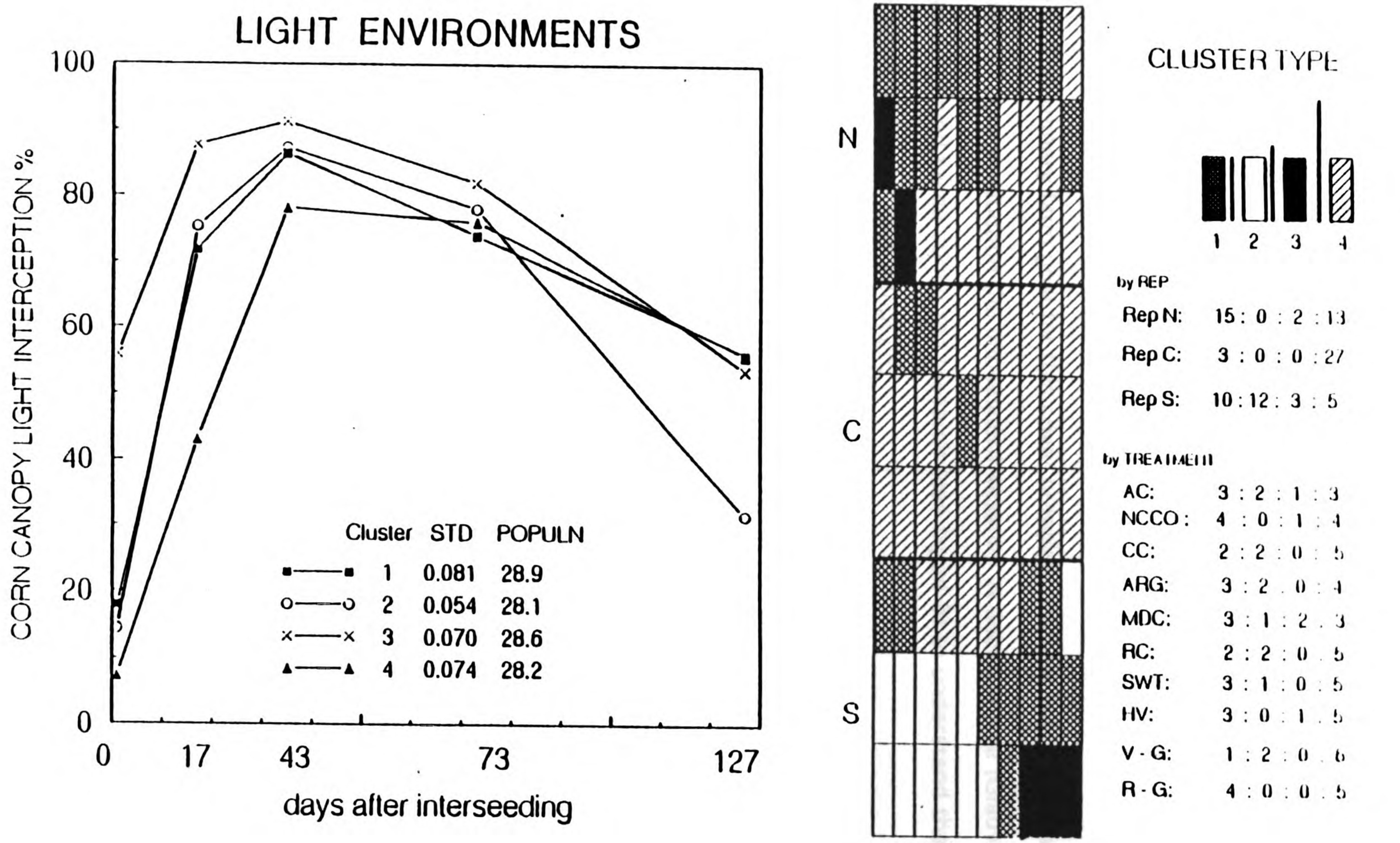


Figure 7. a. Four OM light environments as distinguished by Ward's clustering procedure. b. Spatial frequency and distribution of light cluster type across the field.

Cover Crop Comparisons: Performance

Introduction

In the initial phases of the on-farm research process, overseeding legumes at corn cultivation (or side-dress) was identified by the farm managers as a potentially sustainable practice, which was also compatible with a late spring operational "window". The primary farm goal for this cover cropping practice was N fertilizer substitution for corn production the subsequent season. A decision tree (Gladwin, 1989) was employed twice during the research (see figure 8) to understand the decisions effecting cover crop adoption.

The farm management's performance criteria for overseeded cover crops included mean available N (plant and soil) and distribution of N over the field at planting the subsequent season. Available N (within the two subsequent seasons) needed to be at least equivalent to cover crop seed cost to justify the practice. Uniform N distribution was recognized as important for evaluating practical potential of overseeding. The researchers hoped that the introduction of cover crops might demonstrate other, less direct benefits as well.

The applied research objective was to identify the best species for N (and biomass) contribution to the subsequent crop when interseeded into commercial field corn at cultivation for central Michigan farmers. The components of available N are the soil N and plant N (the product of biomass and N concentration). The small plot trial (EL) assumed greater importance as a check of relative performance, given the late planting and interseeding, and the extreme variability of the corn stand, at OM.

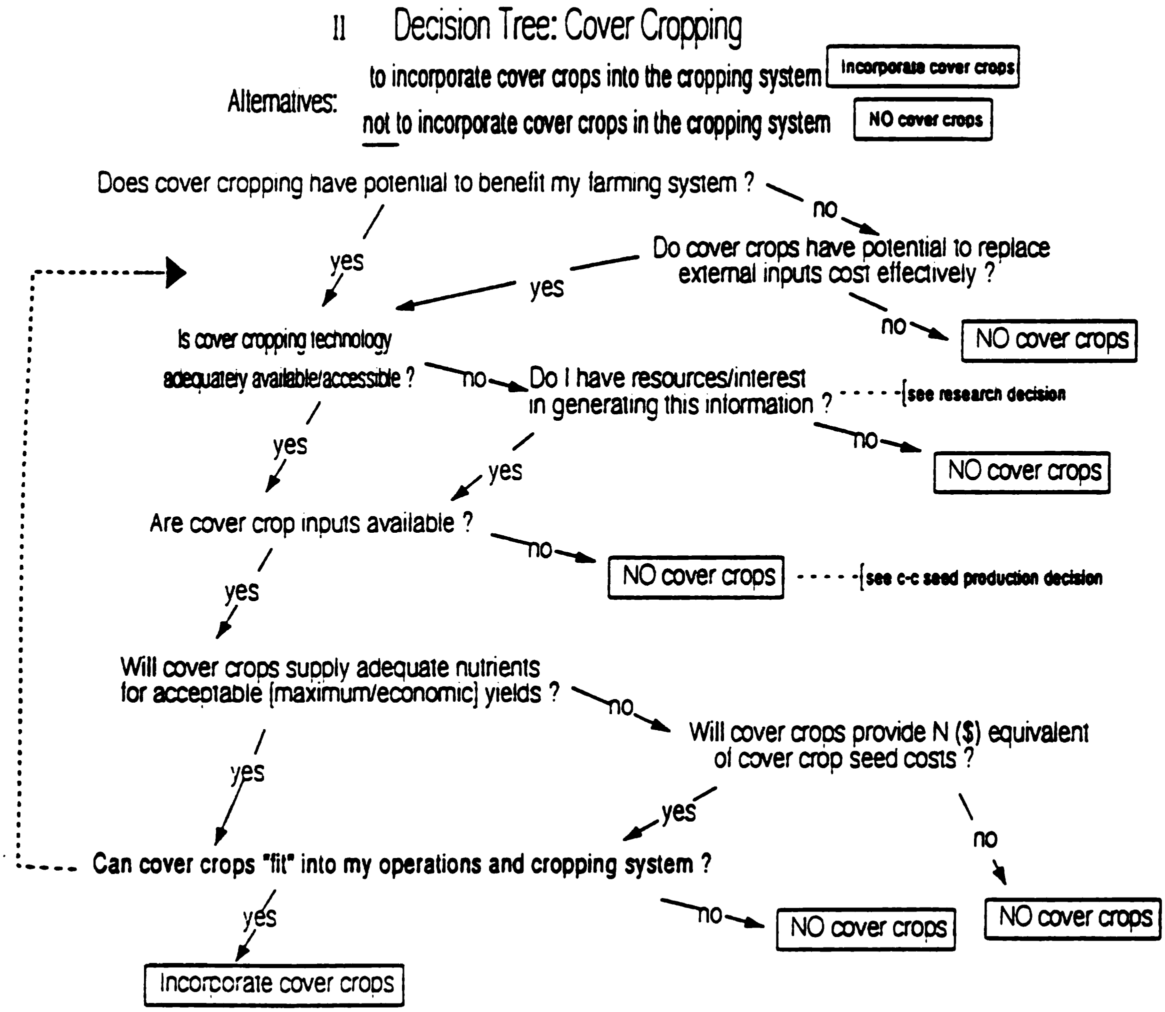


Figure 8. Decision tree for cover cropping created by Omega Farms. Dotted line indicates **reordered** decision process as of winter 1994.

Corn Yield: interseeding year

Method

Each plot (EL) and site (OM) was sampled for corn grain yield (October 26 and November 2, respectively). Ears were hand-harvested from 20' strips of the center 2 rows of each EL plot, and from 2 adjacent, non-guess rows in each OM site. Corn was shelled, then moisture was taken with an automated moisture sensor. Yields and test weight were calculated at a corrected moisture of 15.5%.

Results

Seeding year (1993) corn grain yield, which can be considered an index of the integrated environment (Chapin, 1991), was not effected by cover crop treatment, but did differ with rep at EL. Blocking was validated by these results. Mean yield at 15.5% moisture for EL was 7.59 Mg ha^{-1} (121 bushel a^{-1}).

Corn grain yield in OM was significantly associated with rep ($p=0.01$), and treatment. There was an interaction of slope position and treatment, which may have been related soil moisture characteristics (flooding and drainage) or corn canopy development (figure 7 above). Mean yield for the entire field was 5.9 mg ha^{-1} (94.4 bushel a^{-1}). No clear developmental, physiological or productivity trend seemed to associate treatments. The no cover-corn only (NCCO) treatment ranked fifth among 10 treatments.

One possible explanation for the unexpected relation of corn yield and one cover treatment may be that the yield rankings follow the light clusters for one group, that of the "highest" LI. This group was distinguishable from the other sites even at interseeding (figure 7 above). Sweet and crimson clovers, ARG, and both mixtures, by random assignment, had no sites in this "best developed corn canopy" cluster (Figure 7 above). These species were all associated with low corn yield and low SD. Annual medic, which was associated with the highest corn yield, had 2 sites in this vigorous corn canopy LI cluster. The remaining cover species (except red clover) had one site in the high LI cluster and had intermediate corn yields.

Mean comparison (LSD) procedures resulted in 4 groupings (table 2), but the ANOVA model only accounted for 32% of the variation in corn yield. Annual medic also had the highest standard deviation (30 bushel), red and sweet clovers, and ARG had the lowest SD's (10 bushel); the remaining treatments had SD's ranging from 15-20 bushel. In summary, as is consistent with the literature (Scott et al., 1981), covers probably did not actually influence corn yield at either location. Yield differences at OM were attributed to chance assignment of cover species treatments to field plots.

Table 2. Corn yield, OM 1993. [Fisher's LSD p = 0.05].

Treatment	Mg ha^{-1}	Mean bushel a^{-1}	LSD	SD
Annual Medic	6.9	110	a	31
Hairy Vetch	6.4	102	ab	18
Alsike Clover	6.3	100	abc	17
Red Clover	6.2	99	abc	9
No Cover-Corn Only	6.2	98	abc	18
Annual Ryegrass	5.8	92	bcd	10
Crimson Clover	5.6	90	bcd	16
Vetch-grass	5.3	85	cd	16
Red-grass	5.3	84	cd	20
Sweet Clover	5.1	81	d	10

Soil Nitrogen

Methods

Soils were sampled for nitrate and ammonium on 6 dates at EL; a baseline sample prior to all field activity, a second baseline at interseeding (following tillage, corn planting and fertilization), at maximum corn uptake i.e., physiological maturity (mid-dent), at the cessation of cover crop growth (dormancy) in late fall (which coincided with a drop in soil temperature), at the initiation of cover crop growth in early spring, and at the end of spring growth, just prior to tillage (kill) in May, 1994. Four soil cores were composited for each EL plot on each date. In 1993, EL was sampled to 30 cm (12"), in 1994 to 60 cm (24").

Soils were sampled three times at OM; a baseline following spring discing (prior to corn planting and fertilization), in late fall following cessation of cover crop growth (at the drop in soil temperature, see figure 4 above), and prior to cover crop kill in spring. An early April subset of the central sites of each treatment was sampled to monitor changes in soil N status over winter.

Five soil cores were randomly sampled in a 3 m radius around fixed sample points and composited. There were 3 sample sites on a longitudinal axis of the plot, for a total of fifteen cores (5x3 subsample sites) per plot. All OM soils were sampled to a depth of 60 cm (24").

Soil samples were dried for 72 hrs at 36° C. Dried samples were ground and extracted using a modified 1N KCl procedure (Page et al., 1990). Nitrate and ammonium were determined by the MSU Soils Lab using atomic absorption (Latchat Chemicals, Mequon, WI). Soil pH was measured for OM on the baseline (May 1993) sample set using a Corning pH probe. Data were analyzed using SAS GLM repeated measures, means, LSD and Tukey procedures (SAS 1991).

<u>Results</u>

The experimental variable of interest was soil nitrogen, though soil pH and phosphorous are important soil factors affecting legume performance.

Repeated measures analysis showed no effect of cover crop treatment on soil nitrate, ammonium, or total nitrogen over the six samplings at EL, although date of sampling was always significant. Least significant difference procedures indicated no differences in N parameters with treatment. Soil nitrate and ammonium (KCL extractable) are reported in figure 9. Time trends are evident. A perplexing significant difference was detected in the baseline (April 93) sampling indicated that the control (NCCO) treatment had greater NH_4 at the onset of the experiment. At corn denting, in September, NO_3 in the NCCO plots was also statistically greater than those of the other treatments. Considering the baseline deviation, this fall result was attributed to previous field or treatment history, and not related to the current experimental treatments.

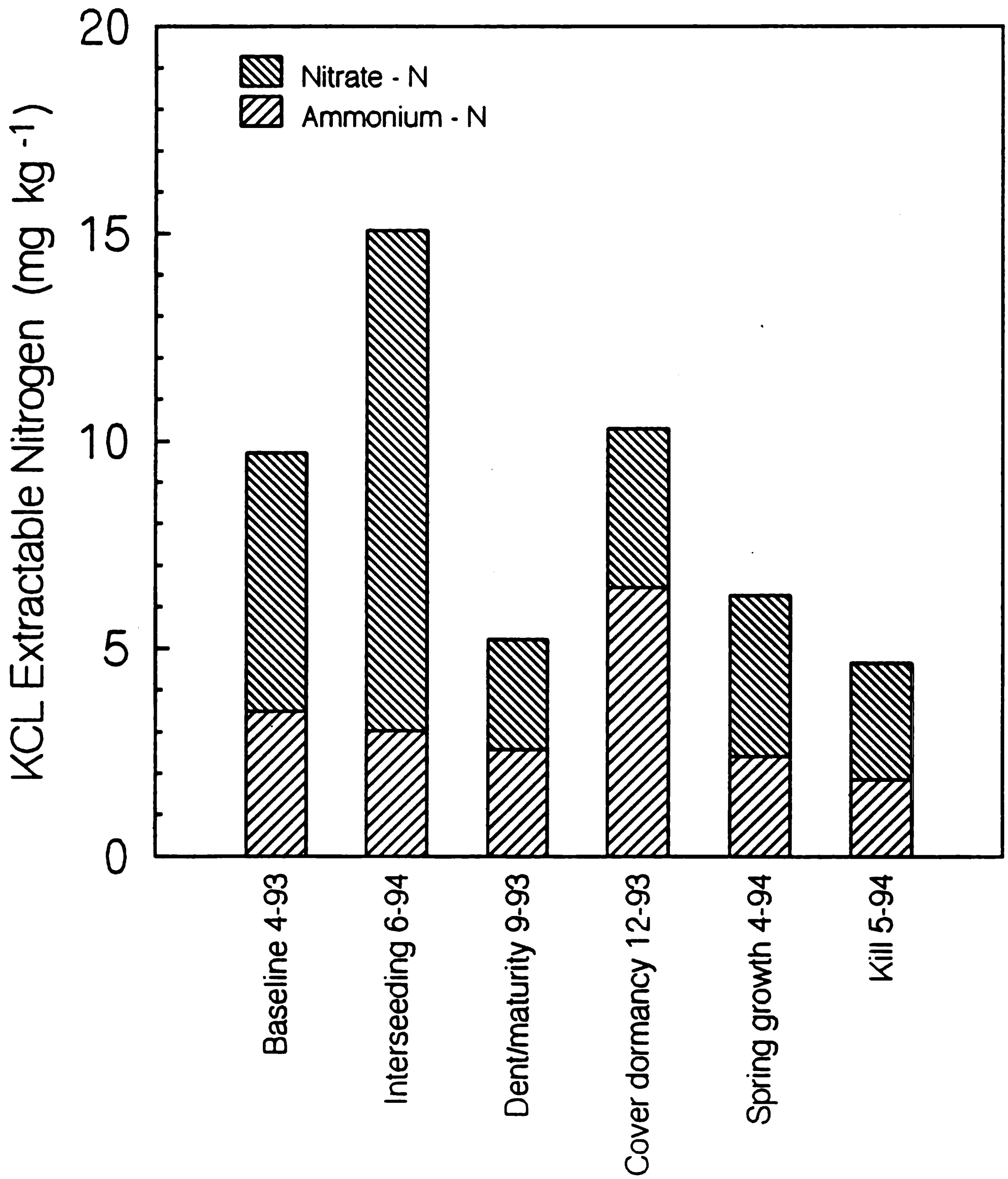


Figure 9. Soil ammonium and nitrate for all plots at EL during the course of the experiment. No treatment differences were detected.

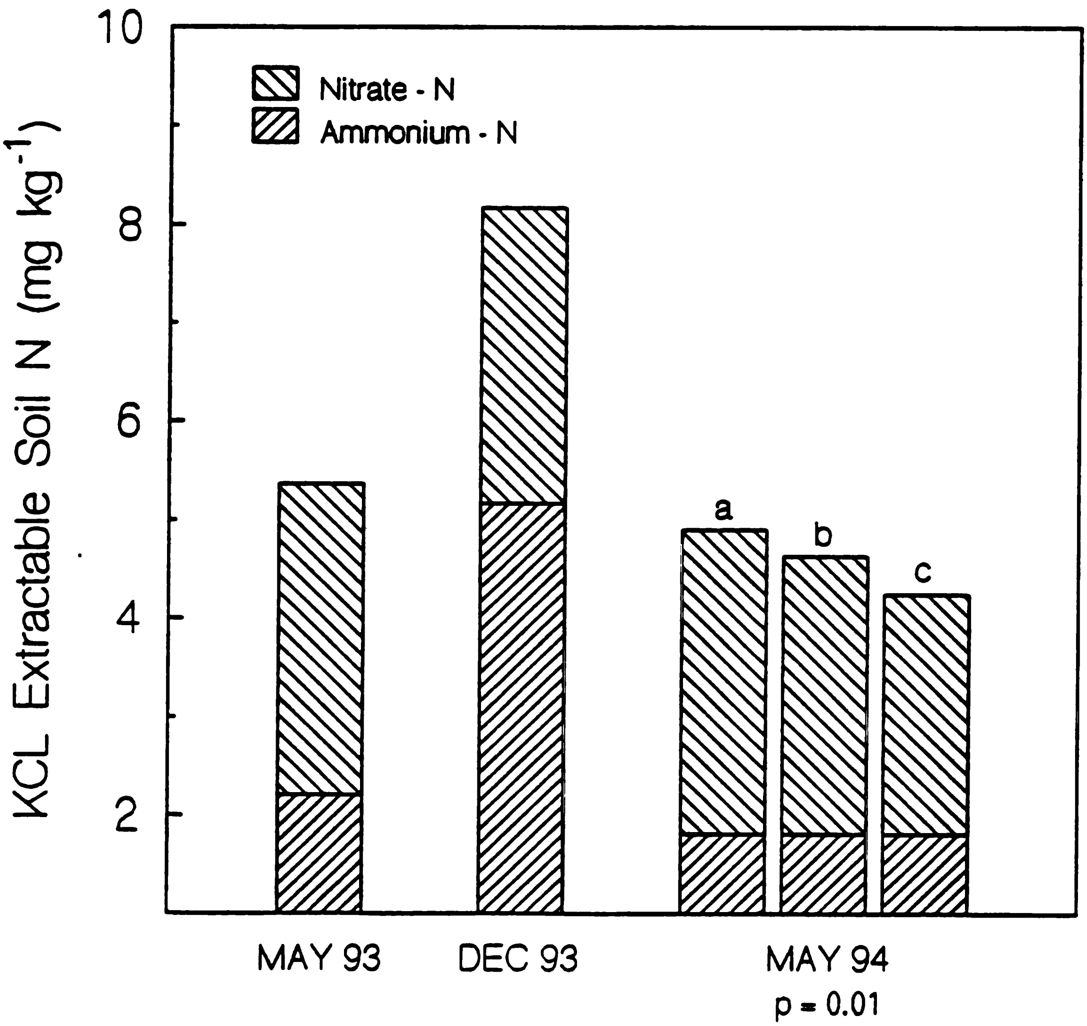


Figure 10. Soil ammonium and nitrate trends at OM for three samplings. LSD at $p = 0.05$.
a = CC,AC,MDC,RC,HV,NCCO   b = MDC,RC,HV,NCCO,SWT   c = RC,HV,NCCO,SWT,ARG,R-G,V-G

At OM there were differences of soil N with rep and site. Soil N (NH_4) was more available in the south rep at the base of the slope. Soil pH did not differ with OM treatment, rep or site, mean soil pH was 6. Lowest site acidity was 4.7.

At OM, nitrate differed (ANOVA $p=0.01$) with cover crop treatment at the final (May 1994) sampling, however the ecological or agronomic significance (within a range of 5 lb a^{-1}) is limited (figure 10). As was observed for EL, plots that had been interseeded with CC the previous year had the highest NO_3 levels, and the three treatments that included ARG tended to have the lowest NO_3 values. Ammonium did not differ with treatment, but did differ with rep. The two southernmost sites tended to have higher NH_4 than other sites. Combined soil N did not differ with treatment, but did differ with rep. Mean separation procedures (Fishers LSD) created groupings around 3 means.

At the end of the experiments (May 94) the trends of soil N with cover crop treatment were similar for both EL and OM. Relative rankings of species were similar (table 2). These non-significant trends were perhaps the most interesting outcome of this analysis. Treatment species (CC, MDC, BKWT) which winterkilled tended to have higher soil nitrate (and therefore combined soil N). Annual ryegrass treatments tended to have the lowest soil nitrate and combined soil N. Relative decomposition and uptake rates likely account for these tendencies. Red clover had the highest NH_4 values at both locations, but there is no obvious explanation.

Soils at both locations had moderate amounts of measured available soil N at the termination of the experiments in May 1994, averaging 4.6 ppm, or approximately 38 kg ha^{-1} (34 lbs N a^{-1}).

Table 3. Trends in soil NO_3 and NH_4 (ppm) with cover crop treatment at two experimental locations at cover crop kill (May 9 (EL) and 13 (OM), 1994).

NITRATE N		COMBINED SOIL N		AMMONIUM N	
EL	OM	EL	OM	EL	OM
CC 3.1	CC 3.5a	BKWT 5.0	CC 6.0a	RC 2.2	RC 2.5
MDC 3.1	AC 3.4a	CC 4.9	RC 5.4ab	HV 2.0	CC 2.5
BKWT 3.0	MDC 3.3ab	SWT 4.9	MDC 5.1ab	BKWT 2.0	NCCO 2.0
NCCO 3.0	RC 2.9abc	MDC 4.8	AC 4.8ab	SWT 1.9	R-G 1.9
SWT 2.9	HV 2.8abc	NCCO 4.7	NCCO 4.6ab	CC 1.8	MDC 1.7
AC 2.9	NCCO 2.6abc	RC 4.7	HV 4.4ab	MDC 1.8	V-G 1.7
RC 2.5	SWT 2.5 bc	AC 4.5	ARG 3.8 b	NCCO 1.8	ARG 1.6
HV 2.4	ARG 2.2 c	HV 4.4	V-G 3.8 b	ARG 1.7	HV 1.6
ARG 2.3	R-G 2.1 c	ARG 4.0	R-G 3.8 b	AC 1.6	AC 1.4
	V-G 1.9 c		SWT 3.7 b		SWT 1.2

Small letters indicate where treatments significantly differ (LSD $p=0.05$). In columns without letters, there were no treatment differences. AC=Alsike Clover, ARG=Annual Ryegrass, BKWT=Buckwheat, CC=Crimson Clover, MDC=Annual Medic, NCCO=no cover-corn only, RC=Red Clover, SWT=Sweet Clover, HV=Hairy Vetch, R-G=red clover-ryegrass mix, V-G=hairy vetch-ryegrass mix.

Cover Crop Nitrogen

Methods

Cover crop N is the product of biomass and N concentration. Shoots were sampled randomly from all plots and both experiments in mid-May 1994, prior to the initiation of anthesis (all species in vegetative phase). Shoots had also been sampled from OM plot's in late November 1993. Whole plant samples were dried and ground to 1 mm with a Wiley Mill. Samples were digested with a micro-Kjeldahl procedure (0.100 g plant material (< 1 mm) in 12M H_2SO_4 with 1.5 g K_2SO_4 (+ 0.075 g SE catalyst). Following a 2 h digestion, NH_4 determined with a Latchat (see above). Shoot nitrogen (NH_4) per hectare was calculated using final dry matter per hectare and N concentration. Data were analyzed with SAS ANOVA and LSD procedures.

Results

At EL, mean total Kjeldahl N (TKN) concentration of the legumes (SWT,RC HV AC) was greater (p=0.002) than N concentration of ARG in May, 1994. Legume N concentration ranged from 3.1 to 3.6%, but did not differ statistically among legume species. Nitrogen concentration of ARG was approximately 2.5%.

Shoot biomass differed with treatment. Consequently, herbage (shoot) N per hectare differed with treatment. Treatments separated into two statistical groups. Results are reported in table 4.

At OM, plant N concentration also differed with treatment (p=0.0001), however treatment ranking was not the same as EL (table 4). Herbage biomass and N ha^{-1} also differed with treatment, and there were significant differences between reps (p=0.0001 and 0.05 respectively). Treatment rankings paralleled those at EL. Coefficients of determination (r^2) ranged between 0.6 and 0.75 for all analyses.

Table 4. Shoot N concentration, biomass, and N content for EL and OM, May 1994.

Shoot N concentration (%)		Biomass kg ha^{-1}		Cover Crop N: kg ha^{-1}	
OM	EL	OM	EL	OM	EL
HV 4.0	SWT 3.6	RC 206	RC 162	RC 74a	RC 58a
RC 3.7	RC 3.6	ARG 121	HV 112	HV 43ab	HV 40 b
AC 3.5	HV 3.5	HV 108	ARG 81	ARG 30 b	ARG 20 c
SWT 2.9	AC 3.1	SWT 95	AC 55	SWT 29 b	AC 18 c
ARG 2.5	ARG 2.5	AC 70	SWT 35	AC 24 b	SWT 13 c

Available Nitrogen in mid-May 1994

Soil N and plant N were summed to estimate N available to the subsequent crop (figure 11). Combined soil N values only were used for the winterkilled and NCCO treatment values. In EL, treatment differences in available N were determined by (and followed the pattern of) herbage N (table 4). There were both treatment and rep effects (p=0.0001 and 0.04 respectively). As in EL, the OM pattern duplicated that of herbage N. Treatment rankings were the same for both EL and OM.

Species that winterkilled had lower available N than did species that overwintered. The NCCO treatment had the lowest available N values (although it did not statistically differ from the winter-killed species). Locations differed at p=0.09, treatments differed over both locations at p=0.0001. Nitrogen values tended to be slightly higher at OM, perhaps reflecting the later sampling date (see figure 10). Biomass production was related to N, as is widely reported (Hargrove, 1986; Power, 1991). Biomass was also of interest because of the importance of soil organic matter for nutrient cycling and improved soil physical properties.

At EL, only RC and HV differed significantly from all the other treatments in available N. In OM, the rankings are similar to EL, but treatments were more distinct. Treatments (not reps) significantly differed at OM. Red clover differed from all other treatment groups, the remaining legumes not differing (see table 4). Treatment differences were more attributable to biomass than to differences in herbage N concentration or soil N. Scott et al. (1987) compared spring production of red, and sweet clovers, and hairy vetch interseeded into corn, and determined RC to have the greatest biomass. Spring growth over 3 dates was reported for ARG, HV, and CC seeded after corn harvest (Shipley et al., 1992). Earliest dates ranked ARG early spring growth slower and biomass and N yield lower than CC or HV. Shipley (1992) reported crimson clover had the most rapid spring growth rates, similar to rates observed at EL and OM in late fall.

Treatment statistical differences did represent practical differences in terms of available N. At OM, the RC treatment was within range of typical rates of fertilizer application for average mid-Michigan yield goals. Hairy vetch would result in reduction of fertilizer rates. The remaining treatments only provided starter N.

Further studies would be required to determine the actual pre-sidedress N values, and uptake and utilization of cover crop N by the subsequent crop.

Available N from red clover came closest to meeting the farmer seed cost criterion. This criterion is dependent on fertilizer N prices ($ .14 lb^{-1} in 1993), and current seed costs. Most species (including red clover) had 15-25 lbs less N than necessary to ensure "economic" viability at 1993 seed and N prices. Hairy vetch was the least economic.

The use of soil and shoot nitrogen was thought to be an appropriate, if conservative estimate of available N in the system. Other calculations (such as fertilizer replacement value) tend to overestimate actual N. By mid-May it was felt that soil samples (which included live and dead fine roots and nodules), would be an adequate estimate of nitrate and ammonium N. In Delaware, Mitchell and Teel (1977) compared yields of crimson clover and hairy vetch. They determined that 90% of the legume N utilized by subsequent season corn in a no-till system was derived from top growth. Mitchell and Teel (1977) reported crimson clover shoots had 160 kg ha^{-1} N compared with 14 kg ha^{-1} N from roots, while hairy vetch shoots and roots produced 150 and 22 kg ha^{-1} N, respectively. Root nitrogen content appears to be generally 10-15 % of shoot N content.

We felt winter and early spring weathering and decomposition of plant material might result in uptake, leaching or immobilization in the SOM fraction, and would account for most soluble N by mid-May. (By spring, no surface residue of the winter-killed species was observed.) In addition, a percentage of the spring herbage TKN (i.e., lignin N) is likely unavailable to the immediate subsequent crop. This is an important topic of other studies (Wagger, 1990; Berg et al., 1987;

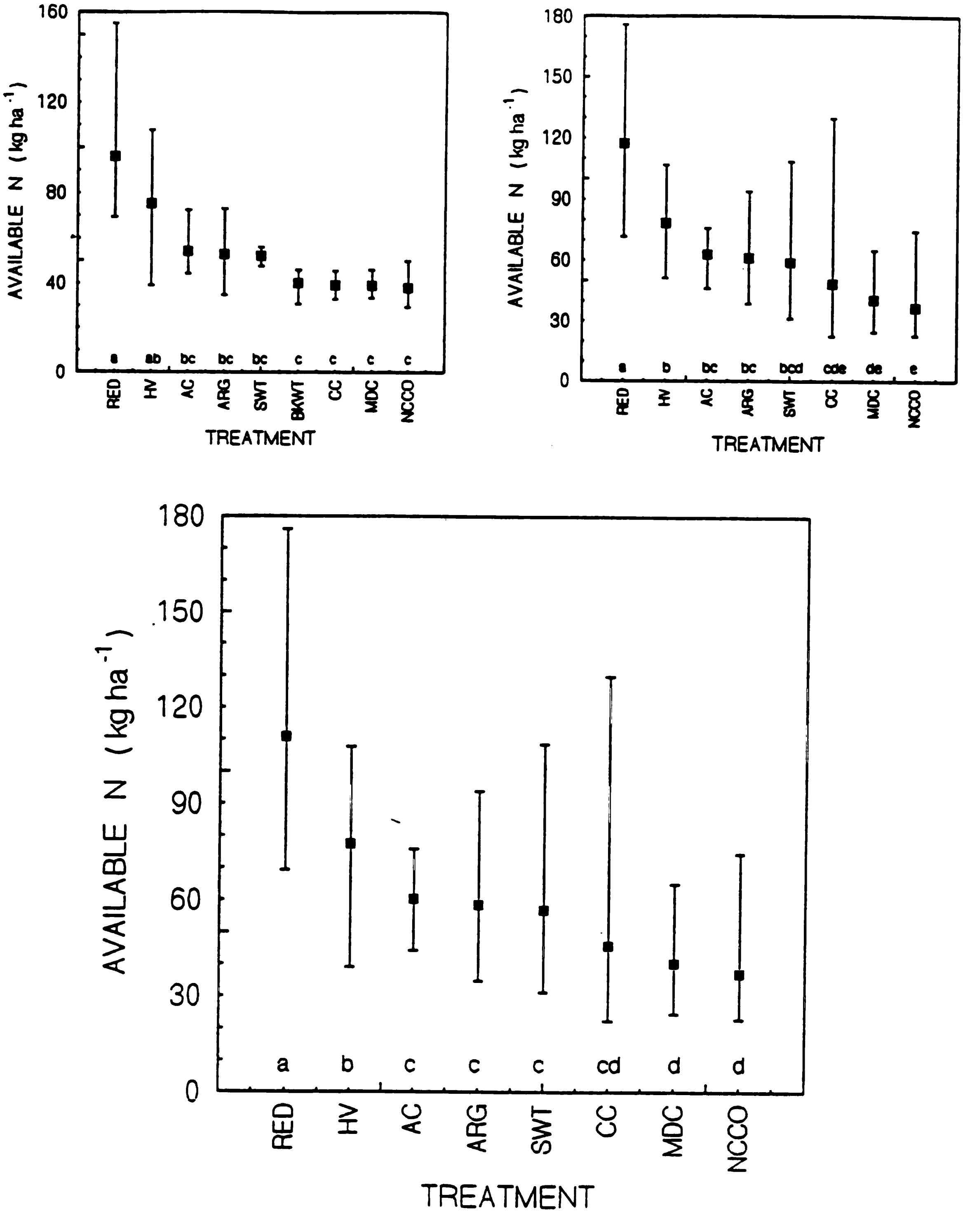


Figure 11. Mean, minimum, and maximum available N (soil + plant N) in mid-May 1994 for cover treatments at EL (upper left), OM (upper right), and over both locations (n = 13) (bottom). LSD's at p = 0.05.

Huntington et al., 1985). In addition, soil nitrogen mineralization can be stimulated by the introduction of plant material or residues. This "priming effect" (Azam et al., 1991) was not quantified or calculated for this study.

Low and high measurements can be indicative of genetic potential in a given environment (Webb, 1972). The minimum N available values (22 or 30 kg ha) were surprisingly uniform across CC, MDC and NCCO treatments within location, suggesting soil factors may be more influential than plant factors in mineralization. The maximum values are also interesting, particularly the high OM CC value.

Late Fall 1993 Nitrogen

It seemed logical that spring N would be associated with plant biomass and soil N at the end of the fall seeding/growing season. Cover crop treatments included two species which winter-killed, CC and MDC, both legumes. Winter-killed species offer potentially lower spring control costs, and possibly better synchrony of N mineralization with crop uptake. But nitrate leaching from agricultural fields is a concern in mid-Michigan.

December biomass and soil N for both locations are presented in figures 12 and 13. Plant N concentration (and available N) were only determined for OM (center sites) (figure 14). Plant N concentration was greatest for HV and V-G, the other treatments had similar N concentrations. December available N (and soil N) did not differ with treatment (figure 14). Soil NH_4 did differ with OM rep and site. Soil N appeared to influence available N ranking. These data provide a rough index of N leaching potential. December soil N levels did differ with location, perhaps reflecting differences in fertilization and yield the previous season. When EL December soil N values are contrasted with the spring N values (figure 11 above), they indicate large decreases in soil NO_3 and NH_4 over the winter. April soil N values were slightly greater than May values, indicating early spring leaching, or uptake by plants or microorganisms. December biomass differed with treatment ($p<0.0001$) and location ($p<0.05$). Crimson clover's exceptionally high biomass and N availability in December do not clearly result in high spring N availability, perhaps due to winter-kill, and N mineralization or volatization. Red clover and HV were the next 'best species' at EL, and late fall success somewhat corresponded to mid-spring performance. Red clover's fall performance at OM is difficult to explain, except in terms of partitioning below ground that was not captured with root sampling. Annual medic's ranking at OM was due to high biomass at a few relatively "bright" sites or to soil N. Like CC, MDC's spring contribution did not correspond to it's late fall ranking was not related to ARG's differential performance with location may be attributable to different soil N. Hairy vetch did well at both locations. The N dynamics of winter-killed species (in interseeded systems) in northern temperate climates remain an important area for investigation.

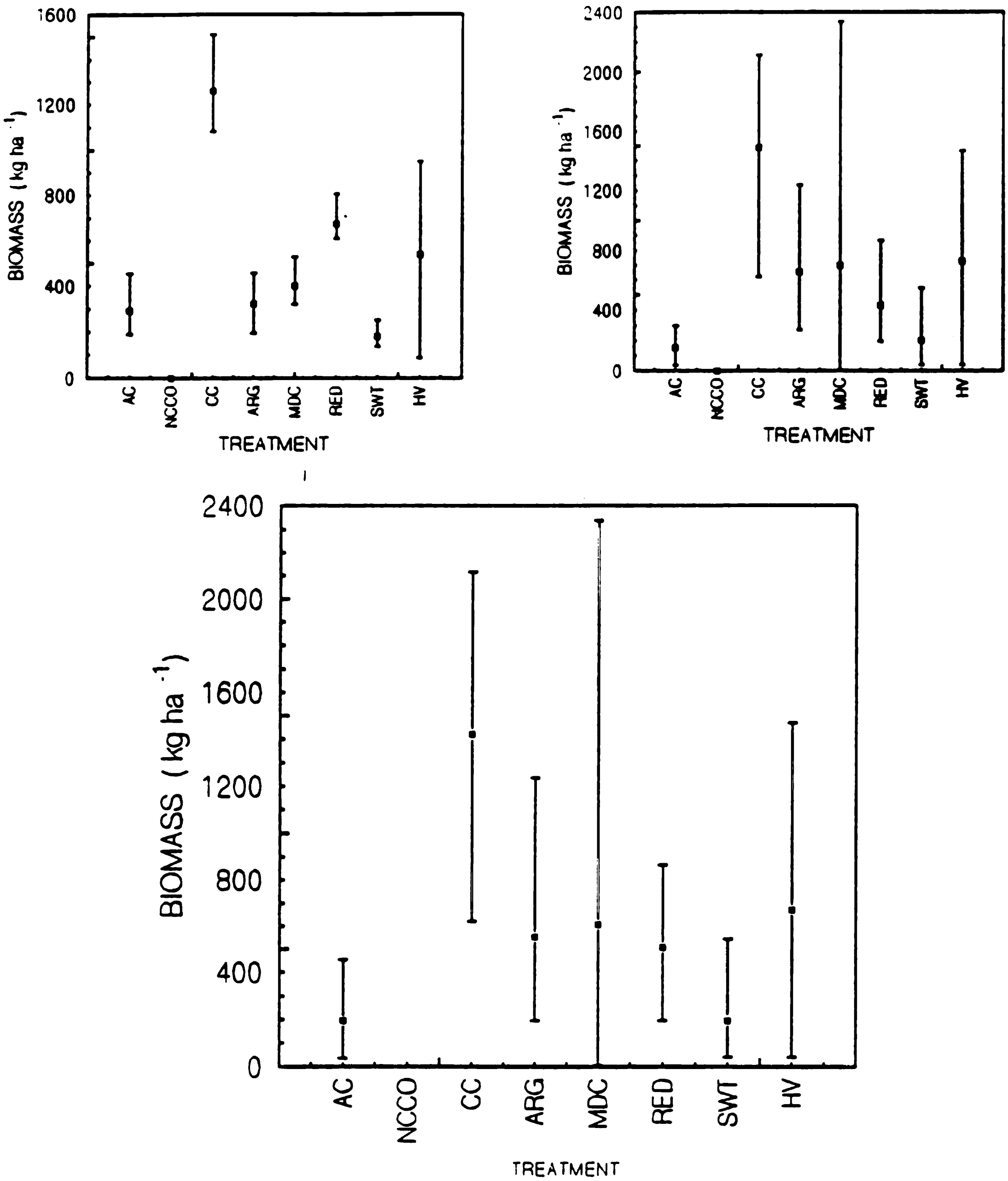


Figure 12. December mean, minimum and maximum biomass for EL (upper right), OM (upper left) and combined locations (below).

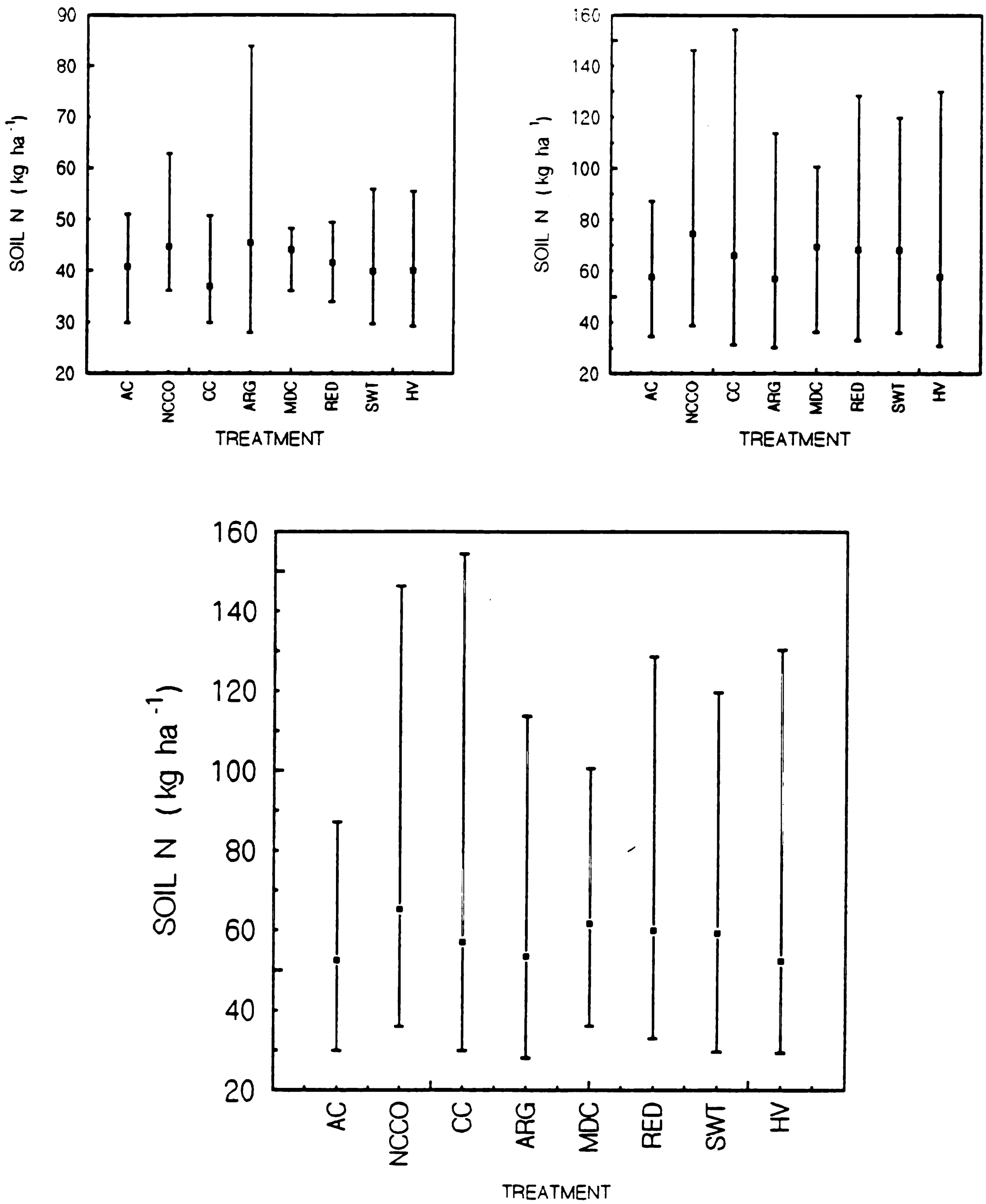


Figure 13. December mean, minimum and maximum soil N for EL (upper right), OM (upper left) and combined locations (below).

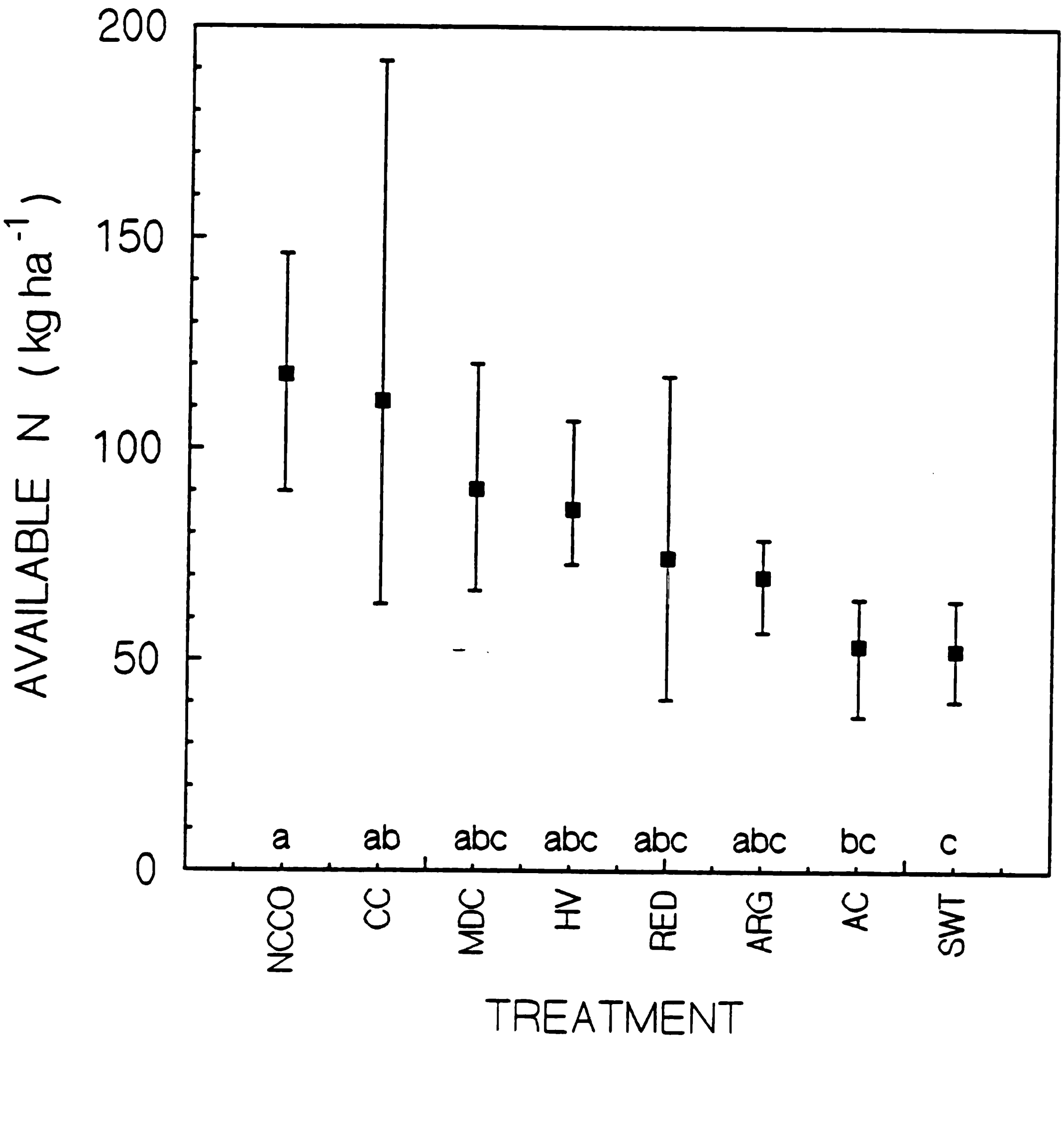


Figure 14. December available N (plant + soil N) for center sites of each OM plot.

Spatial Uniformity

Uniformity of cover crop growth and distribution of biomass and N accumulation through a field is an important performance criteria. From a farm perspective, the within field, within management (operational unit) variability, i.e., the response over a range of ecological microsites comprising the field was a critical parameter of cover species performance, which would influence cover crop species selection. Farmer identification of the uniformity criteria validated farmer participation in the research definition process, and the field scale approach.

When cover species are employed as alternative N sources, the uniform distribution and growth of a cover species across a field may be a key determinant to field management. The farmer cited uniform available N as important to facilitate fertilizer application, for maximum yield of the subsequent year's row crop. Environmentally, there may be microsites where it would be preferable for cover growth not to compensate for poor crop growth ("low" mesic or sandy sites) and where minimal N accrual via fixation would not benefit a crop because of other limiting microsite characteristics. It's possible cover biomass accumulation in poor crop microsites may mitigate the "quality" of these sites in the long term. These are field and system specific issues. The relationship of uniform cover crop growth and soil N uniformity, is addressed later. An analysis of the cover crop distribution and N contribution over a range of field microsites, not just a subset/series of discrete (experimental plot) environments was necessary.

Twentieth century developments in agronomic statistical theory introduced the concept of small plot research design to restrict environmental variability. Statistical analysis was used to partition environmental (experimental) variation, and distinguish management (treatment or species) effects. Prior to this agronomic research (much of it conducted in farmers fields) had reported variance of performance as an important, if empirical, criteria. Fisher's approach serves its purpose. However, there is also a need to describe and understand variability at operational, decision as well as natural scales (Robertson, 1987).

Field variability has ecological implications as well. From a research perspective we were interested in describing variability of each species as it might relate to soil factors or light (as created by the corn canopy). The variability of the corn canopy was described earlier. As discussed, the corn canopy (and yield) reflect both soil and light environment of a particular/given site. It is important to recognize that optimal conditions for corn growth may not be optimal for any or all cover species (or may be more optimal for some species than others). The interseeded system, by definition, is expected to permit adequate corn production. Screening out species which are incompatible with corn interseeding and corn dominated environments was one of the objectives of this experiment. In addition, corn growth modifies its own and the understory environment during the growing season. Corn growth and senescence is one of the dominant ecological features of each cover crop sample site.

There were several alternative ways of assessing variability in this project. These included mean comparisons of species via standard designs and analyses at two locations (and two scales), and comparison of species on the basis of spatially distinct environments (i.e., each of three blocks would be equated with a specific "environment" at OM (primarily based on position along the gradient), and one "environment" at EL). The issue in this case becomes that of the magnitude of within or between block variability, and relative influence on performance. Psuedoreplication issues are also a concern, specifically underlying, undetected factors or natural gradients which may have influenced performance over the three sites within a given OM plot. By the nature of the long narrow plot design at OM, different treatment microsites within each block were spatially closer (40') then were subplot (same) treatment sites (170'). (Field design had the objective of sites sharing similar landscape or topographic position, while main-plots encompassed the slope gradient.) Some consideration can be given to preliminary comparisons of these block environments, despite psuedoreplication, because of the specific field design and scale of the experiment and distances between experimental units. The use of experimental blocks as "environments" for assessment of variability has been informative for sugarcane (Bull et al., 1994).

The two locations represented differing physical factors such as soils, and weather, and management. Although the general system and operations were similar at both locations, there were differences in seasonal timing of operations. See the methodology section for a review of the management differences between locations such as corn planting and cover seeding dates, and associated climatic and soil conditions (moisture and temperature), N fertilization rates and techniques. Resilience to these differences is an important farm decision criteria.

Conventional stability analyses tests for interaction of environments, usually defined as locations or years, and is a tool used by plant breeders (Fehr, 1987; Simmonds, 1981). The objective is to use a mean performance among treatments at locations to select the best relative performance over a set of locations. These mean environmental indices can be calculated to include management or socio-economic constraints along with natural environment (location x year) (Hildebrand, 1993). The value of stability analysis is for determining responses over a wide range of environment and management interactions. This is distinct from understanding variability within a field as a performance parameter. Variability of performance across managements, years, and fields, of course, may be related.

The differing approaches to variability analysis support differing objectives. Stability analyses are tools of commercial seed producers and plant breeders, who are looking to develop standardized varieties as corporate strategy (mass production, economies of scale) are paramount relative to a particular farm's or field management unit's optimization (Francis, 1990). Similar issues have been addressed in the literature of the green revolution and international research centers.

Stability analysis is a technique developed (and more appropriate) for comparison of germplasm than management practices, rather than optimization of a specific cropping system. Reviews of SA approaches have pointed out the relative effectiveness of various SA techniques for different questions (Lin et al, 1986; Pritts and Luby, 1990). Mathematically, regression procedures and modifications are used to detect deviation over a specified range of environments. Verma et al. (1978) proposed a functional stability analysis, which requires identification of environment/management quality, and allows for positive responses to good conditions and resilience-stability to sub-optimal conditions. The immediate management concern with interseeded systems is not "yield" maximization over the field unit (i.e., mean field yield), but consistency of cover performance throughout the field, so that fertilization can be adequately managed and crop demands met. The range and consistency of response is of interest, but the minimum possible response would be a particular concern for farmers relying on interseeding to supply N to a cash crop. Webb (1974) introduced a concept of boundary line analysis for multiple environment comparisons, however our dataset only provides 2 (or 4) "comparable" environments. The range of available N values indicated in figures 12-14 (above) can be used as preliminary indices of risk and potential. (Conversely, performance of an interseeded legume could be very responsive to site fertility conditions, with regard to N uptake or fixation, but stable over a range of overstory canopy densities). Perhaps optimal microsites for corn growth also might have optimal cover crop growth and N accumulation; while less optimal sites would accumulate less N, with a corresponding reduction in leaching potential. Over the long term, the ideal cover crop might mitigate overall field variability.

Geostatistical (GS) analyses are based on the premise that parameters vary in a contiguous concentration gradient that is spatially defined from any specified point in a field (Robertson, 1987). Initially developed for exploration and mapping of geological mineral deposits, GS use in ecology and agricultural research is still developing (Bresler, 1989) mostly to describe interrelated patterns of variability. Extrinsic variability, often unassociated with any natural features, quite possibly differs from intrinsic natural gradients. In agricultural fields, variability is a function of geologic, ecological, and management history as well as current management and natural conditions. Although potentially useful in detecting natural gradients, management gradients can supersede or distort natural gradients (Pierce et al., 1995). Nielsen and Alemi (1989) provided an overview of methods for evaluation of field spatial heterogeneity. The scale of measurement must be appropriate for the parameter considered, because theoretically, closer points should be more similar, but breakpoints or the transition between gradients originating from different points may not be practically detectable except if sample points are contiguous a very fine grid. For any specified parameter the scale might be expected to vary. Some scales of variability of naturally important features of a field may be impractical to measure at a naturally relevant scale; for dynamic features the relevant scale(s) may be difficult to determine.

The variability of performance criteria was quantified with coefficients of variation of each of the treatments (standard deviation divided by the mean of each treatment). Lin et al. (1986) endorse the appropriateness of CVs for stability analysis. Other techniques used in stability analysis tend to be forms of regression and cluster analysis (Eberhart, 1966; Francis, 1990). In another review of stability indices, Pritts and Luby (1990) determined that cultivar (strawberries) yield rankings were only associated with CV. They demonstrated that cultivar rankings varied with the stability analysis technique employed (including CV). Pritts and Luby (1990) indicate CVs are useful for single study evaluations of environmental response and genotype by environment interaction (though they do not feel that it is useful for "cross study comparison"). The use of CVs seemed particularly appropriate for cross species comparisons over such a wide range of variability. Other approaches to stability analysis often involve calculation of environmental mean or index for relative comparison of genotypes within environments to compare across "environments" (generally yields or locations or managements).

However, the focus of this study was variation within fields, across field microsites, as well as across managements and locations. In addition, an environmental index (a parameter mean across all treatments) assumes that an environment has similar influence on a given parameter for all genotypes in a study, this was not a valid assumption for this study (since it included such diverse families, genus and species). Another concern about stability analyses using an environmental index, was addressed by Verma et al. (1978). They redefined "stability" as a positive response to conditions better than average but not sensitive to poor conditions, rather than the generally applied linear assessment from poor to good environments. Within field classification of good and bad sites was not appropriate for our experiments, especially as our performance criteria did not follow linear trends over sites, and as we were interested in the performance over the range of microenvironments. Pritts and Luby (1990) also acknowledge the pitfalls of the environmental classification from a farm practical perspective may not be legitimate. Ott and Hargrove (1989) used CVs to compare "corn yield riskiness" following crimson clover and hairy vetch winter cover crops, both of which compared favorably or were less risky than fallow or wheat winter cover. Differences in variance were attributed to rainfall. Their analysis was for small plot replicates, not full field comparisons.

The CV stability measure is independent of performance level, and decisions about cover species selection should consider both performance level (discussed earlier), and variability. Variance of growth analysis parameters, thought to be supportive of understanding the uniformity of the performance criteria are addressed later.

Methods

Two discreet datasets and scales were considered in the spatial variability evaluation. Spatial variability analyses were primarily derived from the OM location. Two locations and 4 "environments" were evaluated. Because OM was blocked on blocks differed in physical characteristics, each block was considered an environment. The series of OM sites (considered as 3 block environments or as 9 sub-block sites) represented environments along the slope, oriented along the NS gradient. The 9 sampling sites for each treatment were used as one dataset, and variance of biomass and N were quantified.

Results

Performance criteria CV's are presented in tables 4-7. The tables below provide several levels of comparison of coefficients of variation for the performance

Table 5. Coefficients of variation (CV) for available nitrogen (plant + soil sources) by treatment at termination of experiment(s) mid-May 1994. (# in parentheses indicates # of values used in the calculation).

	AVAILABLE N			
TRT	ALL SITES (13)	OM only (9)	EL only (4)	OM by rep (3) N-C-S
AC	20	17.6	24.7	9.2 21.2 16.3
CC	58.9	66.7	13.2	29.7 21.6 79.7
ARG	28.3	27.8	31	22.6 36.9 23.2
MDC	25.3	29.4	13.3	24.0 24.2 26.5
RC	31.6	28.0	41.8	23.1 35.2 29.5
SWT	37.4	43.4	7.5	36.8 30.5 11.0*
HV	27.4	24.8	37.4	9.5 17.1 12.8
<u>NCCO</u>	37.6	43.4	25.8	13.8 27.0 71.8
R-G	---	26.6	---	24.1 9.0 6.9
V-G	---	53.3	---	15.7 26.0 61.5
BKWT	---	---	16.5	---

Column 1 (all sites) considers management (location) effects and environment by genotype interactions, OM only represents across field (environments) within management as does EL.

Table 6. Variability (CV) of components of available N ha^{-1} in May 1994. Winter-killed treatments variability is fully attributable to soils, see table 5 above.

	ALL SITES (13)			OM only (9)			EL only (4)		
TRT	BIOMASS	PLANT N	SOIL N	BIOMASS	PLANT N	SOIL N	BIOMASS	PLANT N	SOIL N
AC	49.7	48.5	17.3	41.2	36.3	18.1	77.2	83.6	16.7
ARG	26.4	35.4	30.5	16.6	30.1	33.6	33.6	38.2	26.8
RC	56.5	55.1	44.9	56.7	53.9	50.6	59.2	63.0	23.6
SWT	85.3	85.1	24.9	74.8	78.6	21.8	49.0	55.0	22.2
HV	45.5	46.3	31.5	40.6	40.5	37.9	61.4	65.9	9.

Table 7. Coefficients of variation (CV) for cover mass and soil nitrogen by treatment in late fall, 1993. (# in parentheses indicates # of values used in the calculation).

	ALL SITES (13)		OM only (9)		EL only (4)		OM by rep (3) N-C-S	
TRT	mass	soil	mass	soil	mass	soil	mass	soil
AC	57.0	33.3	52.7	31.5	41.6	22.9	41.4 42.0 78.9	25.7 35.2 35.9
CC	31.2	73.0	34.4	72.2	15.0	25.5	16.9 41.8 47.0	51.8 9.5 50.7
ARG	54.8	52.0	46.4	51.5	42.0	56.7	68.9 19.2 55.4	41.7 61.3 45.4
MDC	123.7	32.6	128.9	27.8	22.6	12.7	122.9 68.9 129.4	3.4 44.8 15.2
RC	42.1	57.0	49.1	56.6	13.1	19.5	47.6 30.0 21.8	16.4 59.5 46.8
SWT	68.2	48.1	79.3	44.0	27.1	28.8	52.9 59.2 119.4	20.6 27.7 47.7
HV	60.8	57.1	59.6	59.5	66.5	28.0	45.9 20.0 118.8	24.8 3.7 50.7
NCCO	0	55.3	0	53.6	0	27.6	0	73.6 31.4 46.8
R-G	---	---	--	101.8	---	---	--	29.5 18.9 53.8
V-G	---	---	--	59.5	---	---	--	124.6 17.9 27.4
BKWT	---	---	---	---	0	16.2	---	---

Table 8. Coefficient of variation of available N (plant + soil) and biomass for OM (center site (2) of each rep) at end of season December 1993. (# in parentheses indicates # of values used in the calculation).

	OM (3) center site each rep			
	AVAIL N	BIOMASS	PLANT N	SOIL N
AC	27.6	24.4	35.3	27.4
CC	63.1	17.3	8.3	91.8
ARG	16.6	23.7	32.5	18.4
MDC	30.1	129.1	132.2	9.5
RC	52.8	50.6	31.1	59.7
SWT	32.4	70.7	19.6	59.7
HV	21.5	83.7	81.2	60.7
NCCO	24.0	0	0	24.0
R-G*	42.0	32.4	27.9	61.1
V-G*	30.8	29.5	87.8	41.1

criteria available N, cover crop biomass (vegetation), and percent cover. Data are presented for the termination of the experiment in spring 1994, and the end of the growing season in 1993.

In the spring, available N (the sum of plant and soil N) did not tend to vary more at one location than another (EL vs OM). Nor did CV have a clear relationship with magnitude of available N. Variance is often expected to increase with mean. This was not the case for the performance criteria of this system. At OM, the extreme CV were always associated with the south rep. At OM, HV, RC, MDC, ARG, and AC tended to have the lowest and most similar CV's. At EL, CC, MDC, and SWT had the lowest CV's. Among the species which did not winter-kill (table 5) variation on available N is "partitioned" into variation of biomass, plant N and soil N. Plant N content is a product of N concentration and biomass. Variability of plant N was very similar to biomass variability among all the legumes. Annual ryegrass had greater variability of plant N, than of biomass, indicating more variability in N concentration than in the legumes. However, overall CV's for biomass and plant N were lower for ARG than for any of the legumes. Perhaps this is attributable to differing uptake and fixation thresholds for the legumes, a moot issue for ARG. Species variability of biomass and plant N tended to be greater than CV's of soil N, though the magnitude of the difference varied with species. This was especially apparent at EL. At EL, soil N CV's appeared relatively uniform for all treatments (table 6). Among all species, soil N CV's at EL were generally lower for the winterkilled treatments than the other treatments, suggesting plant activity at the time of sampling.

Available N varied most with CC for at OM, but had one of the lowest CV's for EL. Crimson clover's relatively high CV seems associated with the south rep in OM, (a single high value "outlier" site), it seems possible that within a general range crimson is phenotypically stable, but had a dramatic response to some threshold.

In contrast to spring, December CVs for biomass were lowest for CC, while CC soil N CV's were the highest. At EL, the lowest CVs (for both biomass and soil) were associated with CC. Soil N CVs were more consistent (except for ARG), than were biomass CV. Biomass CV was also comparatively low for RC (table 6).

In December, available N was only calculated for the central sites in each of the OM plots (table 7). The most curious contrast is between the MDC and CC data. Crimson clover biomass and plant N had exceptionally low variability, although soil N and available N were quite high. In contrast, MDC had low soil N and available N variability, while the variability of biomass and plant N was extremely high. Perhaps these trends can be explained by uptake capacity versus plasticity under environmental stress. If MDC had a highly plastic uptake (and N immobilization) capacity this might explain both the low soil N and available N CV and the high biomass CV. These results also suggest that MDC growth is dependent on N. Conversely, biomass and plant N ha^{-1} consistency of CC, suggest CC growth is relatively unaffected by microsite soil and light characteristics. The high CV's of available N and soil N may indicate CC growth is independent of soil N. The extreme values of soil N of ARG and HV may be related to root death and mineralization of N. Mixtures were only compared within OM. Values for mixtures were interesting in that the V-G mixture tended to always (on all dates) have higher CV's than the R-G mixture.

Comparison of variance along the field gradient (and within sites) at the initiation and termination of the experiment was conducted to check for any possible compensatory or ameliorative properties/responses to microsites among the different cover species. However, the results were inconclusive. A longer term study would be necessary to determine the practical value of cover crop species to compensate for variability in field conditions, or actually decrease a field's N variability.

Transects

Methods

To better understand and quantify the field distribution of cover variability, OM plot transects (NS) were made 6 times during the experiment, 4 times in 1993, and twice in spring 1994. At OM, spatial variability and cover distribution were assessed for each treatment and plot. Transects were planned to coincide with specific field phases four times during the initial planting season (1993), and twice the following spring (1994) before plowdown. The initial transect was conducted on July 26, 1993, following germination and establishment of all covers, but preceded canopy closure. This transect created a 12.3x12.3 m (40x40') grid (one transect per plot). The second transect (September 9, at corn silking) created a 12.3x6 m (40x20') grid (two transects per plot). All remaining transects resulted in a 6x6 m (20x20') grid for the entire research field area. These included the transects made on October 8 at corn physiological maturity; November 20 at the end of growing season; April 20, 1994 when all overwintered covers were actively growing, and prior to control on May 14.

To assess cover distribution characteristics, north-south transects were made of each plot along a corn interrow. The specific interrows sampled were randomly selected and varied with plot and date. On all but the first sampling date, an east and west planting pass was sampled for each plot. In plots where there was obvious damage to one of the adjacent/framing/bordering corn rows of a transect, the transect was shifted to the next interrow.

A $0.76m^2$ (29") circular quadrat was dropped at 6m (20') intervals along an east and west interrow of each plot (approximately 24 drops per pass). This resulted in cover parameters being described for 72 drops along the N-S slope gradient (resulting in a total of 144 quadrats describing each treatment on each date). Plants either rooted in or overlapping a quadrat were considered to be part of the quadrat. Areas in plots where there was no corn (due to flooding, traffic or equipment failure) were excluded from calculations and mapped as missing data.

Cover presence or absence and dominance, and weed presence or absence and weed dominance within each hoop were recorded for each point (drop). Weeds were further classified as grass or broadleaf, and species cursorily identified. Cover presence or absence was also noted for 8 subsectors of the quadrat (a subsector = $0.1\ m^2$). In a modification of the Braun-Blanquet scale (Causton, 1985), the percentage of sites with cover present in all sectors (full cover), the percentage of sites with cover present in 4 (50%) or less of the subsectors (half sector), and the percentage of sites with cover present in 4-7 (51-99%) sectors (mostly cover) were calculated for each plot. In this section mixtures were not evaluated any differently than sole cover treatments. Mixture transects are addressed later in more detail.

The grids were used to describe and map plots and treatments. Plot data were statistically analyzed using SAS GLM, repeated measures, and mean comparison procedures. Despite the occurrence of some 100 and 0 percentage values for presence-absence parameters, the data were not transformed, because most parameters had a range of values so that the analyses was not skewed.

Results

Conventional cover data will be presented first, then variability and distribution data. Percentage cover estimates have been presented for several cover crop studies, but these have only been reported for small plots (Hayes, 1958; Scott 1981; Gilley et al., 1989). These data are not really comparable to the current field scale study. In small plots, Scott et al. (1981) ranked percent cover in fall and spring. He reported perennial ryegrass and red clover provided the most cover in one fall, while hairy vetch provided the most cover in another. However, in spring, sweet clover and perennial ryegrass provided the most cover. Gilley et al. (1989) found hairy vetch and crimson clover, among other species, provided over 90 % cover, but hairy vetch provided cover for the longest study period.

Analysis of variance for plots (each plot included an east and west transect each date) indicated treatment differences for cover and weed parameters. Block was significant on the first sampling date for all parameters except cover presence-absence. Weed dominance was significant for block (rep 3 separating out) throughout 1993. Block was only occasionally significant for various parameters on other dates (perhaps suggesting the corn canopy rather than edaphic site factors directly came to dominate these parameters).

Overall "cover" percentage was good for all species. Alsike and sweet clover tended to provide less cover in general, but AC was well distributed through the field. Every parameter differed with treatment on every date ($p=0.01$), except half sectors which were only significant on the first and fifth dates. In July, no covers dominated sites, so there were no differences in percentage of cover dominant sites. The significance of percentage of weed dominance increased with time. Mean square errors were relatively consistent for all parameters. In the later transects (4,5,6) (especially the final set), r^2 were higher and MSE lower than during 1993, whether this reflects variability due to canopy effects, or experimental technique is undetermined. It does suggest that there were no clear residual system/canopy effects or that there was some general compensatory growth.

Treatments grouped by mean separation procedures are presented in table 7. Relative treatment performance changed through time. The ranking of treatment groups also seemed to follow trends through time, as expected.

By tasseling (the second transect), both percent of sites with cover dominant and 100% cover were segregating out the AC, MDC (and NCCO) treatments. Annual medic did have a surge of growth between the October and November transect dates, which were not quantified. The earliest transect was generally less indicative of overall performance than the later transects (suggesting that later growth is more influential of final performance).

The most practical data generated form the transects may be % cover dominance and % weed presence. By the late fall transect, treatments were clearly distinguishable. No cover treatment differences were detected for the half-sector analysis, all cover crops provided at least 50% cover at the onset of winter. There was minimal difference in cover presence distribution among treatments, with the exception of AC and MDC; live MDC was not distinguishable from the no cover treatment. However, CD were clearly representative of field conditions, segregating SWT, AC and MDC, from the rest of the treatments.

Sweet clover's autumn performance might have been a seasonal response; shoot senescence was accompanied by development of prominent crown roots (not counted as cover) typically reported for this biennial growing in Michigan. Sweet's relative performance was considerably better in spring. Rapid increases in sweet (and HV) full cover and cover-dominant sites were observed in late spring, between the final transect and cover control.

As noted above, weed dominance of plots was associated with block. Weeds actually dominated very few sites throughout the experiment. The majority of field weeds recorded were broadleafs. In spring 1994, weed dominance of sites was almost entirely due to various species of chickweed, a cool season annual, which is not an agronomic problem. Weed presence-absence however, was clearly effected by treatment. Lower weed occurrence was detectable in the ARG sole and mixture plots beginning in September. The differentiation of ARG treatments persisted until the end of the experiment. Whether this is attributable to ARG stand density and direct competition for space and resources (ARG treatments had high percentages of full cover and cover-dominant sites) or some allelopathic activity is not known. Since ARG cover in spring 94 was less than RC and HV, yet weed presence was detectably less in the grass treatments, some soil allelopathic factor (or exceptional N competitive ability) may have been active. Among the ARG-mixture treatments no consistent ordering was apparent. No association of weed species with cover treatment was observed, and no weed-cover type association detected.

Throughout 1993, ARG, the mixtures, CC and RC had the greatest % of cover dominated sites. Hairy vetch cover dominance increased dramatically in the late fall (and late spring 94). In terms of winter cover (the November transects), the three ARG treatments, HV, and CC followed by RC provided the greatest amounts of cover (in a continuum of values). In spring 1994, RC and HV had the highest % CD, the ARG and mixtures % CD were reduced apparently due to winter-kill of ARG.

The transect data do not support any particular period as one of dynamic transition in species relative or absolute performance. However, the percentage of cover dominance disaggregated (and reordered) over the September-October-December periods. In comparison, the number of full cover sites decreased in December relative to October (without reordering of treatments).

Treatment ranges (along with mean and mode) are presented for the full canopy (October), December (winter cover) and May (final) transects. Data quadrats were mapped on for these dates.

Lack of cover crop stand uniformity (at plowdown) was attributed to a species lack of resource use plasticity, the absence of a facultative resource strategy, and a species limited range of stress tolerance.

Species intolerance of microsite variability (the lack of environmental plasticity) will result in non-uniform stands, and less than optimal, from a management perspective, N contributions due to non-uniformity (availability-distribution).

Table 9: Transect Parameter Groupings 1993. (Tukey's LSD p=0.05).

% of SITES w/	July 26 establishment	SEPT 9 tasseling	OCT 8 physiological-maturity	NOV 22 senescence: late dent	APRIL 20	MAY 14
COVER DOMNT	RG a	G VG C V RG R a	G a	VG a	V R a	V a
	C M R A S G ab	S ab	VG C RG R ab	RG ab	G VG S RG M C A N b	R RG ab
	V VG N b	A M bc	V S abc	C G V abc		VG bc
		N c	A cd	R bc		G cd
			N M d	S c		S de
				A M N d		A C M N e
100% COVER	VG a	RG G VG a	VG C RG R a	VG RG C V R G S a	RG R V a	R a
	C ab	R ab	G S V ab	A ab	S b	V ab
	V R A G abc	C abc	A abc	M bc	A VG bc	RG VG bc
	RG S bc	V bc	M bc	N c	G c	S G c
	M c	S bcd	N c	C	C M N d	A d
	N d	M A cd				C M N e
		N d				
COVER < 50%	N a	M R C N VG RGa	N a	N a	N M C a	N C M a
	A b	S V A ab	G A M V S RG C R VG b	G S M R A V C RG VG b	G b	R S V A RG VG Gb
	G bc	G a			RG bc	
	R V C M S RG VG cd				A cd	
					VG V S R d	

COVER PRSNT	A RG C V VG R S G a	A RG VG a	A RG VG G R C V S a	A RG C a	A R RG a	A RG VG V S C G Ra
	M b	G R V S ab	M ab	VG R S V ab	S VG V ab	M N b
	N c	C abc	N b	G?? M abc	G b	
		M bc		N c	C c	
		N d			M N d	
WEEDS DOMNT	C a	S a	A a	A a	S a	C R M N A V S G RG VG a
	G RG A M S R V VG N b	A N abc	S N ab	M N ab	A G C N R M V VG RGb	
		M bcde	V M RG C G VG R b	R S V C G VG RG b		
		C V RG R cde				
		VG G de				
WEEDS PRSNT	G a	N C A S R V M a	S M N R A a	A S M N R V a	V a	C N M A S V R a
	S ab	G b	C V RG VG G ab	C ab	A S M C N ab	G VG RG b
	M abc	RG bc		G VG RG b	R bc	
	V N A bcd	VG c			RG cd	
	C cd				G de	
	RG R VG d				VG e	

A = Alsike Clover, N = No cover-corn only, C = Crimson clover, G = Annual ryegrass, M = MDC, R = Red clover, S = Sweet clover, V = Hairy vetch, RG = Red clover-ryegrass, VG = Hairy vetch-ryegrass.

Mixtures

Whole field cover and nutrient accumulation, season long performance may be improved with appropriate mixtures of cover crop species which can compensate for growth over a broader range of sites with differing limiting factors. The OM trial included two mixtures: annual ryegrass-red clover which has been successful elsewhere (Scott et al;, 1981), and annual ryegrass-hairy vetch mixture, which has not been reported previously. The ARG was sown at a higher rate (45 lb a^{-1}) than intended, and RC and HV were seeded at full rate (15 and 30 lb a^{-1}). The high ARG rate undoubtably influenced our results. As stated above transects indicated mixtures provided exceptional fall cover. Figure 15 presents information about the transects of the two mixtures.

At the time of the first transect (2 weeks following interseeding), both species in each mix established well. But overall, the V-G mixture performed much better than did the R-G mixture, seemingly because of ARG growth rate relative to RC, and the climbing-vining growth of HV. Red clover was very low. Red clover appeared to compete better with ARG in "shadier" sites. Hairy vetch and ARG appeared compatible at the at the high seeding rates. The percentage of HV also appeared to increase in lower light sites. It's possible that this response was related to N relationships (a dense corn canopy relating to high N uptake, and less N for ARG) as reported by Stern and Donald (1962). Soil N associated with mixture treatments was addressed earlier. The nutrient relationships of grass-legume mixtures have been widely investigated (Dilz and Mulder, 1962; Barea et al., 1989), but were not addressed in this study.

At the final May '94 sampling, over the whole field, yields ranked RC, V-G, R-G, ARG and HV. Red clover alone had 500 kg ha^{-1} more biomass than either mixture. The V-G mixture tended to have higher biomass ($p = 0.03$) than did the R-G. Through the field, the V-G yield exceeded (by at least 200 kg ha^{-1} HV or ARG biomass alone at 5 sites, 2 sites had equal yields to one component (one ARG, one

HV), and 3 sites had intermediate yields. Red clover-ryegrass mixtures exceeded sole crops at 2 sites, but most sites had lower yields than red clover or ryegrass alone, 2 sites had yields that were intermediate between red and ryegrass sole crops. The V-G grass/legume ratio (mass basis) was much lower and had a smaller and more consistent range than did the R-G mixture. On October 7 (93) V-G had a slightly greater total biomass, than did R-G. The grass-legume ratio was also lower for V-G than R-G (figure 16).

Effective mixtures for seasonal nutrient and biomass accumulation will require complementary growth forms (habit, morphology), and synchronization of growth and resource capture, as well as synchrony of tissue decomposition rates and nutrient 'release'. The latter has been investigated in several studies (Ranells and Wagger, 1992; Wagger, 1989; Berg et al., 1987; Huntington et al., 1985). Understanding the performance of species growth in undersown systems would be a necessary prelude to mixture "design" or formulation for resource interception.

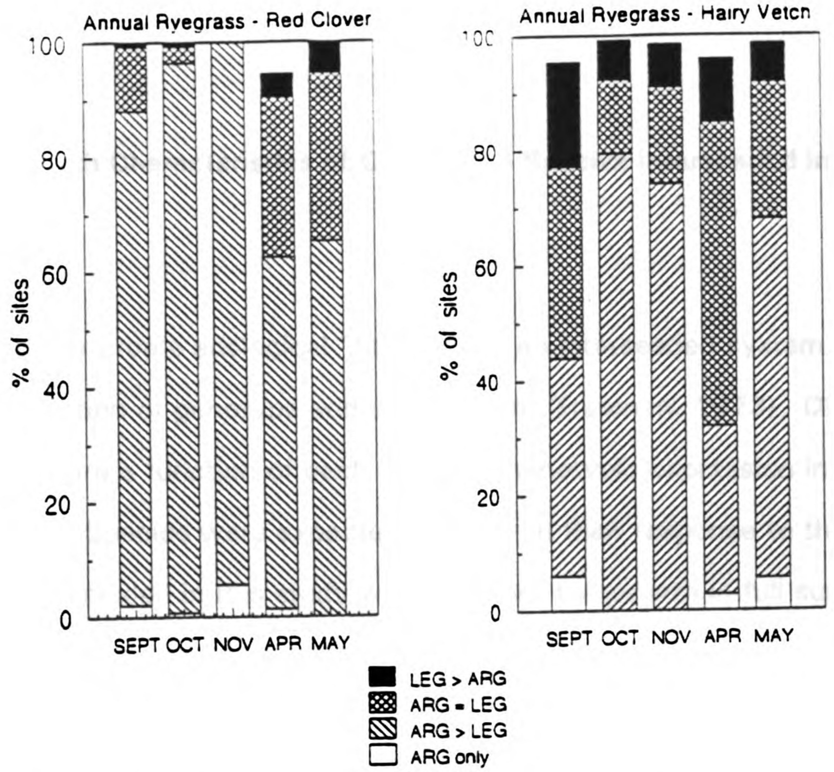


Figure 15. Transect parameters for the two mixtures in 1993 and 1994 indicating percentage of OM quadrats where the legume (hairy vetch or red clover) was equal to, less or greater than annual ryegrass, or ryegrass only was present. ARG = annual ryegrass. LEG = legume.

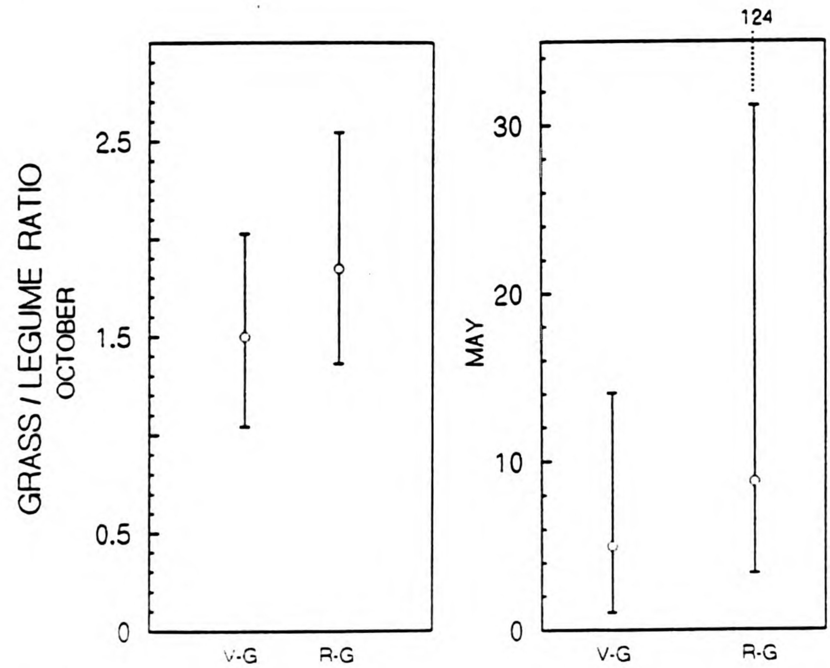


Figure 16. Mean, minimum and maximum ratios of annual ryegrass-red clover (R-G) and annual ryegrass-hairy vetch (V-G) on Oct 7, 1993 and May 10, 1994. Note differences in scale.

Growth Characteristics of Cover Crop Species Interseeded into Corn

Introduction

A cover crop's ecological "fitness" for an interseeded system is determined by the interaction of genotype and environment (Freeman, 1973). Differences in performance are a function of each species phenotypic expression in a particular environment. Species were expected to differ in their response to the understory. The species included in this study were adapted for growth in full sunlight, although several are adapted to interspecies competition for light and soil resources in pastures (AC).

Plant productivity (or yield) is a function of net assimilation rate and partitioning. Both net assimilation rate and biomass allocation are known to be influenced by environment. Light influences allocation patterns (Rice and Bazzaz, 1989) as well as overall growth, as do soil and climatic factors. Chapin et al. (1987) emphasized stress interactions in understanding plant C and N acquisition under multiple stress conditions. Light is the intrinsic stress in an interseeded row crop system.

Introduction of a species into a resource limited environment effects assimilation and partitioning. Stress responses can be primarily morphological or physiological (Jolliffe and Courtney, 1984). However, all morphological responses are physiologically mediated (Jolliffe and Courtney, 1984). Partitioning may be indicative of a species adaptability or acclimation to the environment (Hunt and Nicholls, 1986). The partitioning strategy a plant invokes under stress may determine its survival and productivity in a resource limited environment (Bradshaw, 1965; Givnish, 1988). Morphological responses may be a key adaptive mechanism in the interseeded understory plant community. Assimilate allocation also determines future levels of resource capture, and stress response, and consequently productivity (Jones and Lynn, 1994; Lerdau, 1992). Plant investment in biological "infrastructure" may be especially important because of the dynamism of the understory light environment. Schulze and Chapin (1987) suggest all herbaceous species are somewhat adapted to utilization of resource pulses, but the degree of this adaptation can determine species success.

Van Andel and Biere (1989) discussed the ecological importance of intraspecies variability of growth and growth components, concluding that the relative utility of a particular growth response depends on the environment. Sensitivity and plasticity are components of "stress" responses. The relative plasticity and resilience of growth traits, and their relative influence on biomass accumulation and variability are pertinent ecophysiological factors (Bradshaw, 1965; Schlitching, 1986). The magnitude and rate of response may vary as much as the actual nature of the response. Plant plasticity can provide for compensatory growth under stress or reflect a lack of resilience to stress. Investigation of cover species morphological, biochemical, or physiological plasticity relationship to species performance is necessary.

Agriculturally, cover crop biomass, N content, and soil cover uniformity (not simple survival and reproduction) were defined as the major criteria for "success". Cover crop growth might reflect a field's soil microsites potential for cash crop production, fluctuating over a field. Conversely yield stability, clearly a desirable management objective for cash crops, may be facilitated by plasticity or resilience of growth parameters. In the short term, uniform available N over a field might be related to uniform biomass accumulation throughout the field, because of the relationship of plant biomass and N content. Alternatively, field variability in (total) soil N pools might be exacerbated in the long term by uniform cover crop growth and N accumulation (fixation/uptake). Cover crop canopy uniformity could result or reflect field microsite uniformity or variability. The interaction of species with the microsite nutrient and light characteristics result in compensatory, complementary resource use and accumulation which culminated in either amelioration or exacerbation of field variability. In the seasonally dynamic corn understory, a species may have a set of "optimal" thresholds which trigger stress or plastic responses that result in optimal cover crop N-yield. In managed agroecosystems, plasticity pattern may be dependent on the amount of environmental heterogeneity (as well as the species-specific stress and physiological thresholds) (Schlitching, 1986).

Determining plant and soil interactions impact on field nitrogen spatial variability is pivotal. But in this study, plant species, species associations, and soil factors influence on field variability are interrelated. We elected to focus on the farmer's desire for uniform biological available N contribution (short term) to facilitate uniform fertilization rates within a field. Ultimately, for mixtures, it would be desirable to determine which growth parameters of mixture component species complement each other resulting in uniform field N via biomass, uptake and fixation.

In an interseeded system, management does not permit the cover crop to avoid the limited light in the system, and compete with the primary crop. But, a competitive strategy within the understory, and late (cool) season stress tolerance are potentially productive cover responses. Stress tolerant species might be favored over stress avoidant (Grime, 1975; Givnish, 1988) species. These requirements suggest that species with thresholds triggering tolerance or avoidance strategies that are coincident with corn system dynamics (of development and senescence) would be more successful when interseeded. Species with a broad range of tolerance, but abrupt thresholds beyond that range, might also be successful.

Agroecologically, the contribution of species plasticity to agronomic (field) performance may be important. Traits (or species) which ensure survival (in an evolutionary sense) may not be traits which result in agricultural success, high or consistent "yields" of available N. In an interseeded system, morphological plasticity may or may not confer cover crop biomass accumulation (yield) advantages. Stable and uniform yields may have a different relationship to yield maximization, or optimization (Verma et al., 1978). Across a field, plasticity in resource acquisition or use traits may increase performance "uniformity". It's possible the plasticity pattern of traits (or sets of traits) may differ for high and low performance species or differ with performance criteria.

Some traits are commonly known as plastic (LAI, SLA), other's (C/N ratio) are known to be stable in response to environmental stress or variation (Hunt and Nicholls, 1986; Schlitching, 1986). Schulze and Chapin (1987) indicate that plastic traits may support stability in other parameters. In limited light conditions, when nutrients and moisture are adequate, plant's C/N uptake ratio decreases. To maintain a constant tissue C/N ratio, plant partitioning shifts, (i.e., increased SLA and LAI) increasing relative carbon fixation.

It would be useful to know if specific (or a composite of) plastic traits and resilient traits resulted in maximum or optimal biomass or field N uniformity. The evolutionary function of plasticity in survival and reproduction is understood in natural systems (Bradshaw, 1965; Schlichting, 1986). Winn and Evans (1991) found differences in magnitude, but no interaction of physiological traits with light environment among populations of Prunella vulgaris, an herbaceous perennial. They recommended study of trait plasticity in heterogeneous field environments to understand ecological fitness and productivity. In contrast, among populations of the annual Phlox drummondii Schlichting (1986) found that correlations among phenotypic traits changed as the environment was altered.

Stress responses are often whole plant responses, though mechanisms have not been fully elucidated. The importance of whole plant studies has been outlined by Givnish (1988). Whole plant assimilate partitioning and reallocation, as manifested by leaf area ratio and root:shoot ratio are described by classical growth analysis, and have been used to study commodity species (Hunt, 1990). Growth analysis (GA) has not been used to understanding the performance of secondary, understory crops, yet GA might accelerate the selection process for species for use in polyculture systems and crop associations in understory habitats. Growth responses may also indicate the critical periods of interseeded cover crop growth.

Growth Analysis

Functional growth analysis, and yield component analysis examine morphological parameters relative to plant growth. These analyses incorporate morphological ratios as growth factors (Poorter, 1989; Winn and Eaton, 1983). A stable/resilient ratio of traits might be the consequence of independent trait plasticity and covariance. Determining whether particular ratio characteristics (resilience or plasticity) are common to high performance species (or not common to poor performance) may accelerate cover crop variety and species identification and selection processes.

Species need to balance instantaneous (van Andel and Biere, 1989), optimization of resource acquisition, with the capacity to opportunistically respond to an altered resource environment. Optimal resource use efficiency is always desirable, but not if it precludes resource acquisition near compensatory levels. The cost of reallocation of resources in response to a changing environment, relative to the benefit derived, depends on the duration of the environment(al stress), the real possibility of alleviating that stress through repartitioning, and the longevity of the plant tissue, as well as the direct costs of reallocation (Chapin, 1987, 1991; Osmond et al., 1987).

Adaptation and productivity in the changing light environment suggest a species might benefit from several characteristics. Physiologically, a plant's photosynthetic apparatus must function at extremely low light levels, or it may induce a dormant state (Gutschick, 1987) to survive a long period of low irradiance. Survival from reserves is less likely, as interseeded seedlings have a maximum of 21 days before corn canopy closure when the incident irradiance is reduced to under

300 umole m^2 sec^{-1}, below most 'sun' species compensation points.

Corn maturity, and drydown result in an increase of available light and soil resources coinciding with cooler temperatures (and reduced photoperiods) of autumn in the north central United States. Rapid absolute growth before cessation of growth due to low air and soil temperatures seems necessary for high productivity.

Our hypothesis was that survival in the light limited understory might be associated with maintenance of the ratio of leaf and root assimilative area. Species which maintained a consistent ratio of assimilative to structural tissue, throughout the seasonally changing light environment might be more successful. Ratio-resilience could result in a species having the bio-infrastructure to capture and utilize new or temporarily available resources. As the light available to the understory increased, established understory species with photosynthetic leaf area intact and functional would be positioned and have an advantage in utilizing the newly accessible PPFD resource. In addition species with established comparable root systems will be "ready" for increased uptake of moisture and nutrients with increased transpirational demand and growth rate. Species with less structural support tissue to maintain, with assimilative ratios which are consistent during growth in the corn canopy would succeed in rapid growth during the period of corn drydown. (Alternatively, structural tissue may serve as a reserve for rapid construction of assimilative tissue). The maintenance of a partitioning strategy and ratio of assimilative tissues seem critical to productivity as the corn canopy senesces.

Within this study, species responses were functions of management and environment interactions at both EL and OM. Agroecological responses are expected to differ with location, year, and management. However, within the corn interseeding system, general trends might be consistent, because of similar fertility levels, and overstory canopies.

This analysis of cover crop growth in a interseeded corn system considered differences in pattern as well as magnitude of growth. Normally, herbaceous annuals (and perennials) have seasonal, sigmoidal growth curves. In this study we evaluated the growth curves of annual, perennial, or biennial species when interseeded. The study attempted to determine whether any allocative pattern or response of a species resulted in higher productivity within the corn canopy (time) and/or across the range of field microsites (space). Relative performance of species growing in the corn canopy was measured (chapter 3).

The variation within the field, among field micro-sites is also important to agricultural management decisions. We evaluated the contribution of particular growth trait's plasticity or resilience (through space or time) to performance level and uniformity across a field. This study also attempted to identify which period of growth is most stressful for species interseeded into corn.

Methods

East Lansing plots (figure 3) were sampled 5 times during the interseeded season and the following spring before kill. Omega Farms field sites (figure 2) were sampled 3 times during the interseeded season, and once the subsequent spring before kill. Because of both the variability of the OM corn stand, and the late planting date, EL was more intensively sampled. Timing of sampling coincided with specific corn phenological stages at both sites.

Omega's first sampling corresponded to both first and second samplings at EL (depending on the particular OM site). The first sampling assessed cover crop establishment and juvenile growth. At EL the second sampling was timed to capture responses to corn canopy closure (5 to 7 days), which documented the initial stress response to limited irradiance. The third EL sampling was a mid-way, peak stress, acclimation measurement. The fourth sampling coincided with the end of the 'deep shade, low irradiance period' in EL; i.e. response to a long duration of limited irradiance. While OM sampling 2 aimed at a similar point in corn phenology, the variability of the corn stand resulted in this sampling being less clearly defined for OM plots. The final sampling at EL coincided with harvest and frost; covers made unexpectedly little growth following corn harvest, apparently due to heavy corn residue. Corn drydown and harvest were delayed at OM, the corn only reached harvestable moisture in December. Since the corn was still standing, the final OM sampling was delayed until covers were no longer growing or metabolically active, coincident with a drop in soil temperature (figure 4). Some species sites did have frost damage at this sampling (MDC and SWT).

Samplings attempted to 'capture' responses to early intense stress, acclimation, response to prolonged stress, and late fall growth response to increased light and altered daylength.

Table 10. Operations and sampling calendar for EL and OM.

DATE	EL	OM
May 10 1993	Corn planting	
May 11, 1993	Baseline soils	
May 25, 1993		Baseline soils
May 26, 1993		Corn planting
June 10, 1993	N sidedress	
June 24, 1993	Interseeding LI 1	
June 25, 1993	Soil sampling 2	
July 3, 1993		N sidedress
July 5, 1993	LI 3	
July 9, 1993	Cover sampling 1	
July 12, 1993		Interseeded
July 13, 1993	LI 4	
July 15, 1993		LI 1
July 20, 1993	LI 5	
July 26, 1993		Spatial 1
July 27, 1993	Cover sampling 2	

July 30, 1993		LI 2
August 9, 1993		Cover sampling 1
August 18, 1993		LI 3
August 20, 1993	Cover sampling 3	
August 25, 1993	LI 6	
September 1, 1993	LI 7	
September 9, 1993		Spatial 2
September 10, 1993	Soils sampling 3	
September 16, 1993	Cover sampling 4	
September 24, 1994	LI 8	
October 1, 1993		Cover sampling 2
October 7, 1993		LI 4
October 8, 1993		Spatial 3
October 25, 1993	Corn yield sampling LI 10	
October 26, 1993	Cover sampling 5	
October 27, 1993	Soils sampling 4	
October 28, 1993	Corn Harvest	
November 2, 1993		Corn yield sampling
November 18, 1993		LI 5
November 19, 1993		Spatial 4
December 3, 1993	Soil sampling 5	
December 4,		Soil sampling 2
December 5, 1993		Cover sampling 3
April 12, 1994	Soil sampling	Soil sampling
April 20, 1994		Spatial 5
May 8, 1994	Cover sampling	
May 9, 1994	Soil sampling	
May 10, 1994		Soil sampling 3
May 14, 1994		Spatial 6
May 15, 1994		Cover Sampling

Shoots: At every sampling at EL, 10 plants were sampled from each of the 4 replicate plots. At OM, 5 plants were sampled from each of 3 sites within each plot (totalling 15 plants per plot) in each of three replicates (a total of 9 sites per treatment were sampled at OM). Due to the difficulty of separating individual hairy vetch plants as the season progressed, HV samples were taken on an area basis (0.04 m^2). When individual annual ryegrass plants became difficult to distinguish towards the end of the season, grass was sampled on an area basis also.

Plants were severed at the soil surface with a scissor, and placed in plastic bags and cooled until processing. The mean number of leaves and branches per plant, and number of plants exhibiting chlorotic and/or newly emerged growth were recorded for each sample. Leaves were removed from stems and petioles (petiolules connecting leaflets were left intact) and leaf area was measured for the composite 10 (or 5) plant sample using a LICOR portable leaf area meter. Leaf and stem fractions were each dried in a 60^0 C oven for 72 hrs, and weighed when cool.

Roots: On the same dates, plots, and sites that above ground plants were sampled, soil-root cores were taken with a 3 cm (1.25") stainless steel sampler, to a depth of 25-30 cm. Hamblin and Hamblin (1985) report that in well-drained soils trifolium and medicago spp. have over 70 % of root length in the top 20 cm. Parsons and Jacobs (1985) found the highest subclover root densities at 0-10 cm. Over a 119 day season root death was negligible. In the current study, presence of a plow layer reinforced the decision to sample to 25 cm. Three cores were taken from each plot at each sampling in EL and each site at the first OM sampling. Two cores were taken from each of the 9 treatment sites (6 per plot) for the second and third samplings of OM, because of processing time constraints.

Roots were placed in a cooler at 4°C until washing with a pneumatic root washer (flotation and sieving technique) then pickled in a 10% methyl alcohol solution and chilled. At a later date, non-root debris was manually removed and roots were dyed with malachite green for video processing to estimate live root length and surface area (Smucker, 1990). Root surface area (RSA) was calculated from root length and diameter class. Following filming, roots were dried in a 60°C oven for at least 72 hrs, and weighed when cool.

Late season sweet clover roots presented some processing problems because of the formation of thick crown roots, which were outside the detection diameter of the video processor.

Cover crop roots (and shoots) were initially assumed not to have any major effects or interactions on the established corn stand or growth (Exner and Cruse, 1993; Scott et al., 1981). Initially, root data were to be standardized against the no cover (control) treatment. Cover crop root values were to be determined by subtraction of root values in the control (NCCO) plots from those of the cover crop plots. However, this calculation ((corn w/ cover) - corn only) resulted in numerous instances of "negative" cover root mass and surface area, a biological impossibility. (i.e., greater root mass and area were measured in the NCCO plots). This root data suggests that corn roots responded to the presence of cover roots, and that these may have been species-specific interactions. (An alternative explanation to corn-cover interaction is that the sampling methodology and processing techniques were inappropriate to detect the relatively small amounts of cover crop roots.) Since corn yield was unaffected by cover treatment (table 1), it is assumed that corn roots may have grown deeper due to competitive or allelopathic interaction with some covers. Mitchell and Teel (1977) reported lower root masses for grain rye-crimson clover and grain rye-hairy vetch mixtures than for rye alone (though mixture root N concentration was higher). Hulugalle (1989) reported that undersowing maize with Stylosanthes hamata resulted in a deeper and denser corn root system.

We elected to use the uncorrected, corn and cover combination root data for the calculation of whole plant ratios. Consequently, the root data are numerically inaccurate, and not truly representative of cover root mass or surface area, at least for some species. Coefficients of determination and mean square errors (MSE) of the root data only indicate of the precision of the measurements. There was no way to assess relative accuracy of the root data, so it's value for calculating root-shoot ratio's was limited.

Population: Plant populations were counted to estimate biomass per m^2 from the plants sampled (with minimal sampling disturbance of plots). Counts were made in randomly placed 0.04 m^2 quadrats, 3 per plot (EL) or site (OM) on each sampling.

Data from each sampling were analyzed using standard ANOVA, MANOVA, and mean comparison procedures. Repeated measures analysis verified time trend effects. Univariate analysis indicated normal distributions for most species and parameters, although in several instances MDC distributions were skewed. Heterogeneous variance was an inherent characteristic of all data sets, but transformations were not useful because variance followed no distinct pattern.

Growth curves were constructed for each treatment using SAS GLM procedures to determine the polynomial fit with the lowest MSE and highest r^2 at $p=0.10$ (SAS, 1990). At this significance level the best-fit function was usually clearly discernible. SAS regression procedures were then used to generate coefficients for the polynomial equation. The order of the polynomials describing each treatment was one form of classification of growth pattern. Coefficient of variation, R^2's for regression curves ranged from 0.24 to 0.99 (table 14). Despite this variable "fit", regression equations were calculated in order to compare growth curves over all sampling dates according to the SAS procedure for testing heterogeneity of slope.

The objective of this study was to give some preliminary form to the range of responses observed in two interseeded corn locations. At this point in the study of interseeded systems, specific growth models have a marginal value relative to general understanding of growth responses (Monteith, 1994) of differing cover species in the dynamic corn understory. The strategy of assessing rather than controlling variability within interseeded treatments also precluded conventional modelling. A number of reviews have addressed the techniques of curve fitting in GA (Potvin et al., 1990; Kokoska and Johnson, 1987; Wickens and Cheeseman, 1988). Statistical differences in curves and patterns were determined by a partial slopes (stepwise ANOVA for comparison of coefficients) approach using the SAS Test for Heterogeneity of Slope procedure, a combination of covariance and regression analyses (SAS, 1990). Individual plot growth curves were also constructed using SAS NLIN to check on curve fit for several variables. Generally, the mean treatment coefficients generated from the SAS NLIN procedure closely approximated the coefficients generated by SAS PROC REG. However, the NLIN procedure does not provide a method for determining the "appropriate" (best) polynomial model for a treatment. This was one of the primary objectives of this analysis. Growth curves which appeared dissimilar were occasionally grouped together. This is due to variance which did not allow the curves to be statistically differentiated (with either linear or nonlinear procedures).

A similar approach was used for the OM GA analysis, yet since each curve is defined by only 3 sampling dates, these data weren't directly comparable to EL, only simple trends were determined (linear or quadratic).

Although the data did not conform to assumptions for linearity, analysis of covariance was used to investigate the interrelationships of shoot parameters.

Results and Discussion

The results of the overall analysis of variance for EL and OM growth parameters are presented in table 10 and 11. As expected, species differed in biomass, and LAI. There are also clear treatment differences for the growth components. These results are consistent with other interspecies studies (Poorter, 1989). As stated earlier the most limiting resource in our experiments tended to be light. Soil moisture and nutrients were generally abundant and adequate. Temperature and daylength undoubtably influenced growth and partitioning (Power and Zacharriessen, 1993), but these were relatively uniform over our experimental areas. The question of adaptation of existing plant tissue, relative to development of new tissue in the corn understory, was not investigated in this study, but may be an important clue to acclimation of species to dynamic conditions. Measurements did not distinguish allocation from reallocation, yet this may be an important aspect determining plant survival. All plants continued to allocate to new growth (see below) throughout the study.

One index of the corn overstory's stress on the understory was the overall decline, then recovery, of all the parameters' coefficients of determination and significance tests (Tables 11 and 12). This trend through time supports the assumption that low irradiance may have been more of a stress factor than soil factors. The mid-season decrease of p-value "significance" and coefficients of determination indicating the overall dynamism of the system in mid-season. The invalidity of the root data is also apparent. Significance later in the year in root related ratios is suspect because of the relative magnitude of root and shoot components of the ratios.

Table 11. ANOVA results for EL shoot and whole plant growth parameters for each of five samplings [RCBD model = TRT REP]. Data (EL) for October 26 were analyzed without buckwheat, which had senesced by the final sampling.

	SHOOT MASS		LAI		LS		SLA		VLAR	
DATE	r^2	p	r^2	p	r^2	p	r^2	p	r^2	p
July 9	0.80	0.001	0.80	0.0001	0.93	0.0001	0.93	0.0001	0.93	0.0001
July 26	0.66	0.004	0.74	0.0003	0.95	0.0001	0.94	0.0001	0.82	0.0001
Aug 20	0.53	0.05	0.55	0.03	0.80	0.0001	0.73	0.0004	0.74	0.0003
Sept 25	0.49	0.09	0.58	0.02	0.93	0.0001	0.68	0.002	0.77	0.0001
Oct 26	0.86	0.0001	0.82	0.0001	0.93	0.0001	0.96	0.0001	0.86	0.0001

	ROOT MASS		RSm		LAR		TOTAL MASS	
DATE	r^2	p	r^2	p	r^2	p	r^2	p
July 9	0.57	0.03*	0.61	0.01	0.73	0.0004	0.69	0.002**
July 26	0.20	0.86	0.55	0.04	0.71	0.001	0.19	0.88
Aug 20	0.43	0.03*	0.51	0.06	0.54	0.04	0.51	0.07*
Sept 25	0.56	0.004*	0.54	0.04	0.59	0.02	0.49	0.09
Oct 26	0.46	0.16	0.34	0.40	0.62	0.02	0.89	0.0001

* = Rep effects only significant. ** = Rep and treatment effects significant.

Table 12. ANOVA results for OM shoot parameters by SITE (above) and REP (below). Root and whole plant parameters are in the lower table.

	SHOOT MASS		LAI		LS		SLA		VLAR	
DATE	r^2	p	r^2	p	r^2	p	r^2	p	r^2	p
Aug 9	0.59 0.51	0.0001	0.50 0.43	0.001	0.89 0.88	0.0001	0.69 0.63	0.0001	0.56 0.50	0.0001
Sept 27	0.65 0.47	0.0001	0.74 0.66	0.0001	0.56 0.49	0.0001	0.59 0.52	0.0001	0.48 0.30	0.002
Dec 5	0.65 0.55	0.0001	0.73 0.64	0.0001	0.80 0.78	0.0001	0.86 0.80	0.0001	0.45 0.38	0.004

	ROOT MASS		R/Sm		LARW	
DATE	r^2	p	r^2	p	r^2	p
AUG 9	0.16	0.87	0.48	0.003	0.22	0.54
DEC 5	0.17	0.78	0.47	0.005	0.63	0.0001

Roots

As stated above, the root analysis was of limited use in calculating whole plant ratios and biomass. All the parameters that included roots had lower overall coefficients of determination, reflecting the uncertainty of the technique for this system. Root mass had significant replication effects, often in the absence of treatment differences. This was possibly attributable to the mass of corn roots relative to cover crop roots. Pearson and Jacobs (1985) reported 68% root recovery from sandy soils using flotation and sieving. Soils at EL and OM tended to have a higher clay content, which may have reduced recovery percentages.

However, the EL results may indicate species relative rooting characteristics. The narrowest width class of roots detected with video image processing (<0.2mm) accounted for approximately 75% of the roots measured for every treatment (including NCCO) for sampling's 2 through 5. For sampling 1, the narrowest width class accounted for only 50% of the roots measured. Within this width class, root surface area (RSA) differences with treatment were detectable for samplings 3 and 4 (p=0.05) and sampling 1 (p=0.1).

Within the second width class (0.68 mm) root surface area tended to differ more with block than treatment, although on the third sampling treatments were marginally differentiable (p=0.12). No differences were ever detectable for two larger diameter classes, or when diameter classes were summed together. This may have been due to corn root volume obscuring any treatment differences (block differences in the second width class were also probably due to corn).

When the differences between cover crop RSA and the NCCO plots were summed for the two narrowest width classes (the original intended calculation) samplings 3 and 4 had detectable treatment differences.

Based on these results, RSA increased, then decreased over time. Species RSA differences were indistinguishable at sampling 2, mirroring the chaos in the above ground growth. The lack of detectable differences in the final sampling may reflect no real differences in RSA. The decrease in RSA at the end of the season seems unexpected. It's possible that corn roots were the bulk of roots sampled in samplings 1-4, and were eliminated from the final sampling (because they were dead).

Among treatments, BKWT, CC, and ARG had the highest RSA at sampling one (Figure 17). The NCCO treatment had the lowest mean RSA. (BKWT and CC also had the highest shoot mass.) By the second sampling (canopy closure), NCCO had the highest mean RSA, probably the result of naturally increased corn root growth, and immediate root to shoot partitioning shifts of all the covers. At the third sampling, ARG, HV, RC and BKWT had the highest RSA's. Crimson clover ranked among the lowest, between SC and NCCO. By the fourth sampling, ARG had statistically greater RSA than any other treatment. Crimson and NCCO had the lowest RSA's. At the final sampling, CC mean RSA was the greatest, though not statistically detectable from ARG and RC; AC had the lowest RSA.

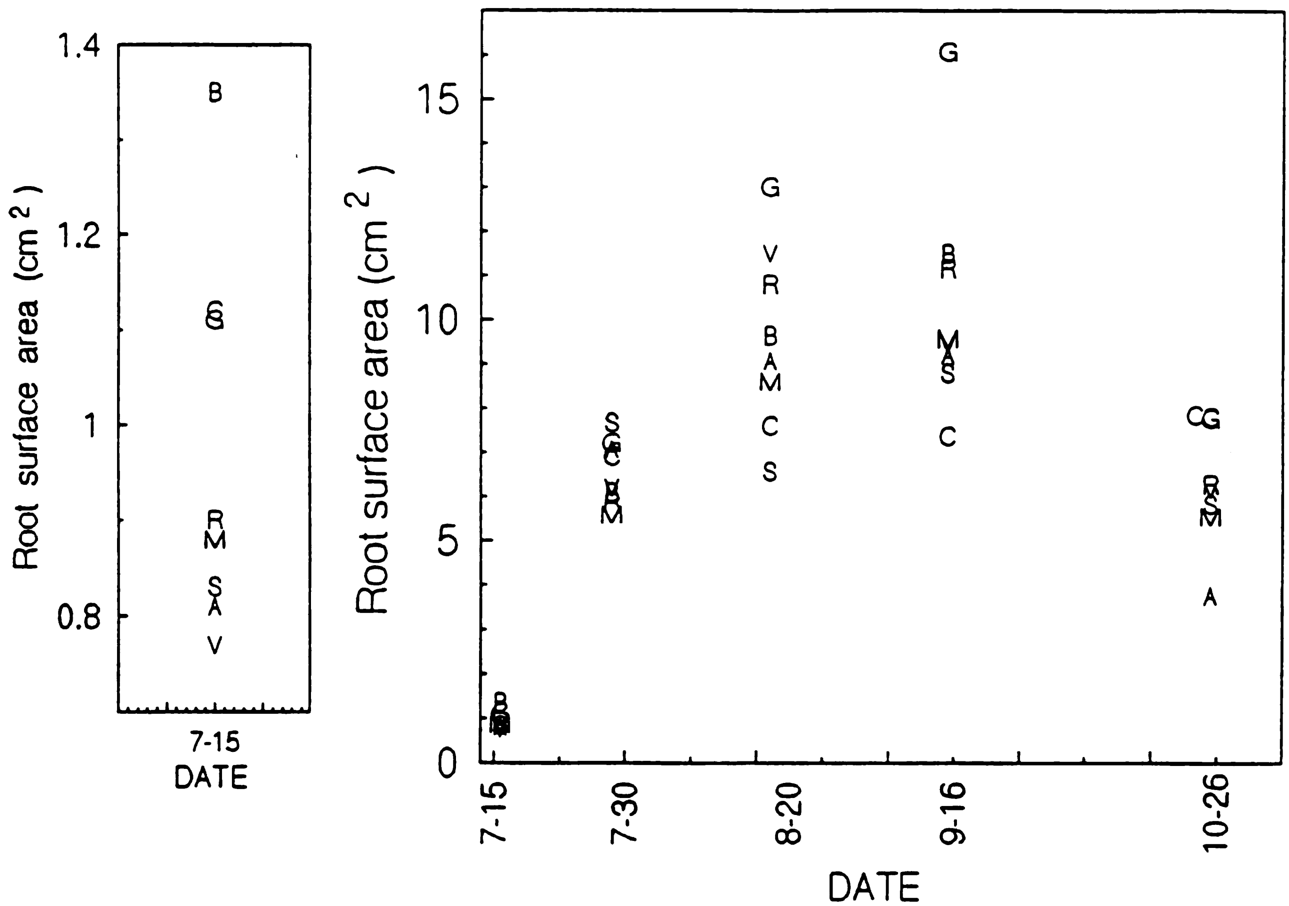


Figure 17. Root surface area (for roots < 2 mm diameter) on 5 dates for cover species interseeded into corn at EL. Enlargement at left is of the July 15 sampling on a larger scale. A = Alsike clover; B = Buckwheat; C = Crimson clover; G = Annual ryegrass; M = Annual medic; R = red clover; S = Sweet clover; V = Hairy vetch.

In sum, ARG tended to have the highest RSA, and the most consistent RSA ranking for most samplings (ARG differences were obvious even during sample processing). Annual ryegrass RSA tended to parallel the trends of leaf area and biomass. Crimson clover seemed to show the most consistent mean RSA through time, resulting in the greatest changes in species ranking. These data suggest a high uptake or utilization efficiency for CC roots, since top growth and biomass were able to increase greatly, although RSA remained constant. (i.e., nutrient uptake per unit RSA had to keep increasing to supply moisture and nutrients for increasing shoot metabolism and growth).

Within the second root class (approximately 20% of total root length) trends in RSA over time were not consistent with the first root width class, but species rankings were somewhat similar (data not shown). Crimson clover appeared to allocate carbon to leaf area more than root area. Annual ryegrass appeared to maintain a more consistent root/shoot ratio.

Relative root mass results can be compared for EL. At the first sampling, root mass m^{-2} was greatest for BKWT and CC, corresponding to their greater shoot mass and high RSA. Hairy vetch (and AC) ranked next, these two species had the lowest shoot mass at the first sampling. Early season field observations indicated HV early root growth greatly superseded shoot growth. Annual medic had the lowest root mass of all species (see Figure 18).

At the second sampling, root mass differences were not detectable, however MDC remained the species with the lowest root mass, but ranked intermediately at the third sampling. Crimson clover and HV remained among the species with the highest root mass for the third sampling, BKWT shifted to the second lowest root mass position for sampling 2 and 3. At the fourth sampling CC had the lowest root mass, this may have been partially due to a processing error. By the fifth sampling CC and HV had the highest root mass again. Sweet clover, probably due to crown root formation, was also in this group. Cyprus medic and AC had the lowest RM for both the fourth and final samplings.

Throughout the study RC was among the higher root mass species. Annual ryegrass tended to be among the lower ranked species for root mass, contrasting with its high ranking for RSA. Apparently, ARG has many fine roots, but low root mass. Root mass and area were not positively correlated. Analysis of root surface area results in a different interpretation than root mass. At all but the fourth sampling, low root mass was associated with species with low leaf-stem ratio, MDC and BKWT (see later). Partitioning to roots on a mass basis was most dramatically limited by MDC, which also had the lowest leaf-stem ratio, suggesting a stress avoidance strategy. Kirchmann (1988) found differences in root mass for sole cropped mediterranean and temperate forage legumes; red clover had higher absolute root mass than mediterranean species in late autumn. In the EL-OM studies, MDC, and to a lesser extent HV are both "mediterranean" species.

Root N was not determined in the current study. Sole cropped sweet and red clover roots provided similar amounts of N (10-15 kg ha^{-1}) on both compacted and good tilth soils in Canada (Bowren et al., 1969). Fribourg and Johnson (1955) found red and sweet clover root N content varied with location and season, but was less than shoot variability. They found no statistical differences in root N concentration. Nitrogen yield differences were highly correlated with biomass. Sweet clover roots tended to have a slightly higher N content than red clover. Over a temperate cropping season, N in red clover roots was less than 3.3 g m^{-2}, but root N content (apparently increasing with increasing root mass) increased in the fall to over 5 g m^{-2}. Root and shoot N concentration were similar. Shoot N was always greater than root N for all species in each of these experiments. All of this data comes from sole cropped stands, so the data isn't applicable to our study system

Shoots

The shoot data suggest clear differences in allocation to structural and assimilative components among species. The lower coefficients of determination for OM relative to EL traits reflect environmental variability among the field scale plots, as expected. Yet the consistent significance of some traits in both locations, indicates not just differences between species, but also potential reasons for relative species performance.

Canonical discriminant analysis is sometimes used for segregating treatments described with multivariate data (Kowal et al., 1976). This analysis only clearly segregated ARG from the other species, although over samplings some treatments were more closely grouped than others.

Growth Parameters

Crimson clover, had the highest late fall biomass, and plant N content. Crimson clover also had the highest biomass at the first sampling in both EL and OM. Of the overwintering species, HV had the highest end-of-season biomass.

Biomass at the end of the 1993 was the outcome of growth and partitioning throughout the season. Growth is a function of net assimilation rate per unit leaf area (ULR, unit leaf rate), and leaf area (light interception). ULR is an expression of photosynthetic capacity which is related to SLA (and leaf N), and PPFD. Unit leaf rate was calculated with the equation (Hunt, 1990):

$$ULR = ((\text{grams m}^{-2}{}_{day2} - \text{grams m}^{-2}{}_{day1})/\text{days})\times(\log LAI2 - \log LAI1)/(LAI2 - LAI1)).$$

The ULR means for each EL growth interval are presented in table 13. Unit leaf rate decreased with time, variance generally increased with time. For intervals 2, 3 and 4 some plots had negative ULR. Negative values indicate maintenance and respiratory costs exceeded carbon fixation for that period. During interval 2 mean ULR did not differ with species, but did differ with rep ($p=0.16$ and 0.09), respectively. Alsike clover and BKWT each had 2 plots with negative ULR's during this period. Annual medic, RC, HV had negative ULR's in one plot each. During interval 3 (the period between samplings 3 and 4) CC, MDC, and BKWT each had one plot with negative ULR. During interval 4, all ARG plots, and all but one SWT plot had negative ULRs. Two HV and one MDC plot also had negative ULR. As is typical ULR and CGR trends were independent, except for interval 1 when they are inversely correlated. Growth rate has generally not been associated with ULR in optimal resource environments (Hunt and Nicholls, 1986; Poorter, 1990), but is usually more dependent on leaf area. In a study of interspecific variation of growth, Poorter (1989) determined that NAR was of secondary importance to growth rate, relative to the strong correlations of SLA and LAR with growth. His study considered wild species selected in their native habitats. Clearly, from this data net assimilation rate per unit leaf area was not directly correlated with biomass production. Lower rates of ULR were associated with periods of low light penetration of the corn canopy (intervals 2, 3), but this is not distinguishable from ontogenetic trends in ULR.

Table 13. Unit leaf rate (net assimilation of biomass m^{-2} per day) of species in EL for 4 growth periods (Jul 9-Jul 26), (Jul 26-Aug 20), (Aug 20-Sept 16), (Sept 16-Oct 26).

INTVL 1 (p=0.0002)				INTVL 2 (p=0.16)				INTVL 3 (p=0.13)				INTVL 4 (p=0.03)			
Spp	ULR	LSD	CV	Spp	ULR	LSD	CV	Spp	ULR	LSD	CV	Spp	ULR	LSD	CV
G	10.8	a	15	C	2.5	a	66	M	2.3	a	91	C	1.9	a	32
A	7.0	b	25	V	1.5	ab	148	V	1.8	ab	84	M	1.3	ab	118
S	7.0	b	33	G	1.4	ab	46	G	1.3	ab	34	R	1.1	abc	56
M	6.3	bc	7	R	1.4	ab	122	B	1.3	ab	95	V	0.9	abcd	186
V	6.1	bc	24	S	0.6	b	67	R	0.5	b	101	A	0.9	abcd	54
C	4.9	bc	28	A	0.6	b	165	S	0.5	b	64	B	0	bcd	0
R	4.8	bc	27	B	0.5	b	255	A	0.4	b	91	S	-0.1	cd	-132
B	4.5	c	20	M	-0.1	b	-917	C	0.4	b	364	G	-0.4	d	-56

At each sampling, LAI covaried with biomass even more than did species. Species then covaried with LAI. Covariance analysis indicated minimal association of biomass with the other parameters. Leaf area index generally tends to increase with growth and biomass. LAI is also influenced by changing resource conditions;

when soil resources are abundant, and irradiance limited, leaf area tends to increase while in N limited environments leaf area is reduced (Hilbert, 1990). Mean LAI followed a less consistent trend at the end of the season for all species, compared to other parameters. Crimson clover had the greatest LAI early and late in the experiment.

Light limits productivity when the intensity of photosynthetic radiation is below a plant or leaf's physiological threshold (Monteith, 1981). Limiting irradiance tends to result in decreased root/shoot ratio (RS), and increased leaf/stem ratio (LS) and these shifts in partitioning were observed in this study, more for the legumes than for ARG. Annual medic was the species with the lowest LS, and highest RS. Conversely, root:shoot ratios are increased by limited soil N or moisture, thereby reducing leaf area and overall growth rate (Hilbert, 1990). As stated earlier soil N and soil moisture were generally not limiting in this study.

Specific leaf area is also influenced by light environment, and tends to increase, as photosynthetic capacity (and leaf N concentration) decreases with shading. Lower N and C per unit leaf area are related to increased availability for total leaf area expansion, and increased radiation interception (Olff, 1992). 'Shade' SLA may also be a response to the lower heat stress associated with the absence of direct irradiance. For many species in steady state environment, high SLA is related to LAR, and consequently crop growth rate (CGR) (Poorter and Remkes, 1990).

Specific leaf area differed with species on all dates at both locations (table 12). There was no correlation of SLA with CGR, although on dates 2 and 4 (EL), the 4 species with the highest SLA were the same species with the lowest CGR.

Mean SLA values apparently were not directly related to productivity of interseeded species. Annual ryegrass had the lowest mean SLA at every sampling at both locations. At OM, HV always had the second lowest SLA, but at EL, HV SLA was 2nd lowest for the first two and final samplings, but was intermediate for samplings 3 and 4. The species with greatest mean SLA varied with sampling. At EL, BKWT had one of the highest SLA's for the first three samplings. At OM the clovers had the highest SLA, RC was the highest. At OM, CC was always among the high SLA group, while at EL, CC initially ranked high BKWT, but on samplings 2-5, CC mean SLA was intermediate among species. Annual medic had the most consistent SLA over time.

Leaf area ratio (LAR) is the ratio of leaf area to plant weight. This measure considers species relative allocation to structural and assimilative tissue. Only above-ground allocation will be discussed for our data (vLAR). LAR has been correlated with relative growth rate (Poorter, 1989). At OM, vLAR responses were site-specific at OM. At EL, vLAR always increased slightly at the second sampling (corn canopy closure), but afterwards there was no common trend. The lowest vLAR for each species occurred the end of the season. The range of magnitude of vLAR did not differ greatly with species, but for all species was lower at EL than at OM. However, CC, RC (and ARG) had higher peak vLAR than did the other species at OM. At EL, peak and lowest vLAR differentiated HV and MDC, from the other species which had higher vLAR.

Leaf stem ratio (LS) is the ratio of leaf weight divided by stem weight. In the botanical literature, leaf weight ratio is a more common expression (Hunt, 1990), but the trends of these parameters would be expected to be similar. Lower leaf-stem ratios are expected with decreased irradiance.

Excepting HV, all species LS decreased with time, as did SLA and vLAR. At both locations and all samplings following corn canopy closure, MDC had the lowest LS of all species. This was apparent in field observations. Buckwheat also tended to have low LS, as did CC. Within sampling dates LS did not covary with biomass.

Growth Patterns

As well as magnitude of growth, pattern of growth over the season did differ with species (Figures 18 and 19). At EL, CC, ARG, and SWT and BKWT each exhibited a different pattern of shoot mass growth than any other species. Alsike clover can be grouped with ARG or SWT. Differences in pattern among RC, HV, and MDC were not detectable. At OM, the results were similar. Crimson clover differed from all other species. Alsike clover and SWT were grouped together; although AC could also be grouped with ARG, MDC, and RC which followed similar growth patterns. Hairy vetch differed from this group only slightly.

At EL, HV and CC patterns in root mass accumulation were not differentiable from one another, BKWT had a unique root pattern, the other species formed another discrete group. Crimson clover's pattern of total mass also differed from all other species (as did BKWT), but AC and HV were not distinguishable from one another. The remaining species (RC, MDC, SWT) were grouped together.

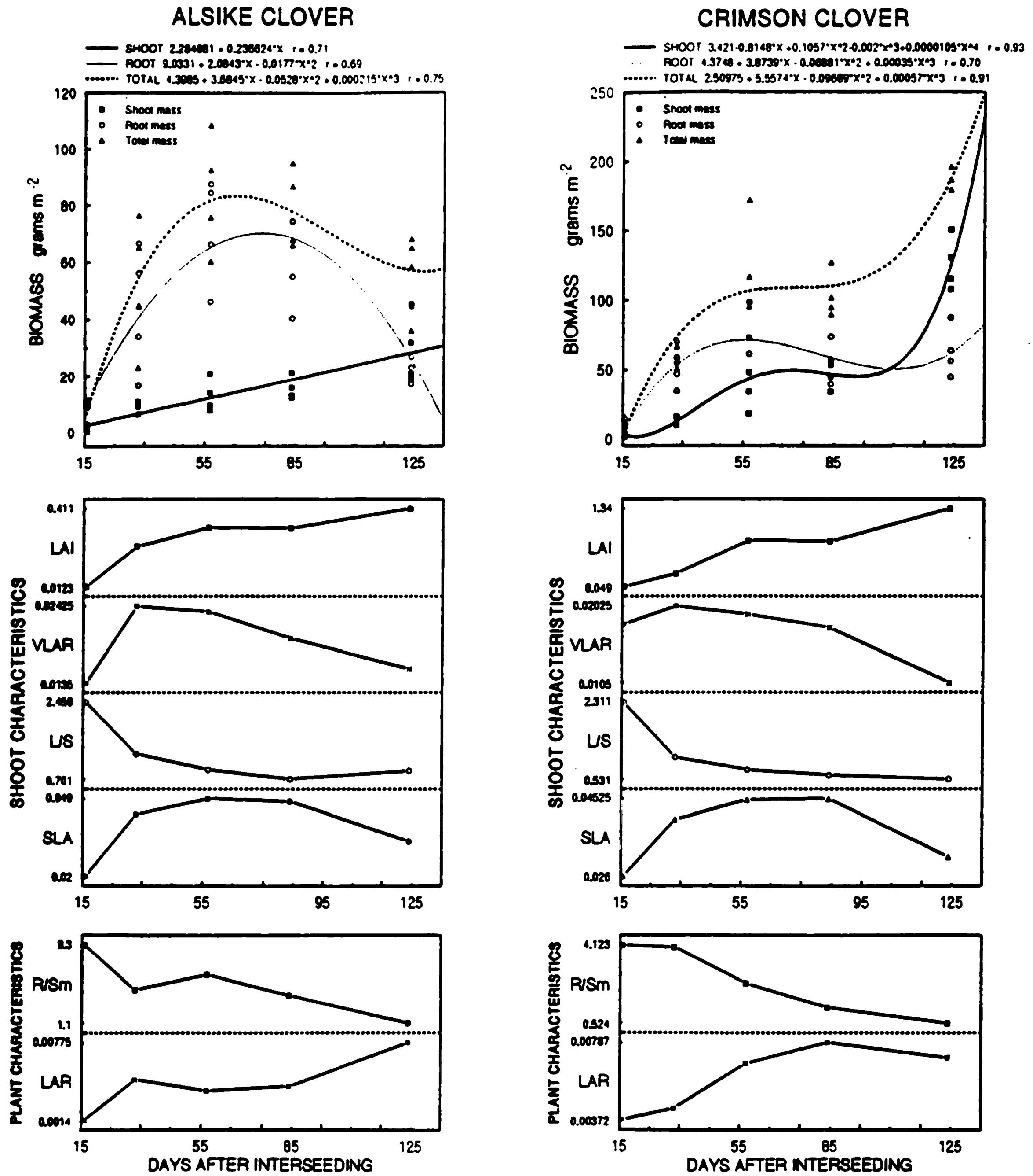


Figure 18. Growth characteristics of 8 cover species (4 reps) over 5 dates at EL. LAI = leaf area index. vLAR = leaf area ratio (shoot). L/S = leaf-stem ratio. SLA = specific leaf area. R/Sm = root-shoot ratio (mass basis). LAR = leaf area ratio (shoot + root).

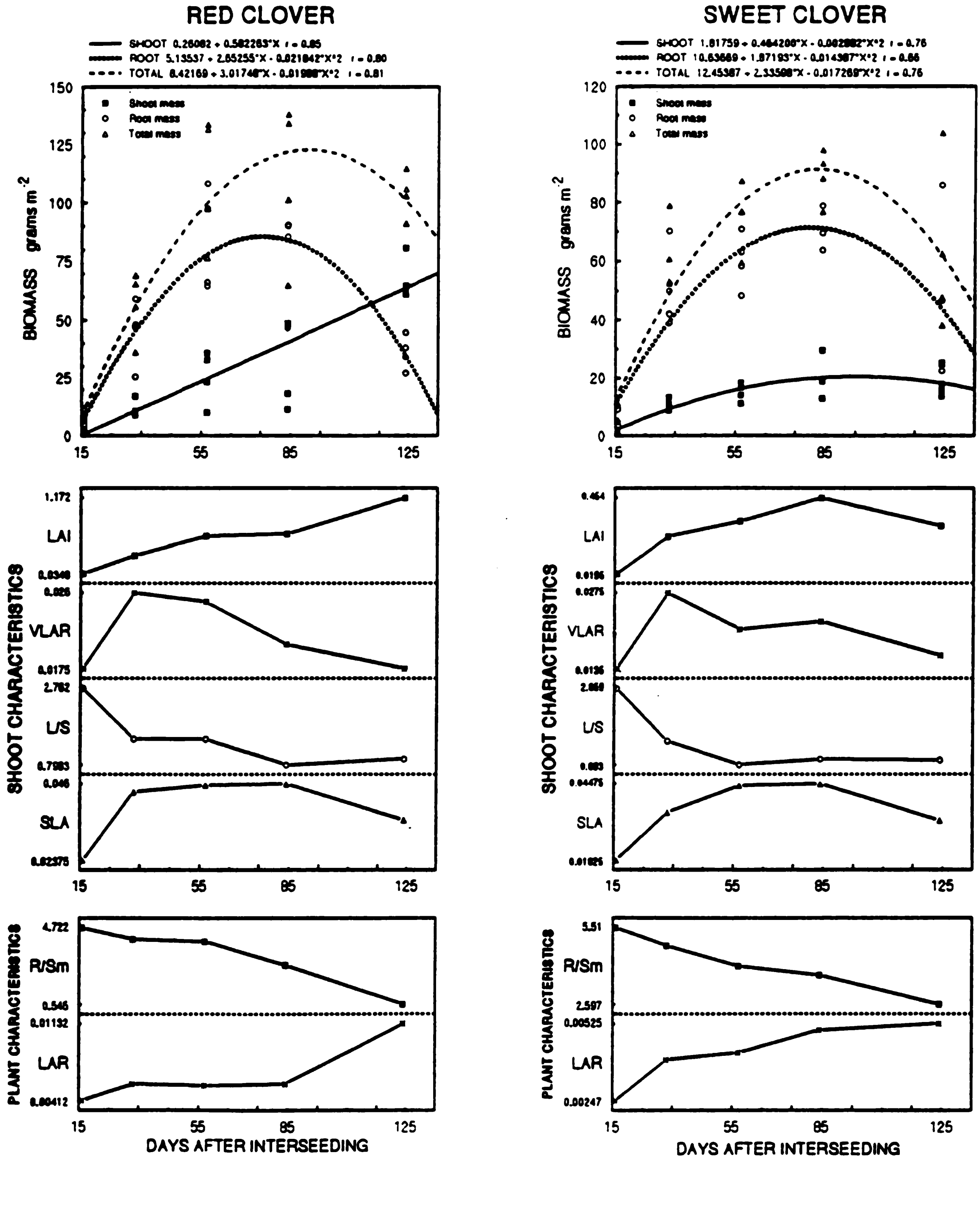


Figure 18. (cont.)

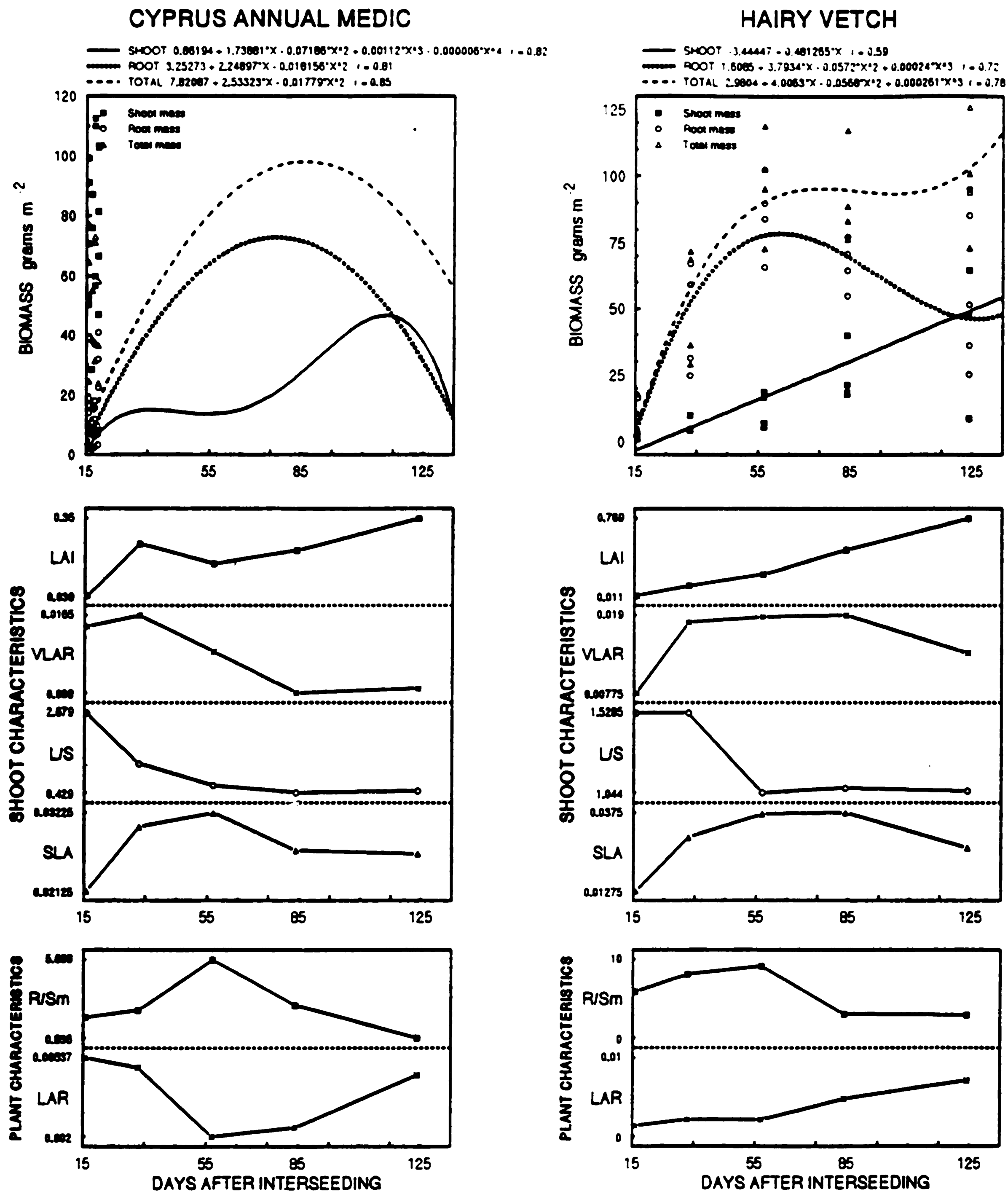


Figure 18. (cont.)

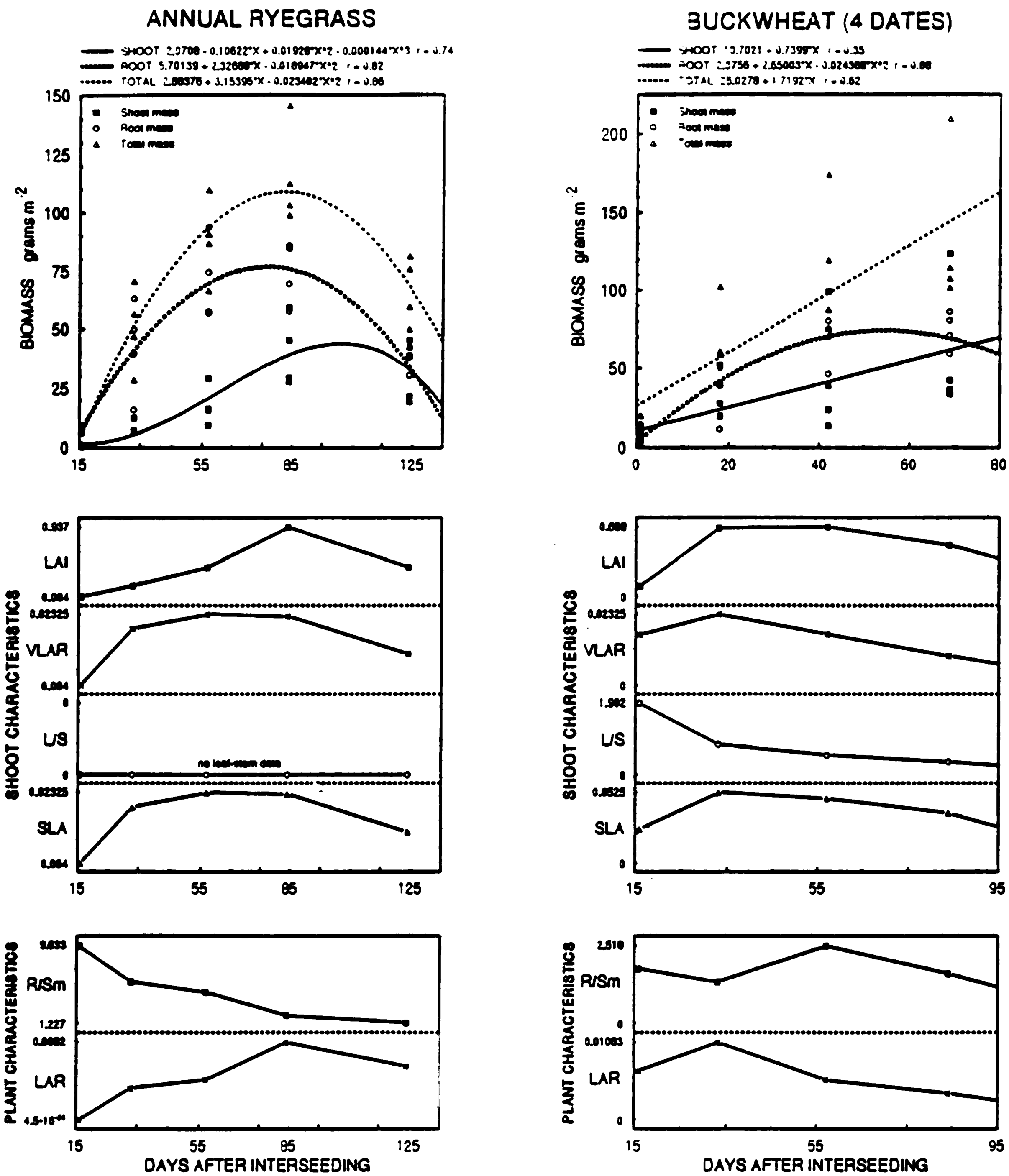


Figure 18. (cont.)

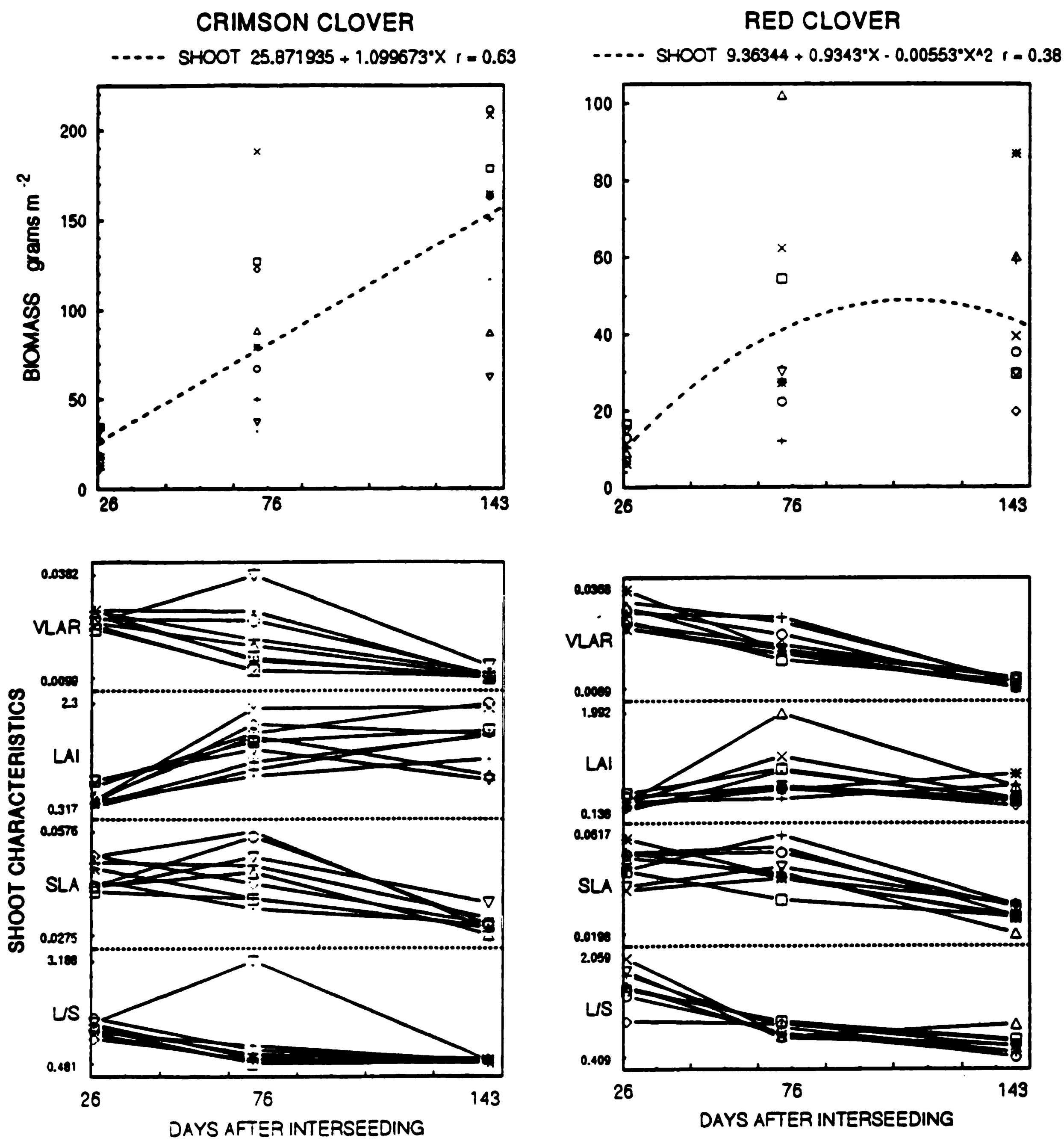


Figure 19. Shoot characteristics of 7 interseeded cover species at OM for three dates and 9 sites. Day 26 = Aug 9 (corn canopy closure); Day 76 = Sept 24-30 (corn grain fill); Day 143 = Dec 5 (soil freezing, end of season). LAI = leaf area index. vLAR = leaf area ratio (shoot). L/S = leaf-stem ratio. SLA = specific leaf area.

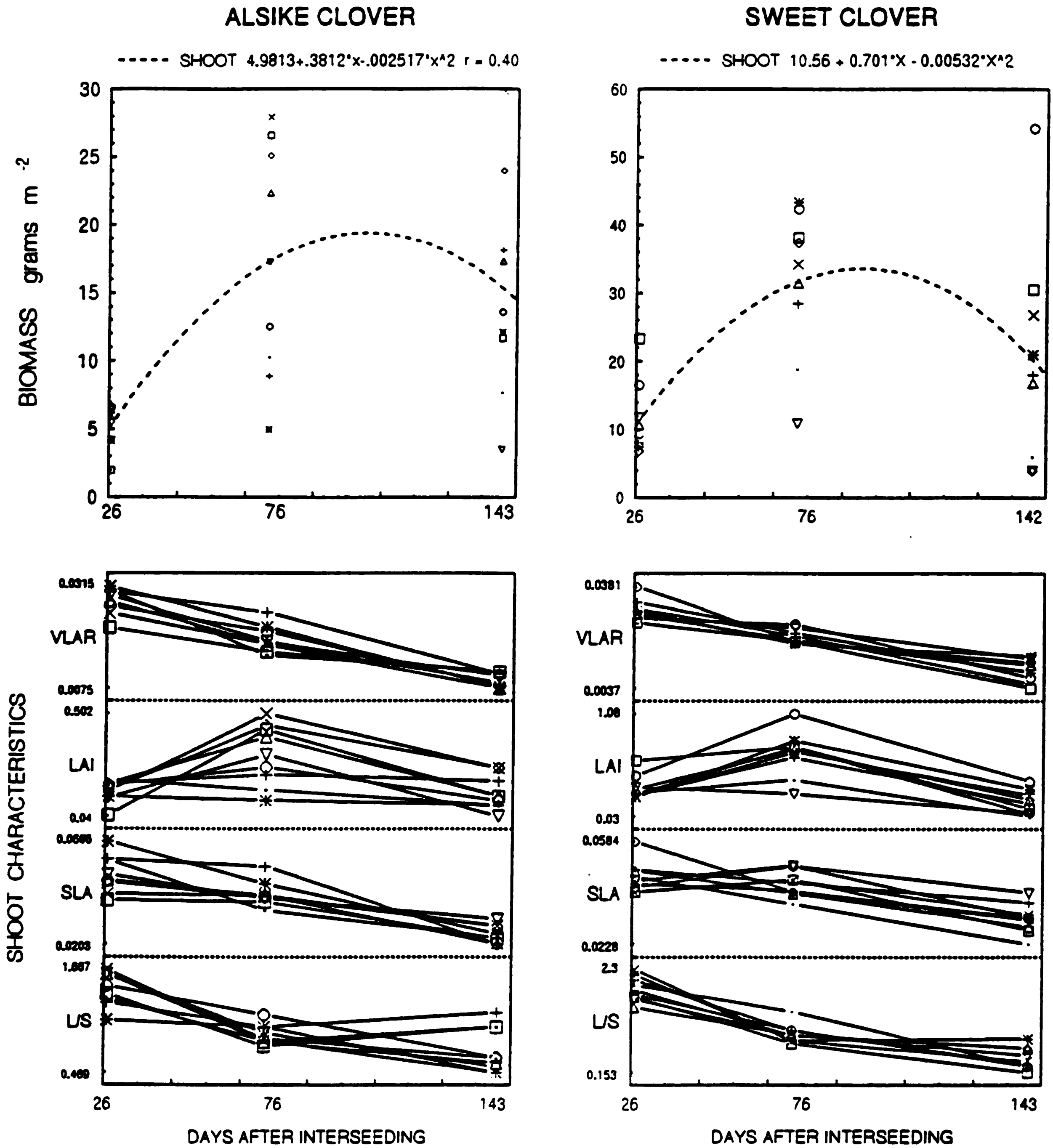


Figure 19. (cont.)

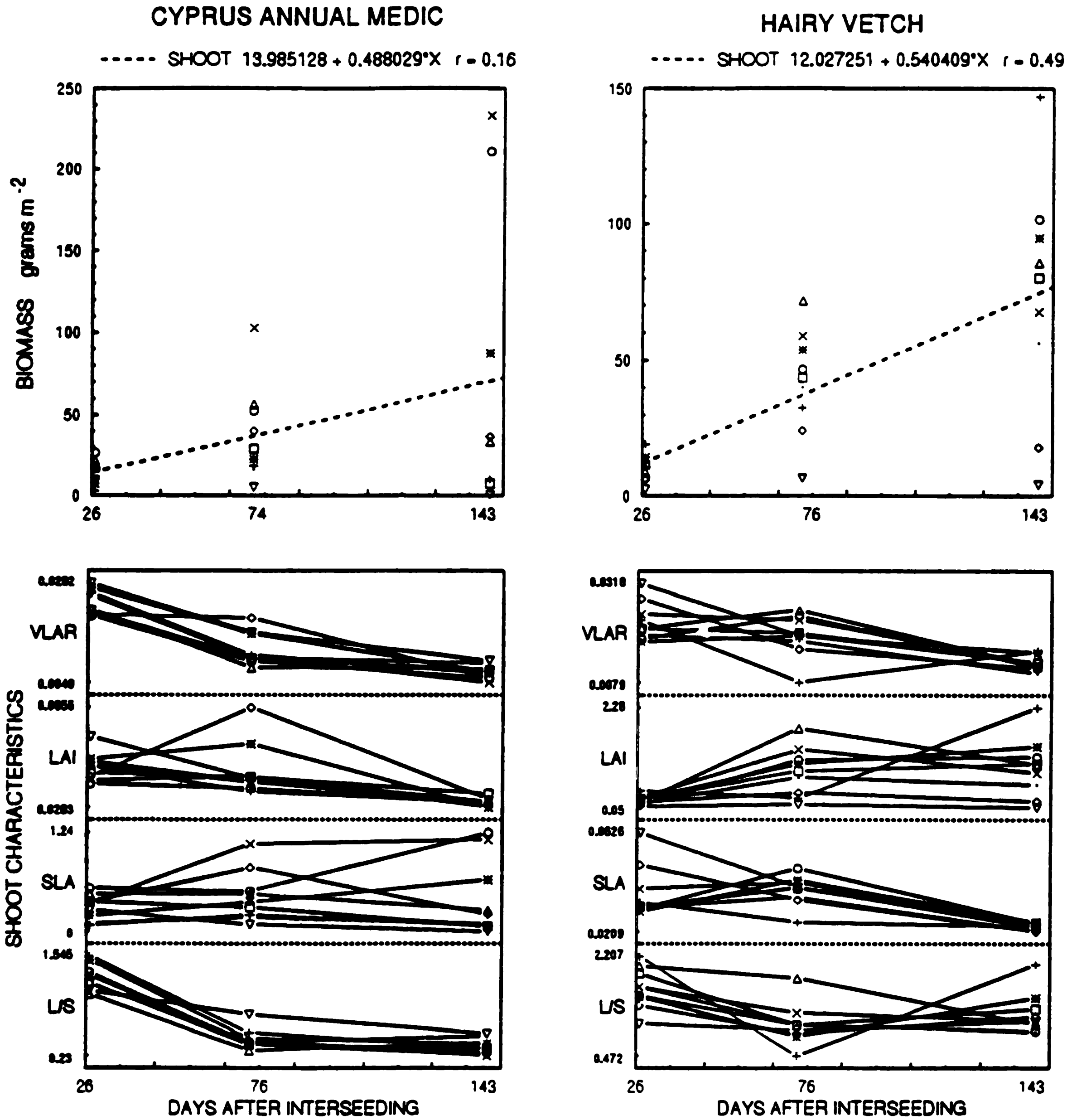


Figure 19. (cont.)

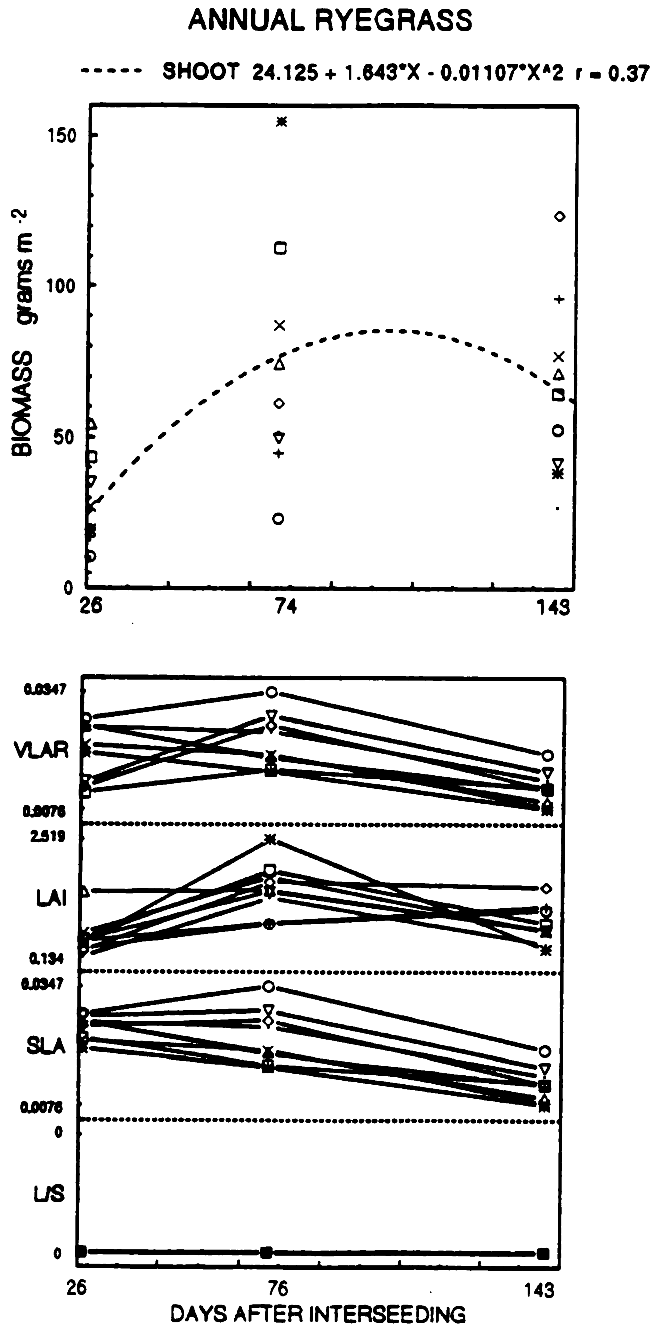


Figure 19. (cont.)

Table 14. Groupings of growth analysis parameters by slope. Species grouped together had no statistical differences (p=0.10) (F=3.07) between response patterns of curves (partial slopes). Means and intercepts may differ within (and between) groups.

SPECIES		MSE	R^2
	LEAF AREA INDEX EL		
AC:	$-0.00346 + 0.0169X - 0.00029X^2 + 0.0000015X^3$	0.011	0.74
ARG:	$0.0368 - 0.0065X + 0.0006X^2 - 0.0000046X^3$	0.048	0.72
MDC:	$0.010662 + 0.02951X - 0.001183X^2 + 0.0000167X^3 - 0.000000074X^4$	0.008	0.64
CC:	$0.058214 - 0.010936X + 0.001754X^2 - 0.0000324X^3 + 0.000000167X^4$	0.041	0.87
RC:	$-0.00784 + 0.0267X - 0.00043X^2 + 0.0000026X^3$	0.024	0.88
SWT:	$0.0162 + 0.0118X - 0.000084X^2$	0.007	0.76
BKWT:	$0.1982 + 0.0202X - 0.00021X^2$	0.09	0.49
HV:	$-0.0245 + 0.0071X$	0.064	0.56
	LEAF AREA INDEX OM		
CC:	$0.501333 + 0.029731X - 0.000175X^2$	0.163	0.62
HV:	$0.342823 + .006019X$	0.273	0.24
MDC:	no equation	0.121	0.03
AC:	$0.145331 + 0.006167X - 0.0000532X^2$	0.009	0.44
ARG:	$0.473638 + 0.038783X - 0.00031X^2$	0.18	0.57
RC:	$0.282453 + 0.19145X - 0.000154X^2$	0.01	0.37
SWT:	$0.312689 + 0.013885X - 0.00013X^2$	0.029	0.64
	SPECIFIC LEAF AREA EL		
		MSE	R^2
AC:	$0.01778 + 0.00228X - 0.00006024X^2 + 0.00000068X^3 - 0.000000003X^4$	0.0001	0.95
ARG:	$0.00349 + 0.0011X - 0.00002X^2 + 0.00000006X^3$	0.00002	0.81
MDC:	$0.0204 + 0.0008X - 0.00002X^2 + 0.00000009X^3$	0.000001	0.79
SWT:	$0.0173 + 0.0012X - 0.00002X^2 + 0.00000005X^3$	0.00001	0.92
BKWT:	$0.0224 + 0.0029X - 0.00008X^2 + 0.0000006X^3$	0.00003	0.83
CC:	$0.0268 + 0.0007X - 0.000006X^2$	0.00002	0.80
RC:	$0.0265 + 0.00074X - 0.000006X^2$	0.00009	0.46
HV:	$0.014 + 0.0008X - 0.000007X^2$	0.00004	0.69
	SPECIFIC LEAF AREA OM		
CC:	$0.044959 + 0.00011X - 0.000002X^2$	0.00003	0.64
ARG:	$0.025397 + 0.00001548X - 0.0000011X^2$	0.00002	0.64
MDC:	$0.042152 + 0.00005X - 0.0000015X^2$	0.00005	0.48
SWT:	$0.047573 - 0.00013X$	0.00003	0.60
HV:	$0.037408 + 0.000116X - 0.0000021X^2$	0.00006	0.49
AC:	$0.048556 - 0.000207X$	0.00003	0.78
RC:	$0.049569 + 0.000067X - 0.0000022X^2$	0.00005	0.70

Table 14. (cont.)

LEAF:STEM RATIO EL

		MSE	R^2
AC:	$2.4886 - 0.0774X + 0.0011X^2 - 0.000005X^3$	0.087	0.85
SWT:	$2.96 - 0.1081X + 0.0018X^2 - 0.000008X^3$	0.047	0.93
CC:	$2.4365 - 0.1293X + 0.00362X^2 - 0.0000429X^3 + 0.00000018X^4$	0.013	0.98
MDC:	$2.8072 - 0.1312X + 0.00305X^2 - 0.000327X^3 + 0.00000013X^4$	0.004	0.99
BKWT:	$2.002 - 0.1027X + 0.0023X^2 - 0.00002X^3$	0.011	0.98
RC:	$2.9183 - 0.1628X + 0.00605X^2 - 0.000089X^3 + 0.00000042X^4$	0.143	0.82
HV:	$1.5002 + 0.02993X - 0.002156X^2 + 0.0000353X - 0.00000017X^4$	0.036	0.67
ARG:	No L/S data		

LEAF:STEM RATIO OM

AC:	$1.4697 - 0.015547X + 0.000079X^2$	0.041	0.73
HV:	$1.67668 - 0.020826X + 0.000145X^2$	0.133	0.38
MDC:	$1.303 - 0.02481X + 0.000143X^2$	0.019	0.91
RC:	$1.617925 - 0.02148X + 0.00011X^2$	0.041	0.83
SWT:	$1.926866 - 0.025757X + 0.000113X^2$	0.053	0.88
CC:	$1.379734 - 0.00745X$	0.244	0.36

SPECIES	LEAF AREA RATIO (vegetation) EL	MSE	R^2
AC:	$0.01233 + 0.0012X - 0.0000371^2 + 0.0000004X^3 - 0.000000002X^40$	0.000001	0.92
RC:	$0.0171 + 0.0007X - 0.000015X^2 + 0.00000008X^3$	0.00001	0.53
= = = = = = =			
SWT:	$0.0137 + 0.0004X - 0.000005X^2 + 0.00000002X^3$	0.000001	0.71
ARG:	$0.0035 + 0.0011X - 0.000016X^2 + 0.00000006X^3$	0.00002	0.81
MDC:	$0.0152 + 0.00016X - 0.000007X^2 + 0.00000005X^3$	0.000001	0.93
HV:	$0.0077 + 0.00067X - 0.000012X^2 + 0.00000005X^3$	0.00001	0.70
BKWT:	$0.0156 + 0.0009X - 0.000032X^2 + 0.0000003X^3$	0.00001	0.85
CC:	$0.0183 + 0.0001X - 0.000002X^2$	0.000001	0.82

LEAF AREA RATIO (vegetation) OM

HV:	$0.23001 - 0.00008931X$	0.00002	0.54
ARG:	$0.20988 + 0.000147X - 0.0000019X^2$	0.00003	0.43
MDC:	$0.023846 - 0.000303X + 0.0000014X^2$	0.00001	0.85
CC:	$0.026628 - 0.000135X$	0.00003	0.63
AC:	$0.027493 - 0.000157X$	0.00001	0.89
RC:	$0.030156 - 0.000171X$	0.00001	0.87
SWT:	$0.029987 - 0.000177X$	0.00001	0.88

Table 14 (cont.)

LEAF AREA RATIO (whole plant) EL

		MSE	R^2
AC:	$0.0014 + 0.00023X - 0.000005X^2 + 0.00000003X^3$	0.000001	0.68
RC:	$0.004 + 0.00014X - 0.000003X^2 + 0.00000003X^3$	0.0000001	0.70
BKWT:	$0.0062 + 0.00062X - 0.000024X^2 + 0.0000002X^3$	0.00001	0.54
CC:	$0.0032 + 0.0001X - 0.0000007X^2$	0.000001	0.52
ARG:	$0.0003 + 0.0002X - 0.0000011X^2$	0.00001	0.57
MDC:	$0.0059 - 0.00012X + 0.000001X^2$	0.000001	0.56
SWT:	$0.0026 + 0.00005X - 0.000003X^2$	0.000001	0.35
HV:	$0.0144 + 0.00002X + 0.0000003X^2$	0.000001	0.56

ROOT:SHOOT RATIO (mass) EL

AC:	$9.941913 - 0.669X + 0.027487X^2 - 0.000402X^3 + 0.0000018X^4$	5.299	0.65
HV:	$5.1625 + 0.3688X - 0.0093X^2 + 0.000053X^3$	16.96	0.31
BKWT:	$1.8569 - 0.0992X + 0.0048X^2 - 0.00005X^3$	1.479	0.14
ARG:	$9.313 - 0.1594X + 0.0008X^2$	7.659	0.57
MDC:	$2.268976 - 0.198004X + 0.016833X^2 - 0.000307X^3 + 0.000001543X^4$	1.926	0.64
CC:	$4.2191 - 0.0367X$	1.390	0.61
RC:	$5.0011 - 0.0377X$	4.545	0.34
SWT:	$5.3626 - 0.0257X$	3.057	0.26

It's interesting that the pattern of biomass accumulation for CC, which had twice the biomass of all the other species, also differed from all other species. It suggests that a different strategy of growth may be related to superior performance. Sweet clover also had a unique growth pattern, perhaps related to it's shoot/root partitioning. Since the EL data are more descriptive of real differences in biomass accumulation pattern than the OM data, ARG may also have a distinctive pattern. That the other species growth patterns were not as clearly differentiable is also important.

The trends/patterns of growth parameters also tended to differ, though not so clearly as biomass (figures 18 and 19, table 13). The parameters considered were leaf area index (LAI), specific leaf area (SLA), leaf/stem ratio (LS), vegetative leaf area ratio (vLAR), root/shoot ratio (mass basis), and whole plant leaf area ratio (LAR). Table 14 presents polynomial equations for these parameters grouped by slope ($p=0.05$). Less confidence should be given to the whole plant parameters than the shoot parameters for reasons given earlier. These curves are derived from mean values, and are general representations of pattern only. Growth patterns are best described and discussed with the (5 sampling) EL data. But comparison of the mean growth trends for EL with the OM trends site by site indicates that several parameters may have been highly responsive to specific microsite conditions, and this plasticity in response may be species-specific. This is discussed later.

Crimson clover had a distinct pattern of LAI, paralleling biomass. Hairy vetch also had a unique LAI pattern.

An increase in SLA with corn canopy closure and a decrease in SLA with corn canopy senescence was evident for most species at EL (figure 18). At OM, SLA responses appeared site specific (figure 19), indicating the sensitivity of this response. All species' SLA was lower at the final sampling than at any other date. A common pattern of specific leaf area (SLA) was shared by RC, HV, and CC.

Alsike clover, which had the lowest biomass and cover in this study, had a unique SLA pattern (as did BKWT).

Leaf area ratio patterns were also difficult to interpret, although CC again had a unique pattern. Leaf area ratio patterns differed (table 13) for CC, BKWT, and RC-AC. At OM, LAR patterns over sites clearly varied (figure 19).

Patterns of LS did not correspond to any performance criteria/magnitude.

Plasticity / Variance of Growth Parameters

The acclimation of species to the low resource conditions (light), may have been less important than the response to the dynamism of the environment, especially light. The ability to adjust to decreasing and then increasing light might be critical to cover crop yield. We were interested in time trends, but also in the plasticity of growth traits across field microsites. In addition to the magnitude and time trends of parameters we examined plasticity, spatially and temporally. We felt that plasticity (or resilience) of some traits might be related to overall performance. The patterns of variance differed as much as the patterns of actual values.

At EL, differences in pattern of LAR were difficult to detect in part because of the large variance of this parameter (figures 18 and 19). Species which seem to have the greatest variability in vLAR, tended to have the best end of season performance (see figure 18).

Figure 19 illustrates SLA trends by site (at OM). Late season variance of SLA for CC may have to do with self-shading.

As with SLA, the species whose variance in vLAR counterbalanced variance in LAI, tended to be the high performers. Species differences in vLAR trends were especially apparent in later samplings.

At OM, LS tended to be more consistent across sites (figure 19) than other parameters, HV had a more variable LS response across sites than did the other species. Leaf stem ratio seemed to have moderate plasticity.

Figures 20 and 21 present the CV of growth parameters through space (y axis) and time (x axis). The amount of variance (magnitude of CV's) differed for different parameters. The conclusion from these figures is that the spatial plasticity of traits clearly varied over time (with sampling). As indicated earlier, plasticity increased during the mid-season (EL), following corn canopy development (with the exception of HV LAI). Low performance species had parallel variances of SLA and LAI, while high performance species tended to have opposing trends, this is most apparent for CC at OM (figure 21), but is observable for other species (HV, MDC) and locations. However, ARG did not conform to this pattern, though it was a high performance species.

Both HV and MDC had prostrate growth habits, and moderate productivity. Yamagata and Nemoto (1992) categorized herbaceous plant growth forms into position fortifying and position extending types. Hairy vetch and MDC (and perhaps ARG) appeared to fall into the position extending type, and this may explain differences in several parameters, especially in terms of plasticity.

Of the parameters, leaf area index tended to have the greatest plasticity for most species at most samplings (though not exclusively, especially mid-season) (figures 20 and 21).

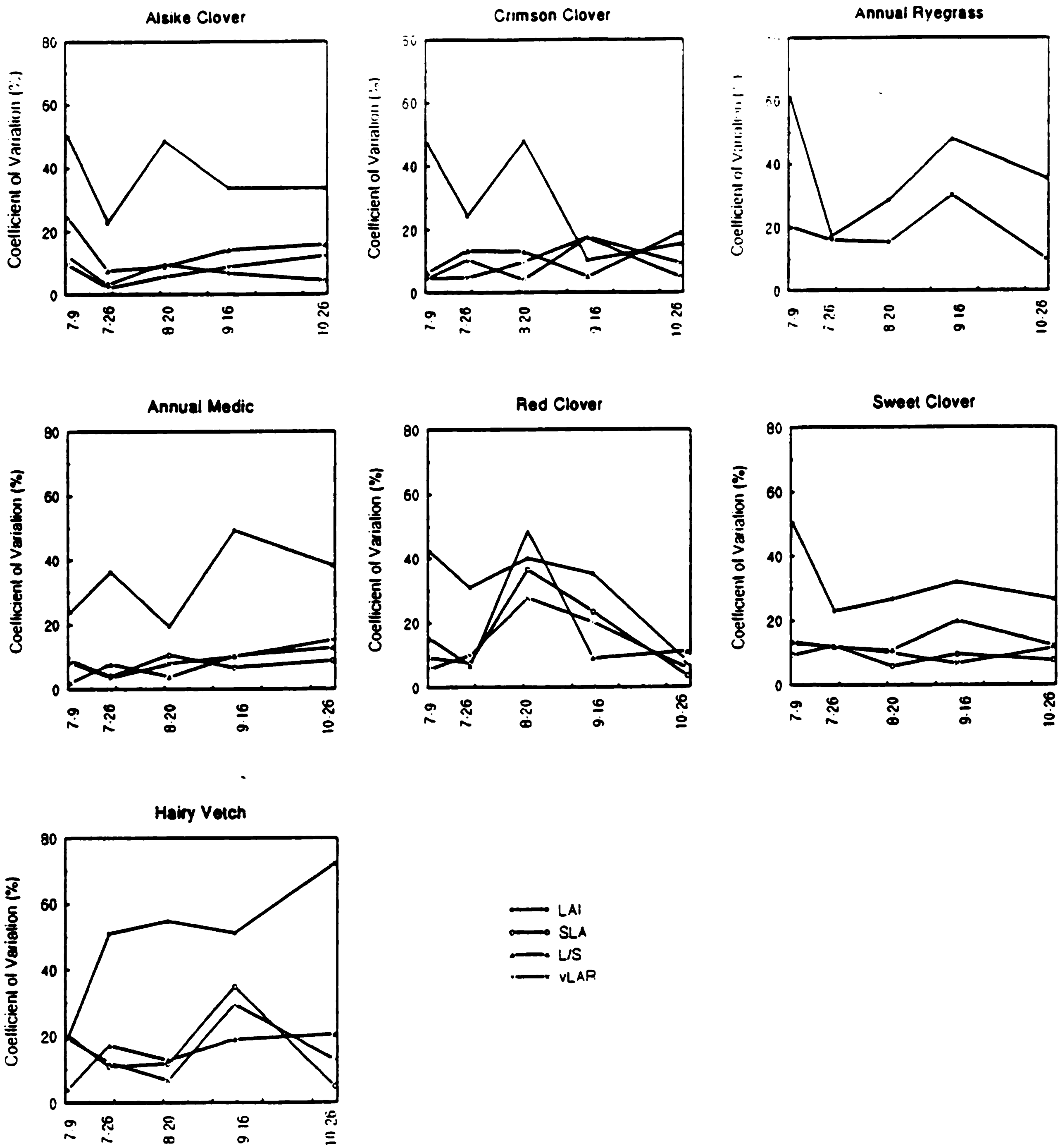


Figure 20. Patterns of coefficients of variation for EL growth parameters on 5 dates.

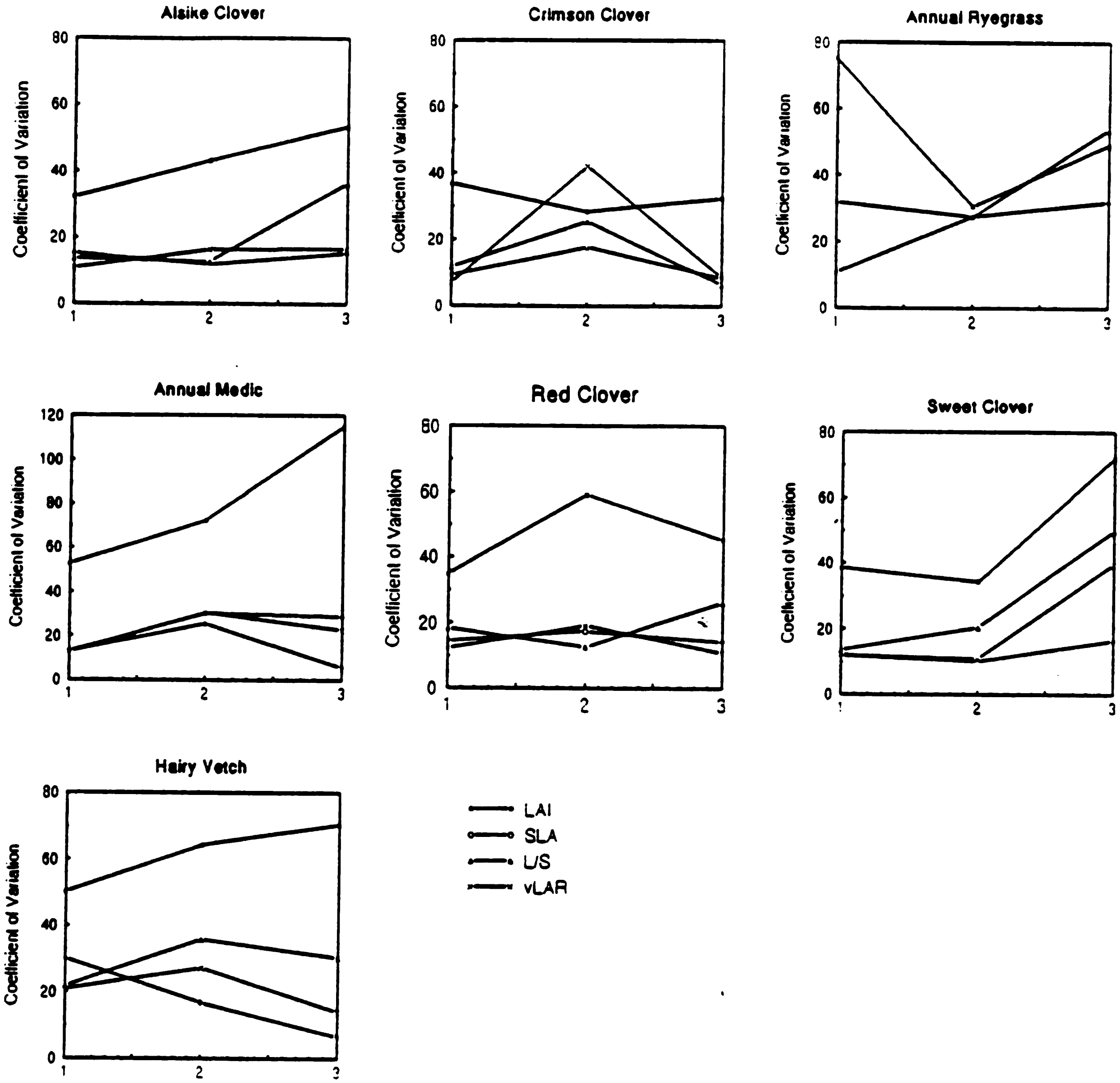


Figure 21. Patterns of coefficients of variation for OM growth parameters on three sampling dates. 1 = AUG 9, 2 = SEPT 30, 3 = DEC 5.

Growth Analysis Summary

The hypothesis that species with a resilient (stable) leaf surface area/root surface area ratio would have better performance was not testable, because of the problems with root data. However, crimson clover, the species with the highest biomass also had the most uniform biomass across the field, and the most consistent RSA value over samplings (figure 17).

No particular growth analysis parameter was directly associated with high biomass except LAI, which is partially a case of autocorrelation. High biomass was associated with species with high LAI, but also with species with low LS.

Biomass accumulation patterns did differ between species. The high performance pattern (of crimson clover) did differ considerably, throughout the season, but especially in late fall.

A plastic trait or species may have advantages in a predictably changing or constant environment, while resilient traits or species may have advantages in dynamic environments. The utility of plasticity in plant traits for survival in this system is apparently trait specific. In this study, trait plasticity does differ and the pattern of trait plasticity differs with species.

Plasticity patterns may be associated with performance, but further work is necessary. Species with complementary plasticity patterns seemed to have better performance. Only in the case of CC was low biomass associated with high plasticity (of LAI).

Leaf Emergence : Senescence

Comparison of the initiation of new growth relative to senescence on a whole plant basis provides another means of examining the critical periods and patterns of growth (figure 19). The proportion of individual plants sampled with new growth evident, and slightly more subjectively, the proportion of plants with leaves showing senescence or chlorosis is interesting in both magnitude and trend. These graphs closely reflect overall stand observations of vigor and biomass.

Individual plants simultaneously exhibited emergent and senescent leaves. In the interseeded system species tend to have prolonged vegetative growth. During vegetative growth senescence is unusual (Leopold and Kriedemann, 1975). The allocation of assimilate to new leaves when existing leaves could not be maintained suggests some interesting stress responses. This data also indicates that plants were responding individually to understory stress conditions. Vigorous intraspecies competition was not apparent, although some self-thinning of stands was observed (see population discussion below).

At EL, the most dramatic decline in the emergence of new leaves preceded peak leaf senescence. This suggests reallocation. The greatest stress (in terms of decreased new growth) appeared to be related to corn canopy closure (July 26). Peak senescence tended to coincide with tasseling (August 20). However, the critical period of growth in the interseeding system appeared to differ with species. The decrease in the rate of emergence of new leaves of CC and AC occurred later than for the other species (figure 22). (Sweet clover's high senescence on date 2 seemed to be associated with some foliar blight.)

Buckwheat, a fast growing 60 day annual, followed a relatively normal development pattern of growth and senescence, unlike the other species (figure 22). (Buckwheat was greatly etiolated and had minimal branching). Hairy vetch and MDC leaf senescence never overtook the emergence of new growth. These species, and SWT, exhibited nearly parallel rise and fall of chlorotic and new tissue. These species also appeared stemmier, more etiolated than other species. Annual ryegrass was distinctive for the consistency of numbers of plants exhibiting new growth, following an initial decline.

Within the remaining "clover species" the differences are more discrete, but perhaps more important. Crimson clover did not exhibit a reduction of leaf emergence nearly as great as the other species early in the experiment (periods 1--2). Crimson clover leaf emergence declined most dramatically later in the experiment, and is perhaps attributable to the stress associated with the prolonged low light. These changes in CC parallel trends in ULR (table 11), and biomass (figures 18 and 19) described earlier. Even as growth declined it closely approximated senescence. Crimson clover's unique early response may indicate the importance of early growth to overall productivity.

Red and sweet clover showed a lag response, with overall senescence exceeding leaf emergence (on a percentage of plants basis) for the early season. Red clover early in the season appeared very stressed and the stands "weak". As the season progressed RC plants and stands appeared more uniform. Alsike clover's pattern of leaf emergence, especially late season high leaf emergence and moderate senescence, suggests it was less tolerant of the canopy conditions and more tolerant of the fall conditions than other species.

Sweet clover, ARG (and BKWT) did not respond to the drydown of canopy with additional new growth, as did all the other species. Sweet clover responded as a true biennial, BKWT had completed it's life cycle. Red clover's increased senescence fits the same pattern, except RC had high levels of new growth.

The first, early decline of all species new growth may be attributable to the closing canopy. Increased leaf emergence and senescence in period 2--3 may reflect acclimation of some species. Senescence tended to peak at date 3, possibly reflecting the stress on all species with canopy closure. The decline of senescence between 3 and 4 may indicate the "completed" acclimation of individual plants.

Compare these to the LAI trends in figure 18, above. Late season senescence of HV and CC seemed to stabilize as growth increased.

In the field, CC, HV, MDC, and to a lesser extent ARG, (all annuals) did not appear to have any morphological response to the shorter days and cooler temperatures of fall. In contrast, SWT (biennial), AC and RC (perennials) did appear to be repartitioning above-ground growth, (despite the figures 22-23). Unseasonably warm temperatures occurred near the time of final sampling. This influence on leaf emergence is not known.

Examination of these responses in terms of plant adaptive strategies of tolerance or avoidance (Grime, 1975; Osmond et al., 1987) is also intriguing. In this system CC appeared to exhibit tolerance then avoidance. The other species exhibited cycles of avoidance and tolerance. Annual ryegrass, after an initial period of avoidance, maintained a low-level tolerance. Despite its high productivity, BKWT exhibited avoidance. However, in terms of reproduction only BKWT and MDC appeared tolerant (or insensitive) of the corn interrow environment.

Comparable leaf emergence and senescence trends for OM are presented in figure 20. Different seasonal timing of the OM and EL samplings may account for differences. The late season OM sampling allowed assessment of low temperature, short day responses. For reference, sampling date 2 in OM corresponds most closely to sampling date 4 in EL. At OM, AC, CC, and HV senescence tapered off as new leaf emergence increased, both relatively and absolutely. Red clover trends are also consistent in EL and OM. Contrasting the two locations, ARG trends appeared to differ most. Late fall trends of annual ryegrass at OM were due to senescence. Similarly, late fall decline of MDC (and SWT) were more apparent at OM data. Distinct trends of annuals and perennials were not apparent.

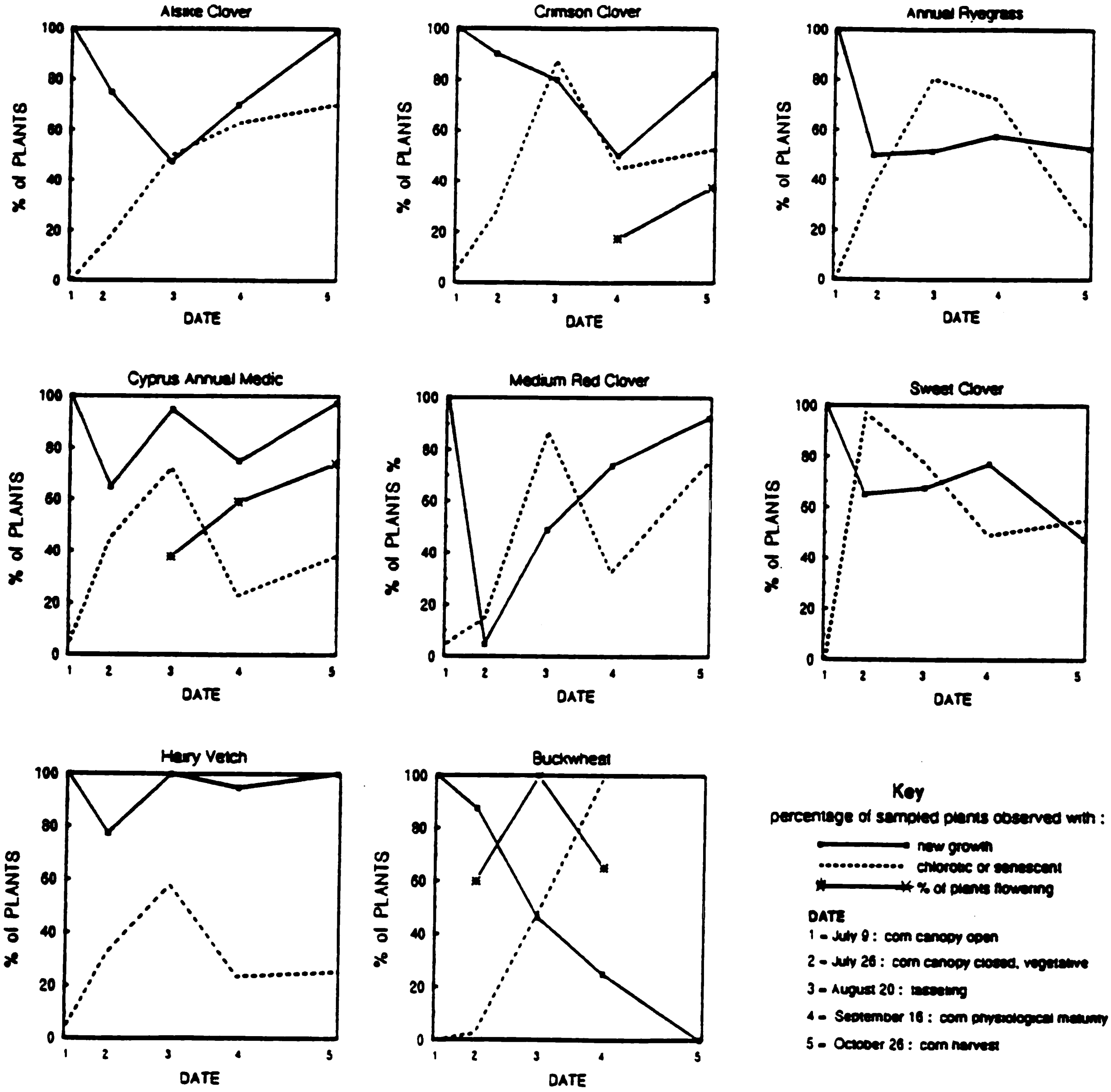


Figure 22. Leaf emergence and senescence of plants at EL. Data based on the percentage of whole plants sampled (40 plants per treatment) which had, either or both, new or chlorotic leaves. Y-axis represents the percentage of plants having chlorotic and newly emerged leaves. X-axis is the number of sampling.

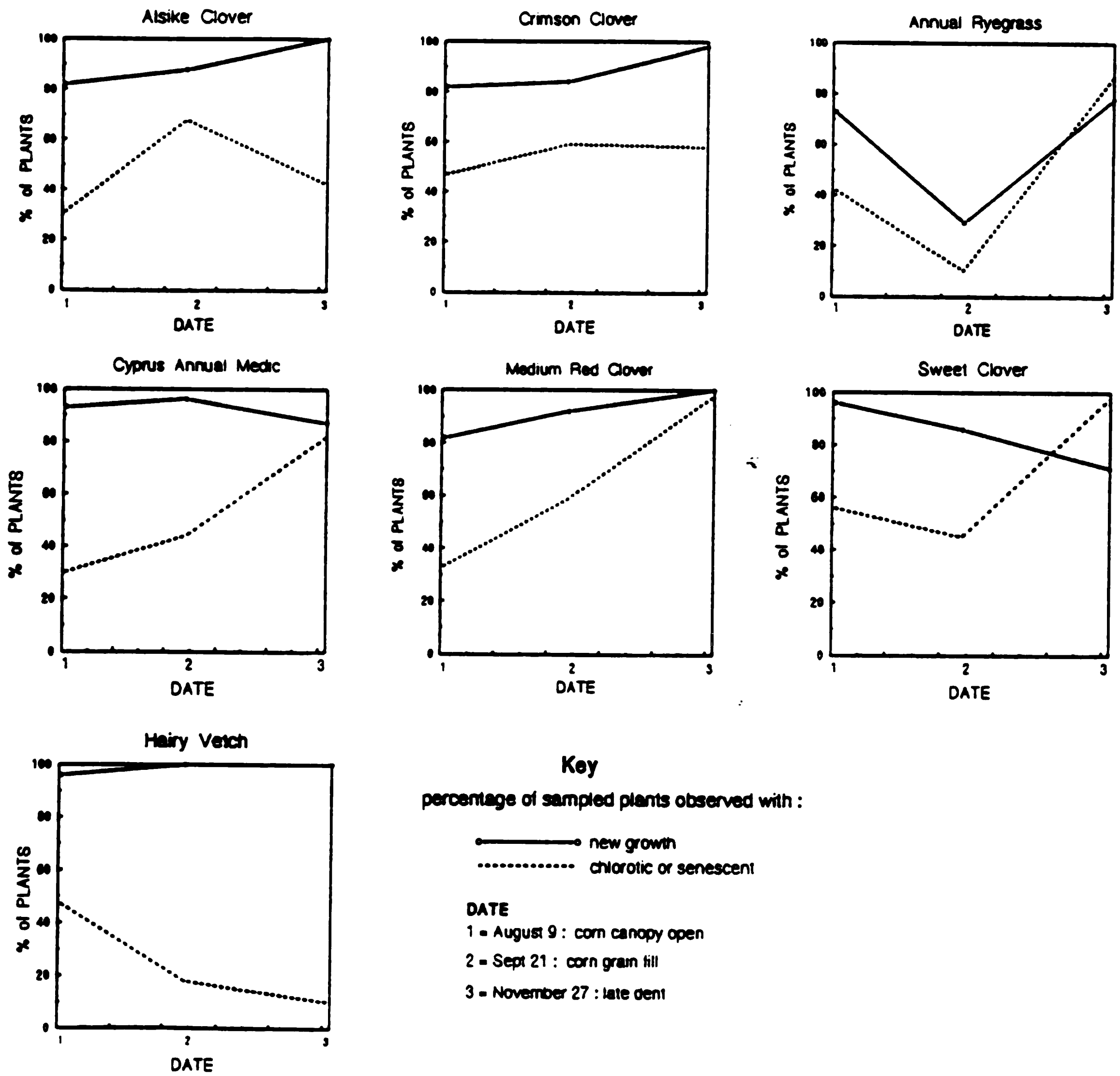


Figure 23. Leaf emergence and senescence of plants at OM. Data based on percentage of whole plants sampled (45 plants per treatment) which had, either or both, new or chlorotic leaves. Y-axis represents the percentage of plants having chlorotic and newly emerged leaves. X-axis is the number of sampling.

Qualitative Observations

Flowering

One premise of interseeding annuals into an established overstory is that reproductive phase/maturity will be delayed, and vegetative state will be prolonged. In these experiments all of the traditional cover crops followed this pattern. Three species did progress to flowering and seed set despite the overstory. These species were "new" either to this latitude or system. Seed viability was not evaluated.

In terms of selecting species for cover cropping, seed hardiness and natural reseeding may be of interest. Flowering may influence insect behavior and populations. Flowering was generally associated with winter kill and senescence. Both BKWT and MDC systems might benefit from association with a crop that could provide for nutrient uptake as they senesced.

Buckwheat began to flower by late July (within 25 DAP) and continued until BKWT death in late September. Seedhead formation was first observed in early August.

Annual medic began to flower 45 DAP, in mid-August, and continued to flower until the end of the season. Seed formation was observed by late August. Annual medic flowering was not uniform. A few MDC sites, apparently those with lower PPFD, flowered later (without seed set) or not at all. At OM, MDC flowering was observed in early to mid-September until mid-November.

In contrast to MDC and BKWT, only individual CC plants flowered (in September-October). Flowering plants were randomly distributed throughout the plots (both at EL and OM) perhaps indicating a genetic 'predisposition' of some individuals to flowering in this system. Flowering was not observed in late fall.

Annual ryegrass reached reproductive maturity in a few isolated sites (in late September). This appeared to be related to attainment of some PPFD threshold in those sites.

Flowering responses may have been related to photoperiod distortion (perception) due to the overstory or lack of influence of photoperiod or PPFD on flowering. Flowering was generally more vigorous in reps and sites with lower corn light interception.

Growth Habit

Hairy vetch and MDC had prostrate growth habits, which were established between the second and third samplings (EL). Buckwheat ordinarily is an erect species, but in the understory, due to either light or high N, some plants seemingly became prostrate, and others lodged. The remaining species all had erect, and in December, rosette growth.

Canopy

Complete canopies were never formed by alsike or sweet clover. Annual ryegrass, and mixture canopies were fully formed by the second harvest at OM (mid-September), CC and HV closed shortly afterward, and RC canopy closed slightly later still. These responses were fairly uniform over the field, except for the two southernmost set of sites. Annual medic canopies only were closed briefly (during a two week extravaganza of growth in mid-October), and not contiguously through the field. At EL, cover canopy closure, was less consistent. Only ARG, CC, and HV had complete canopies, and not in every rep. Closure occurred during October.

Traffic and treading tolerance

In spring 1994, we observed damage from field traffic, most of which we associated with the January harvest, despite frozen ground and snow cover. Red clover clearly was tolerant to traffic, and was almost unaffected. Hairy vetch and ryegrass were intolerant (i.e. completely killed) in wheel tracks. Alsike and sweet clover showed some traffic damage. Similar species sensitivity, but less dramatic damage levels were associated with foot traffic during the field season.

Nodulation

The presence of nodules was recorded for every root sampling. Nodules alone do not indicate N fixation, but nodules are requisite for fixation. Nodulation may also serve as an indice of stress. Table 15 shows nodules were frequently detected on roots of most legume species.

Table 15. Number of EL replicate plots where root nodulation was detected on 5 sampling dates in 1993.

	July 9	July 26	Aug 20	Sept 16	Oct 26
ALSIKE	4	4	3	3	3
CRIMSON	3	4	4	3	4
MEDIC	2	2	2	0	0
RED	2	4	4	4	4
SWEET	1	2	1	3	4
VETCH	2	2	0	4	3

Population

Cover crop populations appeared somewhat related to plant and seed size. All populations appeared to decrease slightly at the end of the season, except hairy vetch which also had the lowest and most consistent populations overall, suggesting minimal intraspecies competition. Alsike appeared to have the greatest self-thinning. Other species, possibly had greater intraspecies competition as growth (and light) increased with corn drydown. This measurement was made for calculation of biomass, not for monitoring populations.

Table 16: EL population counts (individual plants rooted in quadrat) as means of 3-0.04 m quadrats per replicate plot, 4 replicate plots.

DATE	Alsike	Crimson	Ryegrass	Medic	Red	Sweet	Vetch	Buckwt
7-9	128	77	93	93	120	111	38	46
7-26	302	125	231	139	204	332	45	65
8-20	252	126	222	83	157	305	37	36
9-16	117	90	241	102	139	240	46	44
10-26	198	108	111	102	138	157	46	dead

Power (1985) determined that large seeded species had an early season advantage. In our experiment, seed size was not clearly associated with performance. Early growth rates (not germination) among the clovers may have been influenced by seed size. Crimson clover was the largest seeded clover species, and AC the smallest. Hairy vetch was the largest seeded legume, but germination and early growth was slowest of all species. Buckwheat had the largest and heaviest seed, while ARG had the lightest seed.

Summary and Recommendations

Growth of cover crops interseeeded into corn at cultivation was described for a small plot and a field-scale study for two environments (location-management combinations). This study had nine objectives (see page 22).

Species which overwintered contributed more nitrogen to the system than did species which winter-killed. In mid-May, red clover was associated with the highest amount (96 lb a) of nitrogen (plant + soil). Red clover had the highest levels of soil ammonium. Crimson clover resulted in the highest soil nitrate levels in mid-May. Treatment differences in combined soil N were not agronomically significant. Either the cool spring temperatures of 1994 or photoperiod influenced species relative, mid-May, performance. During the 10 days following the final OM sampling, hairy vetch and sweet clover biomass and cover appeared to greatly increase. Other species biomass and cover also increased, but not as dramatically.

Variability of cover crop biomass and associated N did not increase with the magnitude of these parameters. Crimson clover had both the greatest amount and most uniform distribution of biomass over the field in December. In spring, red clover had the best cover and distribution and amount of biomass. Uniform cover crop growth did not necessarily result in uniform soil N. Fall cover was superior for annual ryegrass and annual ryegrass mixtures. Legume species appeared to be favored in sies with more vigorous corn growth (either due to tolerance of shade or low soil N). Fall cover exceeded 50% for all species. Alsike and sweet clovers and annual medic provided the least winter cover. All species biomass and cover were greatly redcued when sites had both a very dense corn canopy and poorly drained, saturated soils. For the cover crop species evaluated, a single season of interseeding was not an economic practice, based on N fertilizer substitution. Interseeding cover crops, particularly red clover, may become economic with increasing fertilizer prices (of approximately 25%), if cover crop seed cost does not increase. Economy of interseeding is a function of both fertilizer and seed costs. Cover crop seed production should be investigated as a farm strategy.

Long term or continuous cover cropping systems benefits were not considered this study, but need to be evaluated, especially soil tilth, OM, and nutrient aspects.

Late fall soil nitrogen levels were not changed by cover cropping, but soil nitrogen immobilization was not evaluated. It will be important to study the N dynamics of winter-killed species, especially with regard to N loss from the system, and in comparison with over wintering species.

Growth patterns differed with cover crop species. Generally, initiation of new growth and biomass accumulation declined with corn canopy closure, then recovered slightly. As the corn canopy senesced, patterns of cover crop biomass accumulation diverged. A distinctive pattern of biomass accumulation (both early and late in the season) was associated with crimson clover, which produced twice the biomass of any other species by late fall 1993. However, growth parameters were not clearly associated with productivity levels. Fall performance did not directly correspond to N contribution at spring plowdown.

The high stress periods appeared to be periods 2 and 4 at EL, and 2 and 3 at OM. The period of greatest stress for interseeded covers appeared to be immediately following canopy closure. Interseeded species were also highly stressed as the corn reached physiological maturity. Fall (post corn physiological maturity-drydown) growth appeared to be important to 1993 performance. Fall growth was related to early season growth. Crimson clover, the species with greatest biomass in December, had greater rates of growth and biomass at the first and second samplings, and in the final fall period. Crimson clover periods of greatest stress appeared to occur slightly later than for other species. This allowed greater accumulation of plant biomass and reserves prior to the onset of stress, and a shorter duration of stress overall (because CC peak stress occurred nearer to the initiation of corn canopy dry-down, which ended the stress period).

It was not possible to test the root-shoot ratio-resilience hypothesis. The data suggest it may be true for some species, but not others. Although interseeding cover crops had no effect on above ground characteristics, including yield, the root data indicate an interaction of cover and corn roots. Research methods need to be improved to better understand this phenomenon, and it's implications for field scale performance.

No particular growth analysis trait determined productivity. A combination of high leaf area index, low leaf-stem ratio, and high leaf area ratio may be associated with better performing species. No clear pattern of trait plasticity was associated with productivity or performance. Leaf area index was the trait with the highest CV. However, species which had a diverse range (or non-parallel) individual trait plasticity's tended to have better fall performance (CC, HV). This suggests that plants that are highly responsive in multiple traits may be more adaptable to resource fluctuations. At OM, the high performance species seemed to have high plasticity but only in response to abrupt resource changes, i.e., high thresholds. This may indicate species should be selected for a field based on the range or heterogeneity of field conditions. Research on such response thresholds is necessary.

This study generated both practical farm information for the farmer, and insight into the ecological, especially plant, factors involved in cover crop performance. Farmer participation in the research process resulted in identification of a uniform performance (N) over the field as a performance criteria. This type of contribution is vital. Farm operational constraints need to be accommodated when an alternative cropping system has a marginal economic value, and systemization of technology needs to be considered from the initiation of the technology development process. The participation of multiple (2-4) farmers (and management perspectives) would enhance the on-farm technology development and evaluation process.

The exploratory on-farm research approach helped us to understand the dynamics of the interseeding system. Field selection and research design greatly influenced which hypotheses can be tested or even which phenomena can be observed. Field Variability characteristics need to be studied from both farm management and ecological process perspecitives. At an applied level, agroecological thresholds for operational "windows" need to be defined for interseeding system. Research on several farms (managements) would increase the validity of agroecosystems research, though logistics would be a challenge. Controlled environment, greenhouse or growth chamber studies are the best "reductionist" complements to field-scale studies. If selected-site (or small plot) studies are desired they should be "nested" in the field-scale study microsites. Field-scale on-farm research provides infinite opportunities to understand and improve agroecosystems function and management.

APPENDICES

APPENDIX A.

Review of 1992 Field Trials:

Omega Farms

A field-scale corn interseeding trial was also conducted at Omega Farms in 1992. Operations were similar to 1993, but the experimental design was different, allowing different questions to be explored.

In 1992, field operations were efficient and cover crops were successfully established, however crop weed management practices contributed to the failure of the 1992 Omega trial. A cool wet season may have also contributed to the lack of success in 1992. It had been anticipated by experienced agronomists that mechanical cultivation would provide adequate weed control both between and within the corn row. However, a dense stand of lambsquarters (Chenopodium spp.) and occasional spots of giant foxtail were not controlled in the corn row. The presence of these weeds did not appear to have any especially adverse effects on the corn stand or productivity, possibly due to the abundant rainfall. However, weed biomass was high in most plots and the weed canopy appeared to be quite dense, and is thought to have contributed to much greater light interception by the overstory, and lower light intensities than expected in the corn understory, cover crop environment. Though excellent stands of all cover crop treatments had established within 2 weeks of seeding throughout the study plots, 95% of all cover crop species had died out in the understory by September. We speculate that the low light intensity, combined with a longer than expected or ordinary duration of shading, (corn canopy maturity was delayed due to abnormally cool air temperatures) are thought to have caused the demise of most cover crops. High precipitation and soil moisture, frequently saturated soils and flooding in poorly drained areas of the field (due to collapsed tile) may have exacerbated/ compounded the stress conditions experienced by the plants. Only one sampling was possible.

From a practical perspective all stands had failed by mid-September, isolated groups of individual plants survived until spring of 1993. We concluded that under long periods (6 weeks) at light intensities below 150 umols and/or saturated or flooded soil conditions, cover species will not persist. The first species observed to senesce was hairy vetch; the HV stand appeared vigorous until mid-August when within several days, every plant disappeared from the field. The next species to disappear was alsike clover. The species that appeared to be most resilient to the adverse field conditions were annual ryegrass and medium red clover (both commercial varieties).

Insect data were collected throughout the 1992 season, even when there were very few cover species.

In conclusion, in 1992 cover crops interseeded into corn failed due to both poor control of the weeds in the row which reduced the light, and the duration of light due to cool temperatures and/or saturated soils. Band spraying over the row, and cultivation, as practiced in the 1993 trial provide the necessary weed control for successful interseeding.

Soils Farm

In 1992, the MSU Soils Farm corn planting to be used for the interseeding trial was extremely irregular. Failure was eventually traced to the field plot's history (a micronutrient study). The corn stand initially planted was disced under in late June. As other land was unavailable the decision was made to redesign the "backup" trial for interseeding of soybeans, which were planted in late June in the same plots. The corn plots had been fertilized with 130 lbs N a^{-1}, excessive for beans. Due to logistical limitations, beans were not cultivated until late July. Beans were interseeded at this time. Weed control in this planting was poor (due to tillage associated with corn discing), and hand weeding was also necessary within the row. The bean stand was also not particularly uniform. The results of this small plot trial were interesting, especially some photosynthetic data, but inconclusive, and probably not useful, due to the cropping practices and timing.

APPENDIX B.

Chlorophyll Fluorescence of Interseeded Cover Crops

Introduction

The use of cover crops for erosion control and nitrogen management is an increasingly important practice. In northern temperate regions, cover crops are often overseeded (relayed) into an established row crop. During the summer the growth/development of the cover species is thought to be checked by low irradiance caused by closure of the overstory canopy until the crop reaches physiological maturity, and the overstory canopy begins to senesce. In temperate climates the primary opportunity for the accumulation of biomass (and N) in the cover crop, is the period when irradiance exceeds the compensation point (calculated on whole plant carbon balance/diurnal cycle), is in mid to late autumn following crop maturity (drydown or leaf drop) and harvest. The other period is in the early spring prior to cover crop kill (via tillage or chemical control). Both these periods are characterized by diurnal atmospheric temperature flux, coolèr temperatures, and short daylengths.

Cool temperatures and bright sunlight are often associated with the degradation of chlorophyll a in leaves (Somersalo and Krause, 1988). Low temperatures are associated with the destruction of chlorophyll and photosystem capacity, as well as direct limitations of PSII via reduction of PEP carboxylase activity (Krause and Weis, 1991). These are known as irreversible and reversible photoinhibition respectively.

In interseeded systems, the irreversible photoinhibition associated with chlorophyll destruction has implications for productivity, because in fall and spring cold days or nights are intermittent with more favorable conditions for photosynthesis, providing the photosynthetic "apparatus" is intact. If no destruction of the PS system has occurred, then only actual hours of low temperatures are lost (plus brief recovery periods), however with destruction, the capacity to utilize better conditions for net biomass accumulation is lost. In addition, species with tolerance for lower temperatures may have faster recovery times due to their capacity for synthesis and resynthesis of metabolites at low temperature.

Performance of interseeded cover crops is a function of their ability to survive low light conditions (during the summer) and their capacity to accumulate biomass during seasons of low, but fluctuable atmospheric temperatures. Comparison of interseeded species responses to the interaction of low temperature, and high irradiance is useful for understanding the relative potential (as one selection criteria) of cover species for mid-Michigan. Chlorophyll fluorescence was selected as the measure for comparison as it reflects long term damage to the photosystem (chlorophyll destruction), and loss of photosynthetic potential (Kowslowski et al., 1991 p. 146).

Cover crop species productivity may differ in because of species light interception, capture, and utilization efficiencies. Light intensity and quality also influence productivity (Monteith, 1981; Smith, 1982).

Chlorophyll fluorescence is a means of measuring the efficiency of light capture via integrity of chlorophyll/chloroplasts and consequently the efficiency of the photosystem. The objective of this study was to determine if cover crop species exhibited differences in chlorophyll fluorescence, and to relate these differences to relative biomass accumulation.

Methodology

In 1993-4 data was collected from seven cover species which had been interseeded into corn. Data was collected on 3 fall dates: when corn canopy was full (PPFD = 300 umol m^2 sec^{-1}) (corn physiological maturity), at corn harvest

(PFD = 650 umol m^2 sec^{-1}), and after heavy frost. Measurements were also made twice the following spring.

Sampling dates were selected for cool (below freezing) night temperatures, and clear, bright conditions the following morning. On each date, six to twenty leaves were collected for each species, for the statistical analysis, an individual leaf was considered a replicate. Single, healthy, fully expanded leaves (from distinct plants) were selected from the top of each canopy, placed in plastic bags, then returned to the lab for measurement and calculation of variable over mean fluorescence. In December leaves were left in a dark cooler overnight, prior to measurement the following morning.

Single leaves were placed in cuvettes of a set to 900 umol actinic light for 60 seconds. Leaves were acclimated to the cuvette 'dark' for at least 15 minutes prior to measurement. In October, leaves had to be measured at 700 PPFD, due to some malfunction of the CF apparatus.

Variable over mean fluorescence (Fv/Fm) was recorded for each leaf. Data were analyzed using a one way classification (CRD) using SAS GLM and LSD procedures.

Results

Results are presented in the figure below. Red clover tended to have low Fv/Fm. Similar species trends were observed in spring 1992 (data not shown). The low Fv/Fm values of medium red clover statistically distinguished it from other species on the three most stressful (ideal conditions for photoinhibition), and potentially the most differentiating dates.

Other remarkable results are the relatively high CF values of crimson clover and cyprus medic, both southern introductions which winter-killed in Michigan. The low crimson clover Fv/Fm values for the DEC 93 and APR 94 measurements are difficult to explain, however a small percentage of crimson clover individuals did overwinter successfully in our experiments. It is possible that some of these were

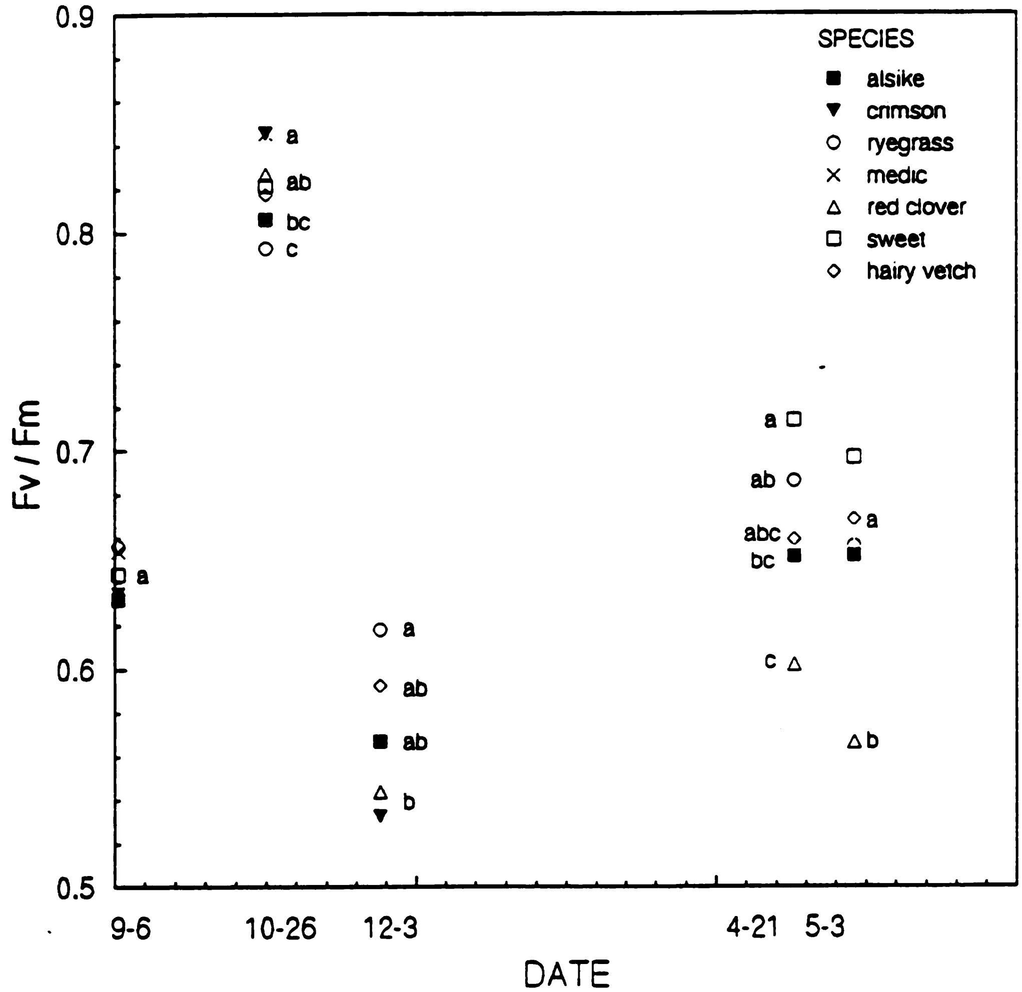


Figure 24. Chlorophyll fluorescence of cover crops in fall 1993, and spring 1994.

the plants sampled. Crimson clover had the highest SD's of any treatment. Further investigation is required.

The range of single leaf Fv/Fm values varied with date. The range of leaf Fv/Fm values for all species was very small in the earlier two samplings (Sept and Oct). For the higher photoinhibition stress dates, annual ryegrass and sweet clover had the lowest Fv/Fm ranges. Red clover had the greatest range, suggesting that individuals in the population determine stand productivity in photoinhibitory conditions.

The biomass accumulation between the two fall samplings was greatest for crimson clover followed by red clover. Crimson, then red clover had the highest biomass in the final Oct sampling. In spring, red clover had the greatest biomass at the spring final sampling.

Discussion

The literature indicates that a higher Fv/Fm ratio is associated with less photoinhibition (Somersalo and Krause 1988; Osmond et al. 1989, Koslowski et al. 1991). However this seems contrary to our results which seemed to indicate a relationship between cool season biomass accumulation and low Fv/Fm. This data shows an inverse relationship of early spring and late fall biomass and Fv/Fm, indicating net photosynthesis greatest in the species with lower Fv/Fm.

Shaded leaves often have higher levels of chlorophyll and perhaps more resistance to chlorophyll destruction, how light attenuation in the fall corn canopy interacts with species susceptibility to photoinhibition is worth further investigation. Leaf developmental stage may also effect CF (Boese and Huner, 1992). It is possible the Fv/Fm differences observed may have reflected leaf age as much as an inherently "different" response to photoinhibition. In autumn, some crimson clover individuals were flowering, suggesting development had progressed further for crimson clover than then other clovers. (Annual medic was also flowering).

Physiological limitations determining performance in this system and climate have management implications. Observations of spring growth suggest that resistance to chlorophyll destruction/photoinhibition (low CF) may contribute to early spring growth, but is not the sole determinant of final fall or spring biomass production of interseeded cover species in mid-Michigan.

Timing of spring cover kill would be important to determining use of CF in ranking species potential. Accumulation of biomass is a function of the duration of the growing season. In spring, as the growing period extends into warmer days and nights, and the conditions for low temperature induced photoinhibition less frequent, the importance of cold tolerance and the relationship of Fv/Fm to biomass would diminish.

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APPENDIX C.

Entomological Survey

Introduction

Field-scale experiments provide an opportunity to study phenomena that are not detectable on smaller plot scales. Agricultural entomological studies require continuous vegetation areas which will allow detection of responses beyond random search or flight patterns.

Ecologically, cover crops may influence row crop insect pests or predators. Covers may change insect habitat in a row crop field by providing alternate food sources, and seasonal food availability or by alteration of microclimate, especially in terms of temperature and humidity, and physical barriers (Clark et al., 1993). Presence of cover crops might alter insect population dynamics due to an extension of the reproductive period because of microclimate or may actually concentrate populations. Changes in pest, predator or parasitoid populations could have implications for production and farm decisions about cover cropping. For example, in Ontario, red clover interseeded into field corn reduced European corn borer damage by at least 50% (Lambert et al., 1987). In sorghum, Touchton et al. (1982) found that crimson clover interseeding influenced some pest populations, though not at economic levels. Ngalla and Eckert (198) reported damage to a corn stand following a red clover cover crop. They attributed this damage to increased populations of corn root webworm. Corn stands in plots without cover (no red clover treatment) were not damaged.

So, as part of a larger cover crop comparison study, it was thought useful to determine if the numbers of several insect species, commonly associated with row crops, were effected by cover crop. The large "cafeteria" of cover crop treatments available in the established study made it possible to compare insect association on the basis of cover crop presence or absence, species, family (legumonosae versus poaceae) or biomass.

Methods

A preliminary survey was initiated to determine if cover crops could influence insect populations important to field corn. The insect species that were counted may influence the current or subsequent crop, or perhaps adjacent fields and other crops.

One method was used to monitor insect species association with cover crop treatment in an interseeded corn field through the summer and fall season (see chapter 2). Differential response to trap color and style is well known (Maredia et al., 1992). Since we used only one trapping method our study is indicative only of whether cover crops had an effect on insect numbers trapped. This data doesn't necessarily reflect actual insect numbers present or potential damage or benefit.

The study area (20 acres) was sited within a larger (180 acre) no-till (and no cover crop) corn field. Corn planting (on May 27) was late for this area due to a wet spring. Weed pressure was very low, the few weeds present were broadleafs. Field operations included a heavy discing, "no-till" planting (field populations of 28,500 a^{-1}). A preemergence (Bladex-Lasso) herbicide mix band-sprayed over the corn row supplemented a single cultivation. Cover species were broadcast overseeded following cultivation on July 12. Field moisture was adequate throughout the season, with occasional flooding of some plots. Corn yields were low throughout the field (94 b a^{-1}), in both study and non-study areas. Corn yield differences were not attributable to cover crops.

The trapping protocol selected monitored low flying insects. No-bait yellow sticky traps (Trece Pherocon (8*12"), Sandoz Ltd) were attached to corn plants, 12 to 18" above the soil surface in an established stand of second year field corn which had been interseeded with 10 cover crop options (treatments). The treatments included a no cover control, six herbaceous legumes, annual ryegrass, and two annual ryegrass-legume mixtures. Each plot was 13 m by 170 m. Two traps were placed in each plot in two rep (equalling 4 traps per treatment). Traps were set 170' apart on the NS axis, and 18' into the "center" of the plots on the EW axis.

On July 30, when all cover species were established, the first trap set was placed in the field. The corn stand's development was quite variable v6-v9 (LI=75%), but populations were similar (28,000 plants a^{-1}). Traps were collected and replaced with new traps on Aug 10. Subsequently, seven more sets of traps were used to monitor populations through the remainder of the growing season. Each trap set was in the field 10-12 days. Tasseling coincided with trap sets 2 and 3. The final trap set was removed from the field 24 October (following corn physiological maturity in late September).

After trap removal from the field, traps were placed in low temperature storage until counting later in the fall. Species selected for counting were of potential economic importance, and rapidly identifiable. Only readily identifiable adult insects were counted. The insect species monitored were western and northern corn rootworm (Diabrotica virgifera virgifera) (WRW, NRW), hover or syrphid fly (family Syrphidiae) (SYR), ladybeetle (family Coccinellidiae) (LB), potato leaf hopper (Empoasca fabae) (PLH), and minute pirate bug (Orius tristicolor) (MPB). Parasitoid wasps (Hymenoptera spp.) (WSP) were only counted for the mid-fall traps (5,6).

Data were analysed using SAS GLM, repeated measures GLM, GLM single degree of freedom contrasts, CORR, and LSD procedures. Transformation (LOG x+1, and log normal) did not alter the outcome of the analyses. No covariance (of insect species) analysis was thought justified with this data.

Results and Discussion

Cover crops did impact some of the insect species counted (table 17). For some species there were apparent temporal trends. Further assessment of several insect species-cover crop interactions is warranted. Although statistical differences were found, it must be stressed that these do not necessarily represent biologically or economically significant differences. In addition, the number of individuals trapped do not necessarily correlate with the number of individuals present, because little is understood about insect behavior in these cropping systems. However, the results indicate that cover treatments can have differential effects on some insect species in field corn.

Western corn rootworm: Counts were highest in set 3-6 (numbers and variance declined overall for set 7) (table 17). Counts only differed with treatment in the two earliest and last sampling periods (table 17). Initially numbers were greater in the annual ryegrass treatment, in the final set all grass treatments tended to have higher counts than treatments without grass (table 18). This may indicate selection of grass plots for extended egg laying and potential rootworm problems if corn were planted in the subsequent season. However, in set 2 (and 4), counts were much lower in annual ryegrass treatment than in any other treatment. It is possible WRW were cycling among treatments, or plots and replicates due to differences in corn phenological development (corn stage was variable within the second rep) to maximize reproduction. Maredia et al. (1992) have reported temporal shifts in

Ladybeetles: Counts were dominated by seven-spotted (C. septempunctuata) ladybeetles (91% of those counted); the occasional no spot and two spot individuals were included in the total ladybeetle dataset. Ladybeetles trapped did not necessarily reflect numbers present in the treatment plots, specifically, hairy vetch (and sometimes sweetclover) plots were observed to have more ladybeetles than other cover treatments, though more ladybeetles were not trapped in these

Table 17. Overall ANOVA results by insect species and trap set.

	1	2	3	4	5	6	7	8	
DATE IN--OUT	7/30--8/10	8/10--8/20	8/20-9/1	9/1--9/10	9/10--9/23	9/23--10/5	10/5-10/14	10/14-10/24	TOTAL
Western Corn Rootworm	0.01	.05	ns	ns	ns	ns	ns	0.002	ns
Hover Flies	ns	ns	ns	ns	ns	ns	ns	ns	0.02
Ladybeetles	0.002	ns	ns	ns	ns	0.05	0.002	ns	ns
Potato Leaf Hoppers	ns	0.0002	ns	0.0001	0.01	0.02	0.01	0.0001	0.0001
Minute Pirate Bugs	ns	ns	ns	ns	ns	ns	0.08	0.03	
Parasitoid Wasps	NA	NA	NA	NA		.001	ns	NA	NA

Table 18. Insect species response to treatment groups. Results of contrasts.

	Cover vs No Cover									Legumes vs Grasses									Mixtures vs Sole Crops								
TRAPSET	SSN	1	2	3	4	5	6	7	8	SSN	1	2	3	4	5	6	7	8	SSN	1	2	3	4	5	6	7	8
Western Corn Rootworm	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	***	**	ns	*	ns	ns	ns	**	ns	ns	ns	ns	ns	ns	*	*	**
Hover Flies	ns	ns	ns	ns	ns	ns	ns	ns	ns	**	ns	*	ns	ns	ns	ns	*	*	*	0.08	ns	ns	ns	*	ns	ns	*
Ladybeetles	ns	ns	ns	ns	ns	0.09	ns	ns	ns	ns	*	**	ns	ns	ns	***	ns	ns	ns	*	ns	ns	ns	0.09	ns	ns	*
Potato Leaf Hoppers	ns	ns	ns	ns	0.08	ns	ns	ns	ns	***	*	***	ns	**	**	***	**	***	**	ns	ns	ns	*	*	**	ns	***
Parasitoid Wasps	--	--	--	--	--	--	ns	ns	--	--	--	--	--	--	--	***	ns	--	--	--	--	--	--	--	**	ns	--

ns>0.05 0.05<*>0.01 0.01<**>0.001 0.001>*** SSN=seasonal total #=sample period

Table 19. Mean counts of adult insects per trap.

WRW	SOLE LEGUMES						NOT LEGUMES			
TRAP SET	ALSIKE	CRIMSON	MEDIC	RED	SWEET	HAIRY VETCH	A. RYEGRASS	RED-GRASS	VETCH-GRASS	NO COVER
*1	25.75	7.5	42.25	13.75	13	21	57.75	23.5	15.75	16.25
*2	126.5	118.75	104.75	110.75	100.25	95.5	29.25	103.75	76.25	117.5
3	122.75	140.75	131.25	104.5	140.75	139	62	92.5	148	119.25
4	64.25	78.5	119.25	71.25	80.75	69.75	40.75	65.75	85.5	88.25
5	85.5	85	107	107.5	106.25	90.75	91.25	94	109.75	95.75
6	19.75	16.5	15.25	16	22	19.75	21.75	27.5	24	19
7	19.25	25.25	18.75	20	27.5	18.75	26	28.25	34.75	17.75
*8	2.25	5.25	0.75	3	2	3.75	6.5	6.5	5.25	2.75
NRW										
1	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0.25	0
3	0	0	0	0.75	0	0	0.25	0	0	0
4	0	0.25	0	0	0	0.25	0	0	0	0.25
5	0	0	0.5	0.75	0.75	0.25	0	0.5	0	0.25
6	0	0	0	0	0	0	0	0.75	0.25	0
7	0	0.25	0	0	0.5	0	0	0.25	0	0
8	0	0	0	0.25	0	0	0	0	0	0
*HOVER										
1	0.25	0.25	0	0.5	0.5	0.75	0.75	0.5	0.5	0.75
2	0	0.5	0	0.5	1	0.5	1.5	0.25	1	0.5
3	1	1	1	0.25	1.5	0.25	0.25	0.5	0.25	1
4	1.75	1.25	0.5	1	2	0.5	2	1	1.5	0.5
5	1.5	3.75	2	1.25	2.5	3	3.25	3.5	4.5	2.5
6	1	1.5	1	0.25	1.5	0.5	1.25	0.75	2.25	1.25
7	0.5	1.5	0.25	1.25	0.5	1	2.75	2.5	1.75	2.25
8	0	0.5	0	0.25	0.25	0.25	1.25	1.5	1	0

LB										
*1	10.75	10.5	2.25	5	6	2.25	1.25	10.5	6.5	9
2	6.25	3.75	4.75	3.25	4	4.75	0	4.25	1.75	4.25
3	3.75	0	2.25	3.75	5.25	3	4.75	2.25	2	2.5
4	0	0	0.5	0	1	0	0.5	0.5	0.75	0.25
5	1	0.75	0.75	1.25	1.25	0.25	0.25	1	2	0
*6	0	0.25	0	0.25	0	0.25	1.25	0.5	0.5	0.25
*7	0.5	3.25	0	0.25	0.25	0.75	0.5	0.75	1	0.5
8	0	0.5	0	0	0	0	0.25	0.25	0.5	0
PLH										
1	1	0	1	0	1.5	2	3	2.5	0.5	1.25
*2	0.5	0	0.25	0.25	0.5	0.25	12.5	0.75	0.25	0.5
3	0	1.25	1	1	1	1.75	0.75	3	2	1.5
*4	1.25	12	0	0.5	1.25	1.5	8.25	0.25	1.5	0
*5	3.25	7.5	2.75	2.25	11.25	5.75	13.5	11.75	10.5	3
*6	4.5	8.5	3.25	3.25	4.75	6.5	17.5	11.25	12.25	7.25
*7	3.25	20.3	7.25	13.25	17	18.5	32.75	18.5	24.75	10.75
*8	7.5	18.25	6	4.75	10.5	8.25	21.5	18.75	19.25	13.5
MPB										
1	0	0	0	0	0	0	0	0	0	0
2	0	0.25	0	0.25	0.25	0	2.75	0	0	0
3	0	0.5	0	0	0.25	0	0	0	0.25	0
4	0	1.25	0	0	0	0	4.75	0	0	0
5	5.25	3.25	2.25	2	1.5	3.75	2.25	1.75	5.25	0.75
6	2.5	1.25	2.75	1.75	3.75	4.75	2.5	3.75	5.5	1.25
*7	1.75	2.75	0.75	0.75	1	1.75	0.75	1	3.25	0.5
*8	0	1.25	0.25	0	0	0	0	0	0	0
WSP										
*6	8.25	7.25	5	6.75	8.25	8.5	19.5	19.75	19.5	11.25
7	9	8.5	3.5	5.75	6.3	11.6	9	6.5	10	5.5

* = significant see table 17.

treatments (table 17). Repeated measures analysis indicated a time by treatment interaction. Ladybeetles prey on aphids, and reportedly prefer clovers to corn (Maredia et al., 1992). Habitat preference may influenced by non-food factors. As ladybeetles were counted in greater numbers in mixtures (table 18), and on several dates in crimson clover (table 17), it's possible they were attracted to high biomass treatments.

Potato leaf hopper: Potato leaf hoppers are associated with legumes, and are pests of alfalfa, but are not generally associated with row crops. However, counts indicated interesting population trends of PLH in cover cropped corn. There were clear temporal trends for PLH, counts varied with trap set (date) (table 19). With the exception of samplings 1 and 3, PLH counts differed with treatment (table 17). Although PLH are not important to corn, PLH were one of two species which showed a significant time by treatment interaction. Trends are presented in figure 2. Counts peaked in the seventh sampling, possibly reflecting a migration from more exposed alfalfa fields (figure 25). Potato leaf hoppers did have a weak positive correlation with biomass. Unexpectedly, grass treatments tended to have higher counts of PLH than legumes (table 19). Crimson clover (an introduced southern species) had the highest numbers of PLH especially with the initial and September counts. Annual medic, another "exotic" species had consistently lower numbers of PLH. The late fall increase in PLH numbers was also apparent in a similar study in 1992 (however in 1992, high counts were associated with sweet clover, crimson clover was not atreatment in that study) (data not shown), and presents an interesting ecological phenomena.

Hover flys: Syrphids are predatory species that prey on several corn pests. Counts showed seasonally significant differences with cover treatment (figure 26). However, for any specific trapset there were no detectable differences with treatment (table 17). Syrphid counts never exceeded 10 per trap, and typically 0 - 2 syrphids counted per trap. The time trends are presented in figure 26. Syrphid

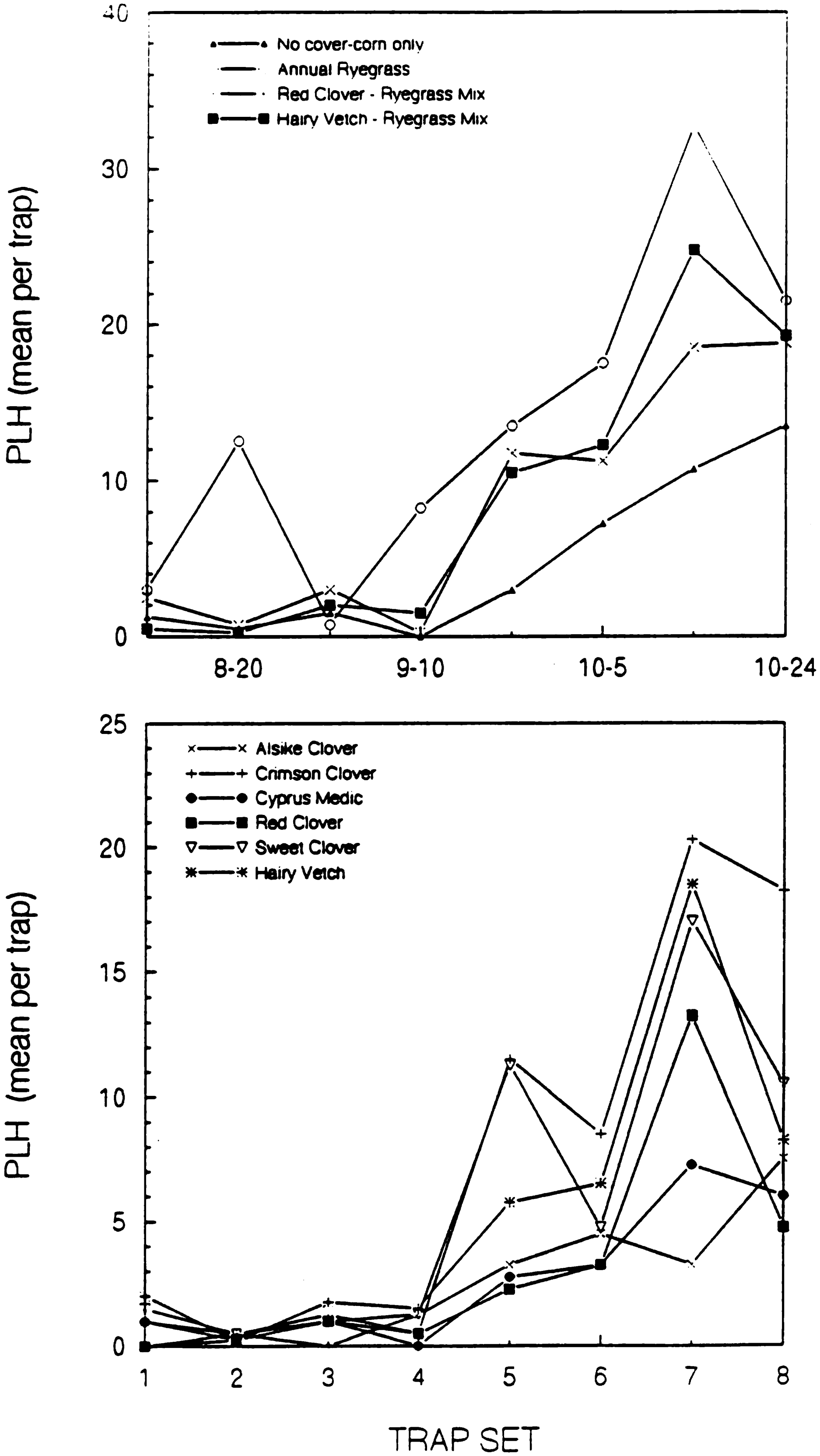

Figure 25. Potato leaf hoppers (PLH) trapped in 8 intervals in 10 cover treatments.

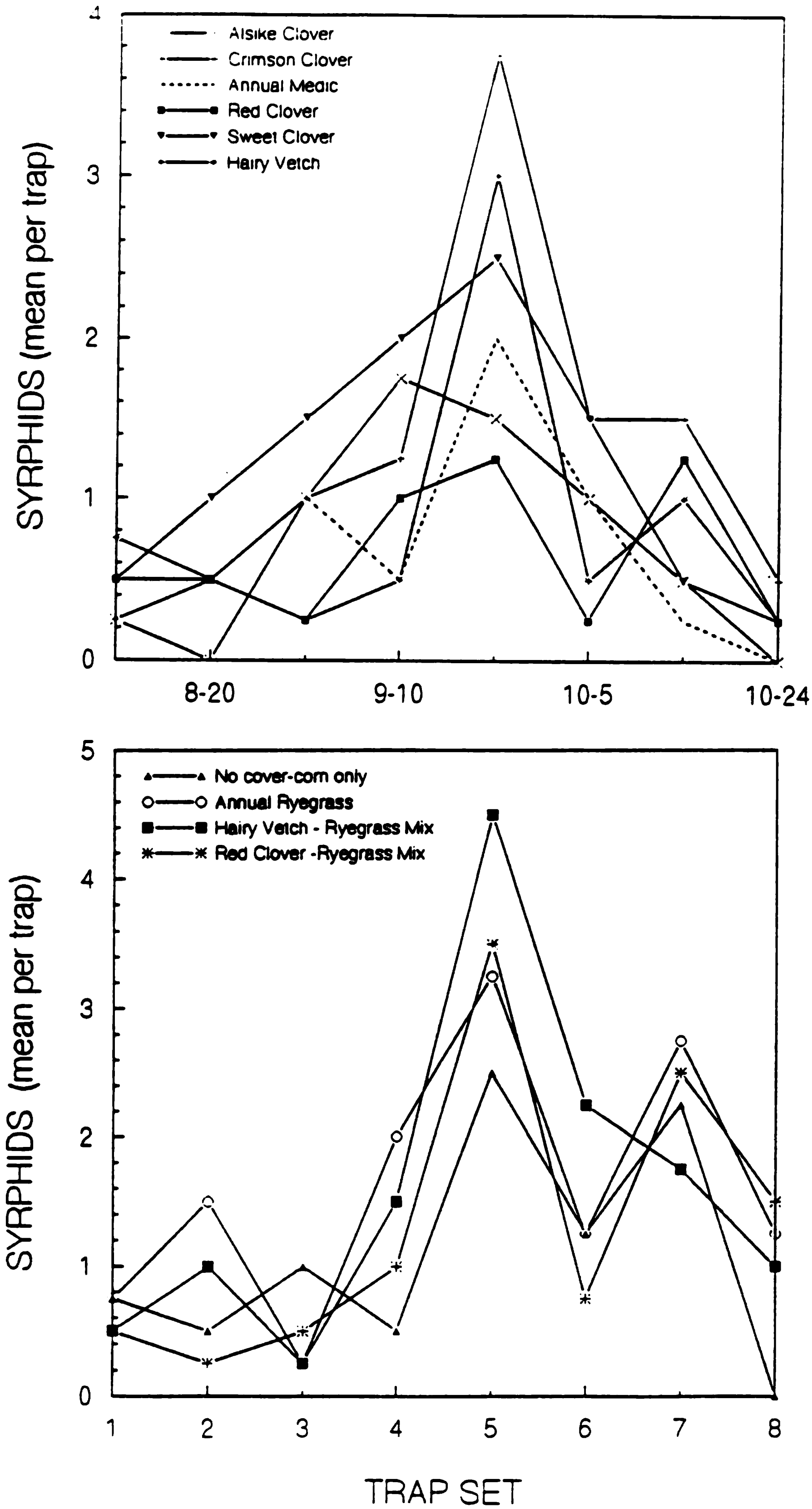

Figure 26. Hover flies (SYRPHIDS) trapped in 8 intervals in 10 cover treatments.

counts peaked between September 12 and 23 (set 5). Syrphid counts were higher in grasses than legumes, and mixtures rather than the sole crops (table 18). Towards the end of the season, hover flies selected plots without legumes.

Parasitoid wasps: Hymenoptera spp. are important beneficials in field corn. In the fifth period (end of silking), more wasps were trapped in grass than legume or bare plots. In trapset 7 WSP numbers tended to be higher in both the hairy vetch, and hairy vetch-ryegrass treatments.

Although occasionally statistically significant, actual numbers of minute pirate bugs were low. Similarly, so few northern corn root worm adults were found that no discussion is warranted.

Summary

The contrasts (table 18) indicated some distinct responses to grasses and legumes; and between mixtures and sole-seeded species. The presence or absence of annual ryegrass resulted in differential counts of insect species (table 18). Similarly a cover crop mixture versus a pure stand also resulted in statistically different counts.

Oddly, mere presence of a cover crop alone relative did not result in detectable differences in insect numbers. This suggests insects were selecting specific cover crops. It is also possible that low cover biomass legume stands (i.e., alsike clover) diluted the cover:no cover effect. See table 18.

Two of the trapping periods (hereafter trapsets), (1 and 6) coincided with biomass sampling. Analysis for correlation of insect species with cover aerial biomass rather than cover crop species indicated that, in the first trap set, none of the insect species counts were correlated with biomass, possibly because cover biomass was generally low. However, in trapset 6 ladybeetles, potato leafhoppers and parasitoid wasps showed weak positive correlations (Pearson coefficients = 0.32, 0.34 and 0.30 respectively; $p = 0.06$) with cover biomass regardless of cover species. Overall, this analysis was inconclusive.

It's important to consider that both mixtures included grasses, and grass and mixtures were among the higher biomass treatments later in the season.

The annual ryegrass stands were dense and vigorous. The presence of annual ryegrass was generally associated with significantly greater numbers of western corn rootworm, syrphids, potato leaf hoppers. Late in the season, greater numbers of ladybeetles and parasitoid wasps were also associated with annual ryegrass and mixtures, suggesting these treatments may have attracted food sources for these predators.

Among the legumes, crimson clover was associated with peaks of PLH and Hover flys, and LB in the mid and late season. An LSD indicated that WSP numbers were greatest in the vetch (and vetch-grass mixture) in the seventh trapset.

These results suggest that more intensive study of agronomically important insects in cover crops interseeded with field corn continue.

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