COMMUN. SOIL SCI. PLANT ANAL., 32(7&8), 1221–1250 (2001)

USING WINTER COVER CROPS TO IMPROVE SOIL AND WATER QUALITY

S. M. Dabney,[1] J. A. Delgado,[2] and D. W. Reeves[3]

[1] USDA-ARS National Sedimentation Laboratory,
P.O. Box 1157, Oxford, MS 38655, USA
[2] USDA/ARS, Soil Plant Nutrient Research Unit,
P.O. Box E, Fort. Collins, CO 80522, USA
[3] USDA-ARS National Soil Dynamics Laboratory,
P.O. Box 3439, Auburn, AL 36831, USA

ABSTRACT

This article reviews literature about the impacts of cover crops in cropping systems that affect soil and water quality and presents limited new information to help fill knowledge gaps. Cover crops grow during periods when the soil might otherwise be fallow. While actively growing, cover crops increase solar energy harvest and carbon flux into the soil, providing food for soil macro and microrganisms, while simultaneously increasing evapotranspiration from the soil. Cover crops reduce sediment production from cropland by intercepting the kinetic energy of rainfall and by reducing the amount and velocity of runoff. Cover crops increase soil quality by improving biological, chemical and physical properties including: organic carbon content, cation exchange capacity, aggregate stability, and water infiltrability. Legume cover crops contribute a nitrogen (N) to subsequent crops. Other cover crops, especially grasses and brassicas, are better at scavenging residual N

www.dekker.com

before it can leach. Because growth of these scavenging cover crops is usually N limited, growing grass/legume mixtures often increases total carbon inputs without sacrificing N scavenging efficiency. Cover crops are best adapted to warm areas with abundant precipitation. Water use by cover crops can adversely impact yields of subsequent dryland crops in semiarid areas. Similarly, cooler soil temperatures under cover crop residues can retard early growth of subsequent crops grown near the cold end of their range of adaptation. Development of systems that reduce the costs of cover crop establishment and overcome subsequent crop establishment problems will increase cover crop utilization and improve soil and water quality.

INTRODUCTION

Cover crops are traditionally defined as crops grown to cover the ground to protect the soil from erosion and from loss of plant nutrients through leaching and runoff (Reeves, 1994). Additional reasons for growing cover crops include weed suppression, carbon sequestration, and integrated pest management. Cover crops can protect water quality by reducing losses of nutrients, pesticides, or sediment from agricultural fields. Soil erosion leads to reductions in soil quality and productivity (Pierce and Lal, 1994). Wind erosion rates of less than 1 t/ha can cause serious crop injury (Hayes, 1965) and damage on sandy soils has increased in recent years where fields have been enlarged by removing tree lines to facilitate center-pivot irrigation systems. No-till management greatly reduces wind and water erosion, but some question its influence on water quality (Shipitalo et al., 1997).

In this paper, we follow a literature review with information from specific experiments and conclude with some observations concerning practical management issues. We try always to keep in mind that cover crops are planted by farmers whose first priority is frequently economic survival. A farmer's choice to include cover crops in cropping systems is based on the perceived balance between advantages and disadvantages (Table 1). The fact that only a very small percentage of U.S. cropland is currently planted with cover crops suggests that most producers find the disadvantages more evident than the advantages. This paper attempts to highlight research showing the biophysical and economic benefits of including cover crops in alternative production systems that may become more prominent in the future.

Table 1. Advantages and Disadvantages of Using Cover Crops

Advantages	Disadvantages
Reduce soil erosion	Must be planted when time (labor) is limited
Increase residue cover	Additional costs (planting and killing)
Increase water infiltration into soil	Reduce soil moisture
Increase soil organic carbon	May increase pest populations
Improve soil physical properties	May increase risks of diseases
Improve field trafficability	Difficult to incorporate with tillage
Recycle nutrients	Allelopathy
Legumes fix nitrogen	
Weed control	
Increase populations of beneficial insects	
Reduce some diseases	
Increase mycorrhizal infection of crops	
Potential forage harvest	
Improve landscape aesthetics	

Cover Crops and Water Quality

Sediment

Sediment is agriculture's number one pollutant (National Research Council, 1993). Even on relatively flat lands such as the Mississippi Delta, water erosion often exceeds tolerable levels (Murphree and McGregor, 1991) and excessive sediment concentration limits fish growth (Dabney et al., 1999). Cover crops produce more biomass than volunteer vegetation and, therefore, transpire more water, allow more rainfall to infiltrate into the soil, and decrease runoff and potential erosion to a greater extent (Dabney, 1998). In addition, cover crops protect aggregates from the impacts of rain drops, reducing soil detachment and aggregate breakdown. By slowing wind and water velocities and by maintaining large aggregate size, cover crops greatly reduce wind and water erosion (Frye et al., 1985; Mutchler and McDowell, 1990; Holderbaum et al., 1990; Bilbro, 1991; Langdale et al., 1991; Decker et al., 1994; Dabney, 1998; Delgado et al., 1999).

Nutrients

Cover crops can increase the nutrient use efficiency of farming systems (Lal et al., 1991; Lal, 1997; Reicosky and Forcella, 1998; Staver and Brinsfield, 1998; Delgado, 1998). Besides reducing the loss of nutrients in eroded soil, cover crops can scavenge residual soil nitrate nitrogen (NO_3^--N) after crops have matured, converting scavenged nitrogen into forage protein. The amount and timing of N uptake by cover crops depends on the availability of soil N, the climate, and cover crop species, seeding rate, planting date, and desiccation time (Gallaher 1977; Groffman et al., 1987; Brinsfield and Staver, 1991; Meisinger et al., 1991; Shipley et al., 1992; Clark et al., 1994; McCracken et al., 1995; Delgado et al., 1999). Winter cover crops generally have a period of fall growth followed by a winter period when growth slows or stops. In the spring, rapid growth involves additional N uptake if residual soil N remains available. However, after the boot growth stage, rye cover crops can double in biomass without taking up additional N (Shipley et al., 1992; Clark et al., 1994; Vaughan and Evanylo, 1998). Legumes cover crops, which can symbiotically fix atmospheric dinitrogen (N_2), usually accumulate N longer in the spring than non-legume cover crops (Sullivan et al., 1991; Clark et al, 1997a, b; Vaughan and Evanylo, 1998). The objectives of scavenging residual soil NO_3^--N or adding legume N into the farming system need to be balanced when using cover crops as nutrient management tools.

Rye (*Secale cereale* L.), forage radish (*Raphanus sativus* L.), and canola (*Brassica rapa* L.) have greater potential to scavenge residual soil NO_3^--N than legume cover crops (Jones, 1942; Chapman et al., 1949; Walker et al., 1956; Jones et al., 1977; Nielsen and Jensen, 1985; Groffman et al., 1987; Meisinger et al., 1991; Shipley et al., 1992; Wagger et al., 1998; Isse et al., 1999). In part, this may be due to faster root growth (Sainju et al., 1998). With high residual soil NO_3^--N, legume nodulation and N_2 fixation are decreased (Viets and Crawford, 1950; Allos and Bartholomew, 1955; Schertz and Miller, 1972; Streeter, 1985) and legumes will scavenge some NO_3^--N (Schertz and Miller, 1972; Morris et al., 1986). In situations where residual N is low, cover crop growth can be N limited. Cereal/legume bicultures are flexible in that they scavenge more NO_3^--N than legume monocultures, yet produce abundant growth based on N_2 fixation when soil N is limiting (Clark et al., 1994; Ranells and Wagger, 1997a; Clark et al., 1997a). In situations with large excesses of soil NO_3^--N, cover crop growth and N scavenging may be limited by solar radiation, temperature, and time. Research to evaluate the importance of cover crop planting date in such situations is presented later in this paper.

Computer models are promising tools for evaluating soil water and nutrient status and for conducting risk analyses of the potential benefits of cover crops in different scenarios. Quemada and Cabrera (1995b) used the CERES-N submodel that describes N transformations of residues decomposing at the soil surface to simulate the decomposition of leaves and stems of crimson clover (*Trifolium incarnatum* L.), rye, wheat (*Triticum aestivum* L.) and oat (*Avena sativa* L.). Bowen et al. (1993) used the CERES-Maize model to simulate the effects of a green manure legume incorporation with conventional tillage in a corn (*Zea mays* L.) rotation. The CERES-Wheat and a modified soybean (*Glycine max* (L.) Merr.)

model were used to simulate a no till winter cover rye—soybean rotation by Wagner-Riddle et al. (1997). Version 1.20 of the Nitrogen Leaching and Economical Analysis Package (NLEAP) has been used to evaluate effects of cover crop planting dates on N use efficiency of a lettuce (*Lactuca sativa* L.)—cover crop—potato *(Solanum tuberosum* L.) rotation (Delgado, 1998; Delgado et al., 1998) and predictions can be compared with the research results presented later.

Pesticide Usage

Water quality risks from pesticides are generally proportional to the amount of pesticide applied; lower application reduces risk. Impacts of cover crops on pesticide (insecticide, herbicide, fungicide) usage can vary from increases to decreases depending on numerous management alternatives. As one illustration, cover crops can suppress weeds and thereby decrease herbicide requirements, or, if cover crops are difficult to control, herbicide rates may be increased (Griffin and Dabney, 1990).

Weed suppression by cover crops has been a key element in the successful adoption of no-till systems in South America (Derpsch, 1998), which has reached 95% in some regions. Weed suppression by cover crops can be due to resource competition, niche disruption, and phytotoxic effects and is affected by cover crop species, planting date, seeding rate, kill method, and kill timing relative to subsequent crop planting (Creamer et al, 1996; Liebman and Davis, 2000). To reduce herbicide requirements, cover crops must be competitive with native vegetation yet be easier to control as main crop planting time approaches. Mechanical treatment of cover crops with mowers or rolling choppers can reduce herbicide inputs (Derpsch et al., 1991; Dabney et al., 1991; Creamer et al., 1995). Cover crops displace weeds while they grow and their residues can further suppress weeds (Evers, 1983; Hoffman et al., 1996; Smeda and Weller, 1996; Moyer et al., 2000). Weed control is usually best from dense cover crop plantings and when cover crops are allowed to grow for the longest time possible (Smeda and Putnam, 1988). Rye residues are among the most effective mulches and have been reported to suppress weed growth for up to 6 weeks after rye desiccation (Putnam et al., 1983; Barnes et al., 1987; Price and Baughan, 1987; Weston, 1990; Williams et al., 2000). Cover crop suppression of weeds is better if cover crops are managed with no tillage than if tilled into the soil (Blum et al., 1997). Living cover crops (living mulches) have greater weed suppression capacity than dead ones, but are often competitive with direct seeded crops for light, water, and nutrients (Fischer and Burrill, 1993; DeHaan et al., 1997; Kandel et al., 1997). Living mulches are, therefore, most practical in transplanted horticultural crops, vineyards, and orchards (Infante and Morse, 1996; Bugg et al., 1996).

Increased seedling disease was found to be a main reason for decreased cotton (Rickerl et al., 1988) and sorghum [(*Sorghum bicolor* L.) Moench] (Dabney et al., 1996) seedling growth following legume cover crops. Residues caused less disease when left on top of the soil than when mixed into the soil, but growth inhibition was caused by a combination of surface and sub-surface effects (Dabney et al., 1996). Waiting until the soil is warm plus delaying planting until 14 to 21 days after killing legume cover crops are the surest ways of avoiding disease problems associated with the damping-off pathogen Pythium (Grunwald et al., 2000). Row cleaners that remove surface residues can improve stand establishment of crops planted 5 to 14 days after killing cover crops (Dabney et al., 1996). In long term studies, cover crops have reduced populations of some soil-borne plant pathogens (Rothrock and Kendig, 1991; Liebman and Davis, 2000).

Cover crop impacts on arthropod pests are complex and depend greatly on cover crop species and management (Lewis et al., 1997). Legume cover crops generally increase cutworm populations (*Agrotis and Peridroma* spp.), but these pests can be managed by killing cover crops 3 to 4 weeks prior to planting (Leonard et al., 1994) or by banding pyrethroid insecticides at planting. Legume cover crops are early season hosts of major pests of cotton (*Gossypium hirsutum* L.) and horticultural crops including tarnished plant bug (*Lygus lineolaris* (Palisot de Beauvois)) and the Heliothine complex of corn earworm (*Helicoverpa zea* (Boddie)) and tobacco budworm (*Heliothis virescens* (F.)) (Stadelbacher, 1981; Snodgrass et al., 1984). Cover crop management can affect the build up of these pests that will later attack crops. Early dessication of cover crops by mowing or herbicide spraying allows the cover crop to act as a trap crop in which portions the F1 generation are destroyed before they can mature (Snodgrass and Stadelbacher, 1994). Laub and Luna (1991) found that mowing cover crops was more effective than herbicide spraying for the control of armyworm (*Pseudaletia unipuncta* (Haworth)) when corn was no-till planted into a killed rye cover crop. If cover crops regrow and reform flowers, a second mowing may be needed to control tarnished plant bugs (Snodgrass and Stadelbacher, 1994).

In the Mississippi Delta, tarnished plant bug overwinters as adults. The earliest F1 nymphs appear on host plants during mid-March. Preferred tarnished plant bug hosts between January and April include: vetchs (*Vicia* spp.); spotted burclover (*Medicago arabica* (L.) Hudson); and crimson clover (Snodgrass et al., 1984). In contrast, subterranean clover (*Trifolium subterraneum*) is much less attractive to tarnished plant bug (Bugg et al., 1990). Bollworm and budworm over winter as pupae and F1 larvae begin appearing in mid-April. For the earliest heliothine pest (bollworm), termination of cover crops prior to about 10 May prevents pupation of the F1 generation. It is therefore desirable that reseeding legume cover crops be early enough to produce hard seed prior to this date. Research is presented later that evaluates winter legume cover crops that may flower and mature earlier than crimson clover. Depending on the timing and species, allowing cover crops to flower and reseed may create opportunities for populations of beneficial insects to build up (Bugg and Van Horn, 1998; Grafton-Cardwell et al., 1999).

Cover Crops and Soil Quality

Cover crops affect several important aspects of soil quality. In this review the following aspects are addressed: soil carbon, nitrogen fertility, mycorrhiza, soil water, and soil temperature.

Soil Carbon

Cover crops increase carbon inputs into agricultural systems (Reeves, 1997; Kuo et al, 1997). This can result in carbon sequestration and increased soil quality (Derpsch et al., 1986; Lal, 1997; Lal et al. 1998; Reicosky and Forcella, 1998; Delgado et al., 1999). Combinations of increased carbon inputs together with reductions in tillage are needed to maximize increases in soil organic carbon (Roberson et al., 1991; Wright et al., 1999). Nitrogen is needed (is immobilized) to balance organic carbon in the formation of soil organic matter (Kuo et al., 1997). This can temporarily increase optimum N requirement in reduced tillage systems that sequester carbon in soils. Cover crops can contribute this N either by scavenging residual N or by N_2 fixation by legumes.

Cover crops increased soil organic matter, macroporosity, mean aggregate size, soil permeability, and crop yield in a 25-year conventional tillage cotton study (Patrick et al., 1957). Even where aggregate size distribution is not changed, cover crops can increase soil microbial biomass C and enzymatic activity (Mendes et al., 1999). Deep rooted cover crops, such as lupin (*Lupinus angustofolius* L.) can be particularly effective in increasing effective root depth and subsoil water storage capacity (Reeves, 1994; Calegari and Pavan, 1995; Chan and Heenan, 1996; Reeves, 1997). By utilizing water and by holding together soil structural units, cover crops improve a soil's capacity to carry machines and improve field accessibility (Känkänen, et al., 1998). However, depending on soil type and management, cover crops may have less impact on soil porosity and hydraulic conductivity than does wheel traffic (Wagger and Denton, 1989).

Nitrogen Fertility

Synchronization of cover crop N release compared with demand by the following crops is needed for efficient production. If release and uptake are not synchronized, yields may be reduced and risks of high post-harvest soil NO_3^--N concentrations and potential leaching losses may be increased (Meisinger et al., 1991; Torbert and Reeves, 1991).

Release of N from cover crops depends on species, growth stage, management, and climate. Lignin, carbohydrates, and cellulose content can affect the rate of N release from the cover crop residues (Muller et al., 1988; Bowen et al., 1993; Quemada and Cabrera 1995a). Residues with C:N ratios greater than 35 cause immobilization of N and slower N release rate (Pink et al., 1945, 1948). In general, high C:N ratio cereal grain cover crops immobilize soil N, increasing the amount of fertilizer N required for maximum economic yield of subsequent crops of corn, sorghum, and cotton (Mitchell and Teel, 1977; Frye et al., 1985; Brown et al., 1985; Hargrove, 1986; Wagger, 1989b; Holderbaum et al., 1990; Doran and Smith, 1991; Sullivan et al., 1991; Decker et al., 1994). An early spring kill of cereal grains reduces accumulation of C more than of N, so the rate of release of cover crop N into following crops is faster (Huntington et al., 1985; Wagger, 1989*a*; Evanlyo, 1991).

Legume cover crops usually have C:N ratios lower than 20 and reduce the amount of fertilizer N required for a given yield level (Touchton et al., 1982; Ebelhar et al., 1984; Doran and Smith, 1991). However, since yield potential is increased, legume cover crops sometimes do not reduce the economically optimum fertilizer level (Frye et al., 1985; Dabney et al., 1989; Utomo et al., 1990). Allowing legumes to grow beyond flowering usually does not increase the amount of N available to subsequent crops because of slower mineralization of cover crop biomass and because a fraction of the cover crop N may be tied up in hard seed (Wagger, 1989a; Wagger, 1989b; Ranells and Wagger, 1992).

Release of cover crop N is faster if the cover crop residues are incorporated with tillage (Wilson and Hargrove, 1986). The slower N release from cover crop residues left on the soil surface is more pronounced in dry than in wet years, is most evident during the first 4 to 8 weeks after killing, and differences due to tillage in accumulative N release disappear after 16 weeks (Varco et al., 1989). Rapid mineralization may be an advantage in some situations where crop demand is rapid (Huntington et al., 1985; Wagger, 1989b; Lemon et al., 1990). In other situations, slower release may be advantageous. Crops like cotton that have relatively long growing seasons and a peak N demand occurring after mid-bloom (Ebelhar, 1990), 11 to 12 weeks after planting in the mid-South (Oosterhuis, 1990), may make good use of slowly-available cover crop N in no-till systems. In Canada, synchrony of N release from summer-killed alfalfa to a subsequent spring wheat crop was better with no-tillage management than with tillage (Mohr et al., 1999). In dry-seeded rice culture, flooding 30 days after planting led to denitrification loss of soil NO_3^--N while cover crop N recovery and rice yield were improved by no-tillage management (Dabney et al., 1989).

Ammonia (NH_3) volatilization has been suggested as a potentially important N loss mechanism from cover crop residues left on the soil surface in no-till systems (Sarrantonio and Scott, 1988; Janzen and McGinn, 1991). However, data sited below suggests that such losses will seldom exceed a few percent of cover crop N content. Dabney and Bouldin (1985) reported on ammonia flux measurements from an alfalfa field. When a 2 to 3 ton hay crop was ruined by rain, accumulative NH_3 losses were less than 1 kg N ha^{-1} during the subsequent 10 days. Also using micrometeorological techniques, Harper et al. (1995) assessed NH_3 losses from a crimson clover field before and after spraying with a herbicide; total losses in the 16 days following treatment were only 0.25 kg N ha^{-1}. Quemada and Cabrera (1995a) studied N losses from leaves and stems of crimson clover and three cereal cover crops in small plastic cylinders subjected to 160 day incubation with periodic leaching. Ammonia losses were greatest for the clover residues and 92% of eventual clover NH_3 losses occurred within the first 16 days. During this period, NH_3-N losses were 4% of the total residue N while NO_3^--N leaching losses accounted for 37% of total N. In subsequent studies in which surface applied crimson clover residues were held at different temperatures and water potentials without leaching, Quemada and Cabrera (1997) found that maximum NH_3 loss of about 6% of residue N within three weeks. These data suggest that N losses as NH_3 escaping from surface placed cover crops is minimal during dry periods, while during wet periods, NH_3 is leached into and held in the soil. Therefore, only small losses of cover crop N from NH_3 volatilization are likely in no-till systems.

Mycorrhiza

Mycorrhizal fungal activity is a soil quality factor that has only recently become widely recognized. Cover crops increase inocula of mycorrhizal fungi in soil (Galvez et al., 1995). Arbuscular mycorrhizal fungi form symbiotic relationships with plant roots that can assist with water and nutrient uptake. Wright et al. (1999) found that a glycoprotein, glomalin, produced by these fungi, is central to the development of soil aggregate stability and that a combination of no-tillage management and active root growth is needed for maximum effect. Mycorrhizal fungi are also important in enhancing early growth and survival of some crops, particularly cotton (Zak et al., 1998). Flint (1999) found that enhanced early growth and yield of cotton planted into a killed wheat cover crop was correlated with earlier and greater root infection with mycorrhizal fungi. He postulated that seedling cotton roots beneficially tap into the existing network of mycorrhizal hyphae that developed in association with the wheat cover crop's root system. When seedlings from conventional and no-till treatments were mutually transplanted, higher mycorrhizal colonization remained associated with the no-till plot rather than moving with the no-till seedlings (Flint, 1999). This growth enhancing factor was more associated with the bulk of the soil than with inoculation of isolated seedlings. Killing cover crops too early may starve mycorrhizal fungi and diminish this soil quality factor. This may be the reason why Elmore et al. (1992) found a wheat cover crop killed 4 to 6 weeks before soybean planting soybean had no impact on soybean growth or yield.

Soil Water

While cover crops may increase water infiltration into soil and soil water holding capacity, they also use water to grow and can potentially reduce yields of the subsequent crop in rainfed semiarid regions by reducing soil water content at planting (Reeves, 1994; Unger and Vigil, 1998). This is less of a problem in humid areas and where irrigation water is available to make up for water deficits at planting time. Summer water conservation by cover crop residues may be more important than spring water depletion by growing cover crops in determining final yield (Campbell et al, 1984; Clark et al., 1997b) if early season water deficits do not delay crop establishment (Ewing et al., 1991). Early killing of the cover crop is a management alternative that can improve soil water management where risks of N leaching are minimal (Unger and Vigil, 1998). Dabney (1998) gives a review of cover crop impacts on hydrology.

Soil Temperature

If incorporated into the soil by tillage, cover crops have little impact on soil temperature. In contrast, living cover crops and cover crop mulches can significantly alter soil temperature. Although plastic mulches increase daily maximum soil temperatures, organic mulches reduce them (Vos and Sumarni, 1997). Reduced daily maximum temperatures can be detrimental in cool regions where crop growth is temperature limited (Janovicek et al, 1997; Drury et al., 1999; Hoyt, 1999). On the other hand, reduced maximum temperatures can be positive in hot regions (Derpsch et al., 1991; Thiagalingam et al., 1996; Orr et al., 1997). During the winter cover crops increase soil temperatures (Calkins and Swanson, 1998).

Although it has been suggested that dark colored mulches (ie. hairy vetch) should allow more rapid soil warming than light colored mulches (ie. wheat straw), research has shown that mulch color has only a slight impact on soil warming. Black mulches increased sensible heat flux into the atmosphere rather than into the soil, and the difference in soil temperature at 0.05 m depth between black and white straw mulches was only 0.5°C (Sharratt and Flerchinger, 1995).

Standing cover crop residues result in higher soil temperatures than flat residues (Fortin and Hamill, 1994). When crops are planted at the cool part of their adapted zone, row cleaners that remove residues and cover crops from the planted area can help improve crop stands (Reeves, 1994; Janovicek et al, 1997; Kaspar and Erbach, 1998). For crops with meristems located below the soil surface, lower daily maximum temperatures is well correlated with slower seedling growth (Stone et al., 1999). However, in crops with epigeal germination, cool temperature impacts can be caused by chilling injury, disease, or insect damage (Brust et al., 1997). In these situations, daily minimum soil temperatures may be more important than daily maxima. This is an area where additional research is needed.

Objectives

Based on the preceding literature summary, research was undertaken to help fill identified knowledge gaps. The objectives of the studies reported herein were (1) to identify cold-hardy, early-maturing, reseeding legume cover crops adapted to the mid-South of the U.S., (2) determine the impact of no-till plus cover crops compared to conventional tillage on soil temperature at cotton planting time, and (3) evaluate the effectiveness of cover crops for nutrient scavenging in on-farm field trials as a function of species, planting date, and cropping system.

MATERIALS AND METHODS

Cover crop germplasm was screened for winter hardiness, early maturity, and hard seeded characteristics in replicated plots on a Grenada silt loam soil (Fine-silty, mixed, active, thermic Glossic Fragiudalfs) in Senatobia, MS (USDA Hardiness Zone 7A; Cathey, 1990). ‘Tibbee’ crimson clover was used as a check. Reported hear are a subset of a larger screening experiments comprising entrants that successfully reseeded for several years: ‘Paradana’ balansa clover (*Trifolium balansae*), and southern spotted burclover. Also reported are growth of nonlegumes rye and ryegrass (*Lolium multiflorum* Lam.) that provide an indication of the variation in growth potential of nonlegume cover crops without N fertilization at the test site. Duplicate plots (2 m by 5 m) of each cover crop were established by broadcasting seed onto a prepared seedbed and rolled in early October. Growth stage was recorded at least weekly beginning in December. Half of each plot was killed with a herbicide 7 to 10 days after Tibbee crimson clover reached full bloom (12 to 18 days after first bloom, second or third week in April). The other half was killed 3 weeks later (early May). We collected biomass samples at each kill date and recorded oven dry weight. No-till cotton was planted after the last kill date. We determined reseeding success by counting volunteer populations in the fall for several years during which additional seed production was prevented by killing the volunteer cover crops each spring prior to first bloom. The experiment was repeated on new areas each year from 1990–1991 through 1993–1994.

On a nearby area of the same soil used in the cover crop screening, soil temperature measurements were made during May 1993 in conventional and no-till plots in an experiment described by Triplett et al. (1996). The no-till treatment had a wheat cover crop that had been desiccated with a herbicide two weeks prior to initiation of temperature measurements on 6 May 1993. The conventional tillage treatment had no cover crop; the soil had been chisel plowed, disked, and had rows hipped. At planting on 10 May, the conventional tillage treatment had the rows partially smoothed with a do-all, while the no-till was planted flat. Four thermistor probes were placed at 2.5 cm depth in each treatment and temperature was recorded every hour during a 2 week period immediately prior to and following cotton planting. Daily minimum and maximum temperatures for each probe were compared using analysis of variance to test for significant differences between treatment means.

In eight on-farm trials in South Central Colorado during the winter 1994–1995, we studied the potential use of winter cover crops under organic carrot (*Daucus carota*), spinach (*Spinacia oleracea* L.), lettuce, and potato production systems. Nutrient uptake studies were conducted on irrigated soils classified: San Luis (fine-loamy over sandy or sandy skeletal, mixed, Aquic Natrargid); Kerber (coarse-loamy, mixed, frigid Aquic Natrargid); Gunbarrel (mixed, frigid Typic Psammaquent); and Shawa (fine-loamy, mixed, frigid Pachic Haploboroll) (Table 2). All these sites were under conventional tillage, and winter cover crops were incorporated after spring herbicide desiccation. All crops were under center pivot sprinkler irrigation, except spinach, which was grown as a surface irrigated field. In studies one through six, two transponders were placed permanently at each site so that the same areas within these plots could be sampled at each sampling period. At each site, four 21 m^2 plots were located under the same sprinkler span to minimize any possible variability between sprinkler nozzles from span to span. Soil and plant samples were collected at random in studies seven and eight. We present the total N and C content of cover crops at the last sampling except as noted below.

Organic carrots received 4.5 Mg ha^{-1} y^{-1} of poultry manure (77 kg N ha^{-1}). Additionally, about 38 kg NO_3^--N ha^{-1} was added with irrigation water. Inorganic N fertilizer was applied to lettuce and potato at 153 and 213 kg N ha^{-1}, respectively. No reports about N fertilizer applied to spinach were obtained. Irrigation water added 27 kg NO_3^--N ha^{-1} to lettuce and 36 kg NO_3^--N ha^{-1} to potato. At the spinach site, NO_3^--N in the irrigation water was at trace levels. Total N uptake was 97, 162, 181, 99 kg N ha^{-1} for carrots, spinach, potato and lettuce, respectively.

Soil samples were collected in each plot during the fall after harvesting of lettuce, spinach, potato or organic carrot; and during the spring after winter cover rye kill. At each time, soils were sampled in 0.3 m intervals to 1.5 m depth. The 0 to 0.9 m data are presented here. Plant samples for rye were collected by harvesting 0.4 m^2 in each plot before spring kill.

Table 2. Effect of Winter Cover Crops on NO$_3^-$-N Mining for Different Cropping Systems of South Central Colorado

Study No.	Cropping System	Winter Cover Crop	Time[¶] of Planting	Soil[§] Texture	Dry Matter (kg ha^{-1})	Cover Crop Content C (kg ha^{-1})	Cover Crop Content N (kg ha^{-1})	C:N Ratio	Soil NO$_3^-$-N Fall (kg ha^{-1})	Soil NO$_3^-$-N Spring (kg ha^{-1})	Soil Type
1	Organic carrots	Rye	Ep	ls	1911[†]	710[†]	57[‡]	12.4	49	28*	Kerber
2	Spinach	Rye	Ep	l	6642	2672	296	9.0	829	556*	Shawa
3	Potato	Rye	Lp	ls	690	296	27	11.0	N/A	134	Gunbarrel
4	Potato	Rye	Lp	ls	809	327	31	10.4	77	68*	Gunbarrel
5	Lettuce	Rye	Ep	sl	7399[†]	2798[†]	178[‡]	15.7	171	18***	San Luis
6	Lettuce	Rye	Ep	ls	4814[†]	1800[†]	95[‡]	18.9	103	11***	Kerber
7	Lettuce	Wheat	Lp	ls	454	194	18	10.8	225	204**	Kerber
8	Lettuce	Wheat	Ep	ls	2203	864	74	11.7	150	83**	Kerber

*, **, *** Difference between Fall and Spring NO$_3^-$-N significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

[†] Early (Ep) and late planted (Lp) were defined as plantings completed before the end of the second week of September, and after the beginning of the third week of September, respectively.

[‡] Soil texture were sandy loam (sl); loam (l); and loamy sand (ls).

[§] Estimated using 30% dry matter content belowground (Delgado et al., 1999).

[¶] Estimated using 25% dry matter content belowground (Delgado et al., 1999).

Studies seven and eight were established with winter cover wheat that was irrigated for cover crop establishment. Winter cover wheat was grazed by horses from late November to the middle of February 1996. Above ground and below ground plant biomass was collected on 20 December, 1995, 15 February, 1996, and 11 March, 1996. Plant data presented for studies seven and eight are from the 20 December, 1995 sampling to minimize the influence of grazing.

Soils collected in March 1996 from each 0.3 m soil depth increment were air dried and passed through a 2 mm sieve. The percentage weight and volume of the coarse fragments was calculated (Delgado et al., 1999). Sieved samples were extracted with 2N KCl. The NO_3^--N and NH_4^+-N content of the extracts were determined colorimetrically by automated flow injection analysis. Plant samples were dried at 55°C, ground and analyzed for C and N content by automated combustion using a Carlo Erba automated C/N analyzer. Statistical analyses were performed using the SAS analysis of variance GLM procedure (SAS Ins., 1988) using LSD to separate means.

RESULTS AND DISCUSSION

Early Maturing Cover Crops

Tibbee crimson clover reached first bloom during the first two weeks of April (Table 3). Because all replications had identical flowering dates recorded within a year, these data have zero error. However, since observations were made only once or twice a week, the reported dates should be interpreted as indicating the end of a 4 to 7 d period when flowering occurred.

As noted in the methods section, balansa clover and spotted burclover were selected for inclusion in this paper because they reseeded more successfully than crimson clover (Dabney, 1995). Their reseeding success was probably due to two factors: the large percentage of hard seed produced and the fact that this hard seed

Table 3. Flowering or Heading Dates in Senatobia, Mississippi

Cover Crop	1991	1992	1993	1994
‘Tibbee’ crimson	4/10	4/8	4/10	4/11
‘Paradana’ balansa	3/27	3/30	4/1	3/26
Spotted burclover	3/20	3/12[†]	3/7	3/30
‘Gulf’ annual ryegrass	4/24	4/17	4/26	After 4/18
‘Abruzzi’ rye			4/2	4/8
‘Elbon’ rye			4/10	4/12
‘Rymin’ rye			4/26	

[†] Reseeded stand.

Table 4. Above Ground Biomass (kg ha^{-1}) of Cover Crops in Late April at Senatobia, Mississippi

Cover Crop	1991	1992	1993	1994
‘Tibbee’ crimson	1390	8370	3590	2460
‘Paradana’ balansa	3800	5670	3280	1820
Spotted burclover	4790	na[†]	2480	3530
‘Gulf’ annual ryegrass	4700	2220	2510	1420
‘Abruzzi’ rye			2480	na
‘Elbon’ rye			1770	1440
‘Rymin’ rye			1860	

[†] Not available.

was produced prior to the time of growth termination that was tied to the flowering of crimson clover. As shown in Table 3, Paradana balansa clover bloomed and was about two weeks earlier than Tibbee and southern spotted burclover was even earlier, although it bloomed over a longer period of time. Early bloom dates allowed seed to mature and harden prior to growth termination. As previosuly noted, early termination can be an asset in cropping systems where cover crops are used as trap crops in IPM management of heliothine pests. Biomass production of these cover crops is similar to that of crimson clover (Table 4) and is at least double that produced by volunteer winter vegetation (weeds).

The large degree of variation in the flowering (anthesis) time of cereal rye was noted. Among three rye cultivars examined, ‘Abruzzi’ was the earliest. It was nearly two weeks earlier than ‘Elbon’ and four weeks earlier than ‘Rymin’ (Table 3). ‘Gulf’ ryegrass and Rymin rye all bloomed two to three weeks later than Tibbee. Elbon flowered about the same time as Tibbee. These differences in maturity are important when considering the time of killing of cover crops. It is desirable to have sufficient persistent and/or erect residue produced to protect the soil and to control wind and water erosion before killing cover crops. It is difficult to do this with later maturing cover crops and still plant crops like cotton at their optimum time.

Soil Temperature

While it is commonly stated that cover crops keep the soil cool, in this study they mainly decreased the amplitude of diurnal temperature fluctuations rather than the mean temperature (Fig. 1). Prior to planting on 10 May, minimum soil temperatures were warmer in no-till than in conventional till beds while maximum temperatures were cooler. During this period, the soil was warming and mean soil temperatures were not significantly different between tillage systems.

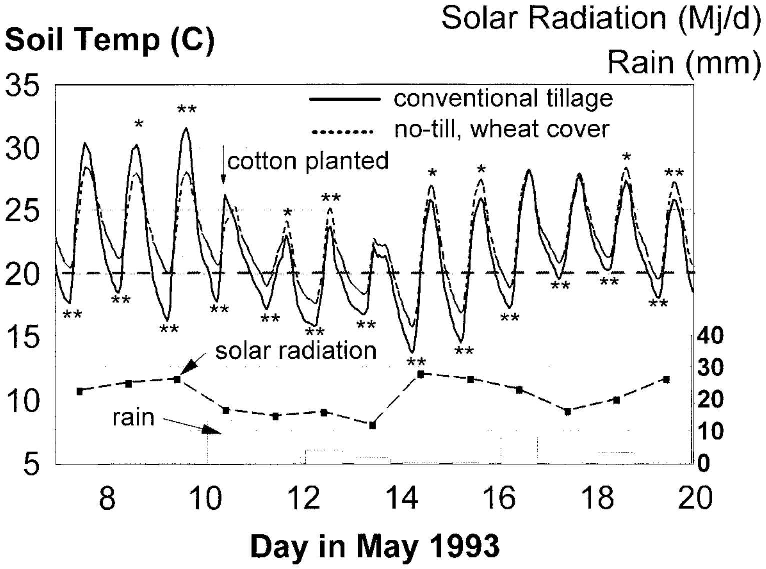

Figure 1. Average of 4 observations of soil temperature at 2.5 cm depth in conventional-till and no-till areas are presented with daily rainfall and solar radiation totals. The 20° reference line is the morning temperature minimum recommended for planting. Significant differences between tillage temperature minima and maxima are shown as * ($P<0.05$) and ** ($P<0.01$).

After planting, when the conventionally tilled beds were flattened and consolidated by rain and a cool cloudy period occurred, the cover crop mulch kept the no-till soil warmer (slowed cooling). This helped to improve cotton stand establishment and later yield (Triplett et al., 1996). Coldest minimum temperatures occurred on clear nights on 14 and 15 May. Periods of cool weather are a common risk after planting cotton and pose threats of seedling damage and disease. It is usually recommended that planting be delayed until the soil temperature in the morning exceeds 20°C with a favorable five-day forcast. As seen in Fig. 1, once this condition was met with no-till, risks from a change in the weather were reduced.

Nitrogen Scavenging

Although organic carrots had lower residual soil NO_3^--N than spinach and lettuce (Table 2 $P<0.05$), cover crops were capable of scavenging the residual soil NO_3^--N in these systems ($P<0.05$). The N uptake of these cover crops varied from 57 to 296 kg N ha^{-1} for early planting and from 18 to 31 kg N ha^{-1} for late planting (Table 2). The farmers killed the cover crops at an early growth stage, from the middle of March to the first week of April. This should have kept the C : N ratios lower than 20, so we can assume that significant amounts of the cover crop N will be quickly mineralized and recycled to the following crop (Huntington et al., 1985; Wagger, 1989a; Evanlyo, 1991; Doran and Smith, 1991). Assuming that 50% of the N in the crop residue can be recycled, the early planted cover crops could have contributed 25 to 132 kg N ha^{-1} to subsequent crops in South Central Colorado. Since the average N uptake was 97, 162, 181, 99 kg N ha^{-1} for carrots, spinach, potato and lettuce, respectively, early planted cover crops can scavenge and potentially recycle a significant fraction of N needed by the following crops. Early planted cover crops, with more growing degree days, had higher dry biomass production with a higher organic carbon and N content than late planted covers (Table 2; $P<0.05$). However, late planted cover crops can still have a significant impact in the protection of soil and water quality since they significantly decrease potential soil erosion (Delgado et al., 1999).

Other Considerations in the Practical Selection and Management of Cover Crops

Cover Crop Adaptation and Establishment

Temperature and rainfall are the primary climatic variables affecting cover crop selection and potential utility (eg. USDA, 1948; SAN, 1998). The warmer and wetter the climate, the greater the potential benefits of cover crop and the greater the number of options available.

Small seeded legumes are more sensitive to timely rainfall at planting than larger seeded cover crops (Keeling et al., 1996). Broadcasting seed is faster than drilling and is therefore attractive to farmers. If done early, broadcast seeding into a standing crop may result in better stands and more early cover crop growth than drill seeding after harvest (Frye et al., 1988). However, establishment of broadcast wheat can be problematic unless done into a fully closed crop canopy prior to leaf drop (Sanford, 1979; Griffin and Taylor, 1986).

Rye is the most cold tolerant, the easiest to establish, the most productive, and the earliest to head among temperate region cereal cover crops. Although less hardy than rye, hairy vetch is the most cold hardy of annual legume cover crops; it also has the highest N percentage. Mixtures of rye and vetch provide more early-winter ground cover than either alone (Holderbaum et al., 1990). Cold hardiness of seedling legumes has been reported in the following order: hairy vetch, yellow sweetclover [*Melilotus officinalis* (L.) Pall.], crimson clover, black medic (*Medicago lupulina* L.), white clover (*Trifolium repens* L.), subclover, barrel medic

(*Medicago trunculata* Gaertn.), and snail medic [*Medicago scuttelata* (L,) Mill.] (Brandsaeter et al, 2000). In an Ohio, USA study (Creamer et al., 1997), fall seeded rye, barley (*Hordeum vulgare* L.), crimson clover and hairy vetch dependably overwintered while 'Nitro' alfalfa (*Medicago sativa* L.), ladino clover (*Trifolium repens* L.), subterranean clover, Austrian winter pea (*Pisum sativum ssp. Arvense* (L.) Poir), and annual ryegrass did not. In climates too cold to allow successful establishment of winter cover crops following crop harvest, alternative management techniques include overseeding cover crops into a winter cereal rotated with a summer crop (Dou and Fox, 1994). In warm climates, cold weather can be used as a natural way to kill summer planted cover crops, for example the tropical legume cover crop sunn hemp (*Crotalaria juncea* L.) (Mansoer et al., 1997).

Volunteer reseeding reduces establishment costs that have been estimated from \$63 to \$111/ha (Frye et al., 1985; Power et al., 1991; Kelly et al., 1995). Volunteer reseeding can result in earlier and more reliable cover crop stands than annual planting (Myers and Wagger, 1991). Because crimson clover seed does not remain hard for longer than one year, in reseeding systems crimson clover makes seed every spring prior to planting a summer crop (Touchton et al., 1982). 'Tibbee' crimson clover (Trifolium incarnatum) has been among the earliest-maturing commercially-available cultivars grown in the Southeast (Boquet and Dabney, 1991). However, it makes seed too late (early to mid-May) to allow planting corn, cotton, or sorghum at their optimum dates. One solution is to select crops that may be planted later, such as tropical corn (Reeves and Wood, 1994). Another solution is to find cover crops that mature earlier or that do not need to produce seed every year.

Southern spotted burclover is the most winter hardy of the annual medics. It was used as a reseeding cover crop in the cotton belt forty years ago. It was allowed to reseed ahead of a late-planted corn crop and would then volunteer before three or four succeeding cotton crops (USDA, 1949). There were once at least three named cultivars of southern spotted burcover in commercial trade (USDA, 1951), however, today there are currently no commercial sources. Subterranean clover has also been used as a reseeding cover crop (Taylor, 1985; Evers et al., 1988; Graves et al., 1991; Dabney et al., 1989; Fairbrother, 1991; Komatsuzaki et al, 1998), but winter hardiness and early seed maturity appear to be negatively correlated in subterranean clover.

Paradana balansa clover is recommended as a promising commercially available reseeding winter legume cover crop for the Southeastern U.S. (Dabney, 1995). It has cold hardiness similar to 'Mt. Barker' subterranean clover: hardy throughout plant hardiness zone 7A but marginal in zone 6B. The balansa clover appears particularly well adapted to heavy clay soils with pH values above 6.5, but it is not considered adapted to highly alkaline soils (Beale et al., 1985). Seed imported from Australia is commercially available in the U.S. (sources listed in SAN, 1998). Because it has very small seed, as little as 5 kg seed ha^{-1} has given good stands. After one seed crop, volunteer stands have been excellent for 3 y in no-till cotton production. In reseeding years, the killing of balansa must be delayed until the first week of May (north Mississippi) and while this may delay establishment of the subsequent crops this will not be required every year.

CONCLUSIONS

Winter cover crops reduce wind and water erosion. They can scavenge and recycle residual soil NO_3^--N and return significant amount of N that can be potentially recycled into the following crops. Legumes can contribute biologically-fixed N. When residual inorganic N is low, cover crops will scavenge most of this N quickly and growth will be N limited. Legume/cereal bi-cultures provide a robust system with capacity to scavenge both soil and atmospheric N and grow abundantly even if soil inorganic N is minimal. When inorganic N is high, earlier planting results in greater N scavenging than later planting. Cover crops can sequester atmospheric carbon, converting it to soil organic matter for improved soil quality. They can compete with and help control difficult to control weeds and reduce herbicide and other weed control costs. Allowing cover crops to grow until three weeks prior to planting permits mycorrhizal fungal associations to benefit subsequent crops without increasing risks of crop disease. Cover crops can reduce soil water content. Cover crop residues reduce diurnal fluctuations in soil temperature in no-till systems, decreasing the maximums and increasing the minimums compared to conventional tillage systems. Reseeding systems may provide cover crop benefits at reduced cost. Balansa clover is a promising reseeding legume for hardiness zone 6B and warmer. Mowing and rolling vegetation offer effective ways of terminating vegetation growth while managing cover crops for weed and insect control that reduce the need for pesticide inputs. Management of species selection, time of planting, and time of killing can potentially match cover crop N release to the following crop, helping to improve soil and water quality.

REFERENCES

Allos, H.F. and W.V. Bartholomew. 1955. Effect of available nitrogen on symbiotic fixation. Soil Sci. Soc. Am. Proc. 19:182–184.

Barnes, J. P., A. R. Putnam, B. A. Burke, and A. J. Aasen. 1987. Isolation and characterization of allelochemicals in rye herbage. Phytochemistry 26: 1385–1390.

Beale, P., A. Craig, and E. Crawford. 1985. Balansa clover—a new clover-scorch-tolerant species. South Aust. Dept. of Ag. Fact Sheet 6/85. 3 pp.

Bilbro, J.D. 1991. Cover crops for wind erosion control in semiarid regions. pp.36–38. In: W.L. Hargrove (ed.) Cover Crops for Clean Water. SWCS. Ankeny, IA.

Blum, U., L.D. King, T.M. Gerig, M.E. Lehmann, and A.D. Worsham. 1997. Effects of clover and small grain cover crops and tillage techniques on seedling emergence of some dicotyledonous weed species. Am. J. Alt. Ag. 12: 146–161.

Boquet, D. J. and S.M. Dabney. 1991. Reseeding, biomass, and Nitrogen content of selected winter legumes in grain sorghum culture. Agron. J. 83: 144–148.

Bowen, W.T., J.W. Jones, R.J. Carsky, and J.O. Quintana. 1993. Evaluation of the nitrogen submodel of CERES-Maize following legume green manure incorporation. Agron. J. 85: 153–159.

Brandsaeter, L.O., T. Smeby, A.M. Tronsmo, and J. Netland. 2000. Winter annual legumes for use as cover crops in row crops in northern regions: II. Frost resistance study. Crop Sci. 40: 175–181.

Brinsfield, R.B. and K.W. Staver. 1991. Use of cereal cover crops for reducing groundwater nitrate contamination in the Chesapeake Bay region. In: W.L. Hargrove (ed.) Cover Crops for Clean Water. SWCS. Ankeny, IA. pp.79–82.

Brown, S. M., T. Whitwell, J. T. Touchton, and C. H. Burmester. 1985. Conservation tillage systems for cotton production. Soil Sci. Soc. Am. J. 49: 1256–1260.

Brust, g.E., R.E. Foster, and W. Buhler. 1997. Effect of rye incorporation, planting date, and soil temperature on damage to muskmelon transplants by seedcorn maggot (Diptera: Anthomyiidae). Env. Entom. 26: 1323–1326.

Bugg, R.L., G. McGourty, M. Sarrantonio, W.T. Lanini, and R. Bartolucci. 1996. Comparison of 32 cover crops in an organic vineyard on the north coast of California. Biological Ag. and Hort. 13: 63–81.

Bugg, R.L., and M.Van Horn. 1998. Ecological soil management and soil fauna: best practices in California vineyards. In: R. Hamilton, L. Tassie, and P. Hayes (eds.). Proc. of the Viticulture Seminar: Viticultural Best Practice, Mildura Arts Centre, 1 Aug 1997, Mildura, Victoria, Australia. Australian Soc of Viticulture and Oenology, Inc., Adelaide, South Australia, Australia.

Bugg, R.L., F. L. Wäckers, K. E. Brunson, S.C. Phatak, and J.D. Dutcher. 1990. Tarnished plant bug (Hemiptera: Miradae) on selected cool-season leguminous cover crops. J. Entomol. Sci. 25: 463–474.

Calegari, A., and M.A. Pavan. 1995. Effects of corn-winter green manure rotation on soil aggregation. Arq. Biol. Tecnol. 38: 45–53.

Calkins, J.B. and B.T. Swanson. 1998. Comparison of conventional and alternative nursery field management systems: soil physical properties. J. of Env. Hort. 16: 90–97.

Campbell, R.B., R.E.Sojka, and D.L. Karlen. 1984. Conservation tillage for soybean in the U.S. southeastern coastal plain. Soil Tillage Res. 4: 531–541.

Cathey, H. M. 1990. USDA Plant Hardiness Zone Map. USDA-ARS Misc. Pub. No. 1475.

Chan, K.Y. and D.P. Heenan. 1996. Differences in the properties of a red earth after ten years of wheat-lupin and wheat-subterranean clover rotations. Aust. J. Exper. Agric. 36:539–543.

Chapman, H.D., G.F. Liebig, and D.S. Rayner. 1949. A lysimiter investigation of nitrogen gains and losses under various systems of covercropping and fertilization and a discussion of error sources. Hilgardia 19:57–95.

Clark, A.J., A.M. Decker, and J.J. Meisinger. 1994. Seeding rate and kill date effects on hairy vetch-cereal rye cover crop mixtures for corn production. Agron J. 86:1065–1070.

Clark, A.J. A.M. Decker, J.J. Meisinger, and M.S. McIntosh. 1997a. Kill date of vetch, rye, and vetch-rye mixture: I. Cover crop and corn nitrogen. Agron. J. 89:427–434.

Clark, A.J. A.M. Decker, J.J. Meisinger, and M.S. McIntosh. 1997b. Kill date of vetch, rye, and vetch-rye mixture: II. Soil moisture and corn yield. Agron. J. 89:434–441.

Creamer, N.G., M.A. Bennett, B.R. Stinner, J. Cardina, and E.E. Regnier. 1996. Mechanisms of weed suppression in cover crop-based production systems. HortScience. 31:410–413.

Creamer, N.G., M.A. Bennett, and B.R. Stinner. 1997. Evaluation of cover crop mixtures for use in vegetable production systems. J. Ag. Food Chem. 45: 866–870.

Creamer, N. G., B. Plassman, M.A. Bennett, R.K. Wood, B.R. Stinner, and J. Cardina. 1995. a method for mechanically killing cover crops to optimize weed suppression. Am J. Alt. Agri. 10:156–161.

Dabney, S. M. 1995. Cover crops in reduced tillage systems. Proceedings of the Beltwide Cotton Conferences. pp. 126–127.

Dabney, S.M. 1998. Cover crop impacts on watershed hydrology. J. Soil Water Cons. 53:207–213.

Dabney, Seth M. and D.R. Bouldin. 1985. Fluxes of ammonia over an alfalfa field. Agron. J. 77:572–578.

Dabney, S. M., G.A. Breitenbeck, J.L. Griffin, and B.J. Hoff. 1989. Subterranean clover cover crop used to increase rice yield. Agron. J. 81:483–487.

Dabney, S. M., N. W. Buehring and D. B. Reginelli. 1991. Mechanical control of legume cover crops. pp.146–147. In: W.L. Hargrove (ed.) Cover Crops for Clean Water. SWCS. Ankeny, IA.

Dabney, S.M., R. A. Rebich, and J.W. Pote. 1999. The Mississippi Delta MSEA program. Proceedings of the 10th Conference of the International Soil Conservation Organization. 23–27 May 1999, West Lafayette, IN.

Dabney, S.M., J. D. Schreiber, C. S. Rothrock, and J. R. Johnson. 1996. Cover Crops Affect Seedling Growth. Agron. J. 88:961–970.

Decker, A.M., A.J. Clark, J.J. Meisinger, F.R. Mulford, and M.S. McIntosh. 1994. Legume cover crop contributions to no-tillage corn production. 1994. Agron. J. 86:126–135.

DeHaan, R.L., C.C. Sheaffer, and D.K. Barns. 1997. Effect of annual medic smother plants on weed control and yield in corn. Agron. J.: 813–821.

Delgado, J.A. 1998. Sequential NLEAP simulations to examine effect of early and late planted winter cover crops on nitrogen dynamics. J Soil Water Cons. 53 : 241–244.

Delgado, J.A., M.J. Shaffer and M.K. Brodahl. 1998. New NLEAP for shallow and deep rooted crop rotations. J. Soil Water Cons. 53 : 338–340.

Delgado, J.A., R.T. Sparks, R.F. Follett, J.L. Sharkoff, and R.R. Riggenbach. 1999. Use of winter cover crops to conserve soil and water quality in the San Luis Valley of South Central Colorado. pp 125–142. In: R. Lal (ed.) Soil quality and soil erosion. CRC Press Boca Raton Fl.

Derpsch, R., N. Sidiras, and C. H. Roth. 1986. Results of studies made from 1977 to 1984 to control erosion by cover crops and no-tillage techniques in Paraná, Brazil. Soil Tillage Res. 8 : 253–263.

Derpsch, R., C.H. Roth, N. Sidiras, and U. Köpke. 1991. Controle da erosao no Paraná, Brasil: Sistemas de cobertura do solo, plantio direto e preparo conservacionista do solo, GTZ, Eschborn, Germany. 272 pp.

Derpsch, R. 1998. Historical review of no-tillage cultivation of crops. Japan International Research Center for Agricultural Sciences (JIRCAS) Working Report No. 13 : 1–18, Paraguay.

Doran, J.W., and M.S. Smith. 1991. Role of cover crops in nitrogen cycling. pp.85–90. In: W.L. Hargrove (ed.) Cover Crops for Clean Water. SWCS. Ankeny, IA.

Dou, Z., and R.H. Fox. 1994. The contribution of nitrogen from legume cover crops double-cropped with winter wheat to tilled and non-tilled maize. Eur. J. Agron. 3 : 93–100.

Drury, c.F., C.S. Tan, T.W. Welacky, T.O. Oloya, a.S. Hamill, and S.E. Weaver. 1999. Red clover and tillage influence on soil temperature, water content, and corn emergence. Agron. J. 91 : 101–108.

Ebelhar, M. W. 1990. Year-to-year variation in nitrogen response. pp. 93–106. In: W.N. Miley and D. M. Oosterhuis [eds.] Nitrogen Nutrition of Cotton: Practical Issues. American Society of Agronomy.

Ebelhar, S. A., W. W. Frye, and R. L. Blevins. 1984. Nitrogen from legume cover crops for no-tillage corn. Agron. J. 76 : 51–55.

Elmore, C.D., R.A. Wesley, and L.G. Heatherly. 1992. Stale seedbed production of soybeans with a wheat cover crop. J. Soil Water Cons. 47 : 187–190.

Evanylo, G.K. 1991. Rye nitrogen cycling for corn and potato production. pp. 101–103 In: W.L. Hargrove (ed.) Cover Crops for Clean Water. SWCS. Ankeny, IA.

Evers, G.W. 1983. Weed control on warm season perennial grass pastures with clovers. Crop Sci. 23 : 170–171.

Evers, G. W., G. R. Smith, and P. E. Beale. 1988. Subterranean clover reseeding. Agron. J. 80 : 855–859.

Ewing, R. P., M. G. Wagger, and H. P. Denton. 1991. Tillage and cover crop management effects on soil water and corn yield. Soil Sci. Soc. Am. J. 55: 1081–1085.

Fairbrother, T.E. 1991. Effect of fluctuating temperatures and humidity on the softening of hard seed of subterranean clover (*Trifolium subterraneum* L.) Seed Sci. Technol. 19 : 93–105.

Fischer, A. F. and L. Burrill. 1993. Managing interference in a sweet corn-white clover living mulch system. Am. J. of Alt. Ag. 8 : 51–56.

Flint, E.H. 1999. Comparisons of no-tillage and conventional cotton (Gossypium hirsutum L.) with evaluations of mycorrhizal associations. PhD Dissertation. Mississippi State University. Mississippi State, MS 90 pp.

Fortin, M.-C. and A.S. Hamill. 1994. Rye residue geometry for faster corn development. Agron. J. 86 : 238–243.

Frye, W.W., W. G. Smith, and R.J. Williams. 1985. Economics of winter cover crops as a source of nitrogen for no-till corn. J. Soil Water Conserv. 40: 246–248.

Frye, W. W., J.J. Varco, R.L. Blevins, M.S. Smith, and S.J. Corak. 1988. Role of annual legume cover crops in efficient use of water and nitrogen. pp. 129–154. In: W.L. Hargrove (ed.) Cropping Strategies for Efficient Use of Water and Nitrogen. Spec. Pub. No. 51. ASA, Madison, WI.

Gallaher, R.N. 1977. Soil Moisture conservation and yield of crops no-till planted in rye. Soil Sci. Soc. Am. J. 41 : 145–147.

Galvez, L., D.D. Douds, Jr., P. Wagoner, L.R. Longnecker, L.E. Drinkwater, and R.R. Janke. 1995. An overwintering cover crop increases inoculum of VAM fungi in agricultural soil. Am. J. of Alt. Agric. 10 : 152–156.

Grafton-Cardwell, E.E., Y.L. Ouyang, and R.L. Bugg. 1999. Leguminous cover crops to enhance population development of Euseius tularensis (Acari: Phytoseiidae) in citrus. Biol. Control 16 : 73–80.

Graves, W. L., W. H. Weitkamp, M. R. George, G. R. Smith, B. L. Kay, and C. Gomez Pitera. 1991. Stand persistence and estrogenic activity of hardseeded subterranean clover cultivars for southern and central California. J. Prod. Agric. 4 : 111–114.

Griffin, J. L. and S.M. Dabney. 1990. Preplant-postemergence herbicides for legume cover-crop control in minimum tillage systems. Weed Tech. 4: 332–336.

Griffin, J.L. and R.W. Taylor. 1986. Alternative establishment methods for wheat following soybean. Agron. J. 78 : 487–490

Grafton-Cardwell, E.E., Y. Ouyang, and R.L. Bugg. 1999. Leguminous cover crops to enhance population development of *Euseius tularensis* (Acari: Phytoseiidae) in Citrus. Biological Control 16 : 73–80.

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

Grunwald, N.J., S. Hu, and A.H.C. van Bruggen. 2000. Short term cover crop decomposition in organic and conventional soils: characterization of soil C, N, microbial and plant pathogen dynamics. Eur. J. of Plant Pathol. 106: 37–50.

Hargrove, W. L. 1986. Winter legumes as a nitrogen source for no-till grain sorghum. Agron. J. 78 : 70 –74.

Harper, L.A., P.F. Hendrix, G.W. Langdale, and D.C. Coleman. 1995. Clover management to provide optimum nitrogen and soil water conservation. Crop Sci 35 : 176 –182.

Hayes. W. A. 1965. Wind erosion equation useful in designing northeastern crop protection. J. Soil Water Conserv. 10 : 153 –155.

Holderbaum, J.F., A.M. Decker, J.J. Meisinger, F.R. Mulford, and L.R. Vough. 1990. Fall-seeded legume cover crops for no-tillage corn in the humid east. Agron J. 82 : 117–124.

Hoffman, M.L., L.A. Weston, J.C. Snyder, and E.E. Regnier. 1996. Allelopathic influence of germinating seeds and seedlings of cover crops on weed species. Weed Sci. 44 : 579 –584.

Hoyt, G.D. 1999. Tillage and cover residue effects on vegetable yields. HortTechnology 9 : 351–358.

Huntington, T.G., J.H. Grove, and W.W. Frye. 1985. Release and recovery of nitrogen from winter annual cover crops in no-till corn production. Commun. Soil Sci. Plant Anal. 16 : 193 –211.

Infante, M. L., and R.D. Morse. 1996. Integration of no-tillage and overseeded legume living mulches for transplanted broccoli production. HortScience. 31 : 376 –380.

Isse, A.A., A.F. MacKenzie, K. Stewart, D.C. Cloutier, and D. L. Smith. 1999. Cover crop and nutrient retention for subsequent sweet corn production. Agron. J. 91 : 934 –939.

Janovicek, K.J., T.J. Vyn, and R.P. Voroney. 1997. No-till corn response to crop rotation and in-row residue placement. Agron. J. 89 : 588 –596.

Janzen, H.H. and S.M. McGinn. 1991. Volatile loss of nitrogen during decomposition of legume green manure. Soil Biol Biochem. 23 : 291–297.

Jones, M.B., C.C. Delwiche, and W.A. Williams. 1977. Uptake and losses of 15N applied to annual grass and clover in lysimeters. Agron. J. 69 : 1019 –1023.

Jones, R.J. 1942. Nitrogen losses from Alabama soils in lysimeters as influenced by various systems of green manure crop management. J. Am. Soc. Agron. 34 : 574 –585.

Kandel, H.J., A.A. Schneiter, and B.L. Johnson. 1997. Intercropping legumes into sunflower at different growth stages. Crop Sci. 37 : 1532–1537.

Känkänen, H., A. Kangas, T. Mela, U. Nikunen, H. Tuuri, and M. Vuorinen. 1998. Timing incorporation of different green manure crops to minimize the risk of nitrogen leaching. Agr. and Food Sci. in Finland 7 : 553 –567.

Kaspar, T.C. and D.C. Erbach. 1998. Improving stand establishment in no-till with residue-clearing planter attachments. Trans. ASAE 41:301–306.

Keeling, J.W., A.G. Matches, C.P. Brown, and T.P. Karnezos. 1996. Comparison of interseeded legumes and small grains for cover crop establishment in cotton. Agron. J. 88:219–222.

Kelly, T.C., Y.-C. Lu, A.A. Abdul-Baki, and J.R. Teasdale. 1995. Economics of a hairy vetch mulch system for producing fresh-market tomatoes in the Mid-Atlantic Region. J. Amer. Soc. Hort. Sci. 120:854–860.

Komatsuzaki, M. S. Moriizumi, and O. Endo. 1998. Subterranean clover reseeding and seed survival in upland fields. Japanese J. of Farm Work Res. 33: 63–71.

Kuo, S., U.M. Sainju, and E.J. Jellum. 1997. Winter cover crops effects on soil organic carbon and carbohydrate in soil. Soil Sci. Soc. Am. J. 61: 145–152.

Langdale, G.W., R.L. Blevins, D.L. Karlen, D.K. McCool, M.A. Nearing, E.L. Skidmore, A.W. Thomas, D.D. Tyler, and J.R. Williams. 1991. Cover crop effects on soil erosion by wind and water. pp. 15–21. In: W.L. Hargrove (ed.) Cover Crops for Clean Water. SWCS. Ankeny, IA.

Lal, R., E. Regnier, D.J. Eckert, W.M. Edwards, and R. Hammond. 1991. Expectations of cover crops for sustainable agriculture. pp. 1–11. In: W.L. Hargrove (ed.) Cover Crops for Clean Water. SWCS. Ankeny, IA.

Lal, R. 1997. Land use and soil management effects on soil organic matter dynamics on Alfisols in Western Nigeria. In: R Lal, J.M. Kimble, R.F. Follett, and B.A. Stewart. (eds.) Soil processes and the carbon cycle. CRC Press Boca Raton Fl.

Lal, R., J.M. Kimble, R.F. Follett, and C.V. Cole. 1998. (eds.) The potential of U.S. cropland to sequester carbon and mitigate the greenhouse effect. Ann Arbor Press, Chelsea, MI.

Laub, C.A. and J.M. Luna. 1991. Influence of winter cover crop suppression practices on seasonal abundance of armyworm (Lepidoptera: Noctuidae), cover crop regrowth, and yield in no-till corn. Environ. Entom 20:749–754.

Leonard, B.R., P.A. Clay, R.L. Hutchinson, and J.B. Graves. 1994. Cultural management of cutworms in conservation tillage systems for cotton. La. Agric. 37:14–15.

Lemon, R.G., F.M. Hons, and V.A. Saladino. 1990. Tillage and clover cover crop effects on grain sorghum yield and nitrogen uptake. J. Soil Water Cons. 45:125–127.

Lewis, W.J., J.C. van Lenteren, S. C. Phatak, and J.H. Tumlinson. 1997. A total system approach to sustainable pest management. Proc. Natl. Acad. Sci. 94:12243–12248.

Liebman, M., and A.S. Davis. 2000. Integration of soil, crop and weed management in low-external-input farming systems. Weed Res. 40:27–47.

Mansoer, Z., D.W. Reeves, and C.W. Wood. 1997. Suitability of sunn hemp as an alternative late-summer legume cover crop. Agron. J. 61:246–253.

McCracken, D.V., J.E. Box, Jr., W.L. Hargrove, M.L. Cabrera, J.W. Johnson, P.L. Raymer, A.D. Johnson, and G.W. Harbers. 1995. Tillage and cover crops effects on nitrate leaching in the Southern Piedmont. Proc USDA-ASAE Clean Water-Clean Environment-21st Century. Vol II, Kansas City. MO ASAE, St Joseph MI.

Meisinger, J. J., W.L. Hargrove, R. L. Mikkelsen, J.R. Williams, and V.W. Benson. 1991. Effects of cover crops on groundwater quality. pp. 57–68. In: W.L. Hargrove (ed.) Cover Crops for Clean Water. SWCS. Ankeny, IA.

Mendes, I.C., A.K. Bandick, R.P. Dick, and P.J. Bottomley. 1999. Microbial biomass and activities in soil aggregates affected by winter cover crops. SSSAJ 63:873–881.

Mohr, R.M., M.H. Entz, H.H. Janzen, and W.J. Bullied. 1999. Plant-available nitrogen supply as affected by method and timing of alfalfa termination. Agron. J. 91:622–630.

Mitchell, W.H., and M.R. Teel. 1977. Winter annual cover crops for no tillage corn production. Agron. J. 69:569–573.

Morris, D.R., R.W. Weaver, G.R. Smith, and F.M. Rouquette. 1986. Competition for Nitrogen-15- depleted ammonium nitrate between arrowleaf clover and annual ryegrass sown into bermudagrass sod. Agron. J. 78:1023–1030.

Moyer, J.R., R.E. Blackshaw, E.G. Smith, and S.M. McGinn. 2000. Cereal cover crops for weed suppression in a summer fallow-wheat cropping sequence. Can. J. Plant Sci. 80:441–449.

Muller, M.M., V. Sundman, O. Soininvaara, and A. Merilainen. 1988. Effect of chemical composition in the release of nitrogen from agricultural plant materials decomposing in soil under field conditions. Biol. Fertil. Soils. 6:78–85.

Murphree, C. E. and K. C. McGregor. 1991. Runoff and sediment yield from a flatland watershed in soybeans. Trans ASAE 34:407–411.

Mutchler, C.K. and L.L. McDowell. 1990. Soil loss from cotton with winter cover crops. Trans. ASAE **33**:432–436.

Myers, J. L. and M. G. Wagger. 1991. Reseeding potential of crimson clover as a cover crop for no-tillage corn. Agron. J. 83:985–991.

National Research Council. 1993. Soil and Water Quality: an Agenda for Agriculture. National Academy Press. Washington, D.C. 516 pp.

Nielsen, N.E., and H.E. Jensen. 1985. Soil mineral nitrogen as affected by undersown catch crops. In Assessment of nitrogen fertilizer requirement. Proc. NW-European Study Ground for the Assessment of Nitrogen Fertilizer Requirement. Netherlands Fert. Inst., Haren, The Netherlands.

Oosterhuis, D. M. 1990. Growth and development of a cotton plant. pp. 1–24. In: W.N. Miley, and D. M. Oosterhuis [eds] Nitrogen Nutrition of Cotton: Practical Issues. ASA, Madison, WI.

Orr, D.B., D.A. Landis, D.R. Mutch, G.V. Manley, S.A. Stuby, and R.L. King. 1997. Ground cover influence on microclimate and Trichogramma (Hymenoptera: Trichogrammatidae) augmentation in seed corn production. Env. Entom. 26:43–438.

Patrick, W.H., C.B. Haddon, and J. A. Hendrix. 1957. The effects of longtime use of winter cover crops on certain physical properties of commerce loam. Soil Sci. Soc. Am. Proc. 21:366–368.

Pierce, F. J. and R. Lal. 1994. Monitoring the impact of soil erosion on crop productivity. pp. 235–263. In: R. Lal (ed.) Soil Erosion Research Methods, second edition. St. Lucie Press, Delray Beach, FL.

Pink, L.A., F.E. Allison, and U.L. Gaddy. 1948. Greenhouse experiments on the effect of green manures crops of varying carbon-nitrogen ratios upon nitrogen availability and soil organic matter content. Agron J. 40:237–248.

Pink, L.A., F.E. Allison, and U.L. Gaddy. 1945. Greenhouse experiments on the effect of green manures upon N recovery and soil carbon content. Soil Sci. Soc. Am. Proc. 10:230–239.

Price, H. C. and R. A. Baughan. 1987. Establishment of freshmarket tomatoes in a no-till system. Acta Horticulturae 198:261–268.

Power, J.F., J.W. Doran, and P.T. Koerner. 1991. Hairy vetch as a winter cover crop for dryland corn production. J. Prod. Agric. 4:62–67.

Putnam, A. R., J. DeFrank, and J. P. Barnes. 1983. Exploitation of allelopathy for weed control in annual and perennial cropping systems. J. Chem. Ecol. 9: 1001–1010.

Quemada, M., and M.L. Cabrera. 1995a. Carbon and nitrogen mineralized from leaves and stems of four cover crops. Soil Sci. Soc. Am. J. 59:471–477.

Quemada, M., and M.L. Cabrera. 1995b. CERES-N model predictions of nitrogen mineralized from cover crops residues. Soil Sci. Soc. Am. J. 59:1059–1065.

Quemada, M., and M.L. Cabrera. 1997. Temperature and water effects on nitrogen mineralization from surface-applied cover crop residues. Plant and Soil 189:127–137.

Ranells, N. N. and M. G. Wagger. 1992. Nitrogen release from crimson clover in relation to plant growth stage and composition. Agron. J. 84:424–430.

Ranells, N.N. and M.G. Wagger. 1997a. Grass-legume bicultures as winter annual cover crops. Agron. J. 89:659–665.

Reeves, D. W. 1994. Cover crops and rotations. pp.125–172. In: J.L. Hatfield and B.A. Stewart (eds.) Crops Residue Management. Advances in Soil Science. Lewis Publishers, Boca Raton, FL.

Reeves, D.W. 1997. The role of soil organic matter in maintaining soil quality in continuous cropping systems. Soil Tillage Res. 43:131–167.

Reeves, D.W., and C.W. Wood. 1994. A sustainable winter-legume conservation tillage system for maize: Effects on soil quality. Proc. 13th Int. Conf. of ISTRO, Vol. II. The Royal Veterinary and Agric. Univ. and the Danish Inst.

of Plant and Soil Science, Aalbord, Denmark, 24–29 July 1994, pp. 1011–1016.

Reicosky, D.C. and F. Forcella. 1998. Cover crop and soil quality interactions in agroecosystems. 53: 224–229.

Rickerl, D. H., W. B. Gordon, E. A. Curle, and J. T. Touchton. 1988. Winter legume and tillage effects on cotton growth and soil ecology. Soil Tillage Res. 11: 63–71.

Roberson, E.B., S. Sarig, and M.K. Firestone. 1991. Cover crop management of polysaccharide-mediated aggregation in an orchard soil. Soil Sci. Soc. Am. J. 55: 734–739.

Rothrock, C. S. and S. R. Kendig. 1991. Suppression of black root rot on cotton by winter legume cover crops. pp. 155–156. In: W.L. Hargrove (ed.) Cover Crops for Clean Water. SWCS. Ankeny, IA.

Sainju, U.M., B.O. Singh, and W.F. Whitehead. 1998. Cover crop root distribution and its effects on soil nitrogen cycling. Agron. J. 90: 511–518.

SAN. 1998. Managing Cover Crops Profitably, second edition. Handbook Series Book 3. Sustainable Agriculture Network. National Agricultural Library, Beltsville, MD. pp. 158–159.

Sanford, J.O. 1979. Establishing wheat after soybeans in double-cropping. Agron. J. 71: 109–112.

Sarrantonio, M. and T.W. Scott. 1988. Tillage effects on availability of nitrogen to corn following a winter green manure crop. Soil Sci. Soc. Am. J. 52: 1661–1668.

SAS Ins. (Statistical Analysis System). 1988. SAS/STAT Users guide. Ver 6.03, Third Edition. SAS Inst., Cary NC.

Schertz, D.L. and D.A. Miller. 1972. Nitrate-N accumulation in the soil profile under alfalfa. Agron. J. 64: 660–664.

Sharratt, B.S. and G.N. Flerchinger. 1995. Straw color for altering soil temperature and heat flux in the subarctic. Agron. J. 87: 814–819.

Shipitalo, M.J., W.M. Edwards, and L.B. Owens. 1997. Herbicide losses from conservation-tilled watersheds in a corn-soybean rotation. Soil Sci. Soc. Am. J. 61: 267–272.

Shipley, P. R., J.J. Meisinger, and A.M. Decker. 1992 Conserving residual corn fertilizer nitrogen with winter cover crops. Agron. J. 84: 869–876.

Smeda, R. J. and A. R. Putnam. 1988. Cover crop suppression of weeds and influence on strawberry yields. HortScience 23: 132–134.

Smeda, R.J. and S.C. Weller. 1996. Potential of rye (Secale cereale) for weed management in transplant tomatoes (Lycopersicon esculentum). Weed Sci. 44: 596–602.

Snodgrass, G.L., W.P. Scott, and J.W. Smith. 1984. Host plants and seasonal distribution of the tarnished plant bug (Hemiptera: Miridae) in the Delta of Arkansas, Louisiana, and Mississippi. Environ. Entomol. 13: 110–116.

Snodgrass, G. L. and E. A. Stadelbacher. 1994. Population levels of tarnished plant bugs (Heteroptera: Miridae) and beneficial arthropods following early-season treatments of *Geranium dissectum* for control of bollworms and tobacco budworms (Lepidoptera: Noctuidae). Environ. Entomol. 23: 1091–1096.

Stadelbacher, E. A. 1981. Role of early-season wild and naturalized host plants in the buildup of the F1 generation of *Heliothis zea* and *H. virescens* in the Delta of Mississippi. Environ. Entomol. 10:766–770.

Staver, K.W. and R.B. Brinsfield. 1998. Using cereal grain winter cover crops to reduce groundwater nitrate contamination in the mid-Atlantic coastal plains. J. Soil Water Cons. 53:230–240.

Stone, P.J., I.B. Sorensen, and P.D. Jamieson. 1999. Effect of sol temperature on phenology, canopy development, biomass and yield of maize in a cool-temperate climate. Field Crop. Res. 63:169–178.

Streeter, J.G. 1985. Nitrate inhibition of legume nodule growth and activity. II Short term studies with high nitrate supply. Plant Physiol.77:325–328.

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

Taylor, G. B. 1985. Effect of tillage practices on the fate of hard seeds of subterranean clover. Aust. J. Exp. Agric. 25:568–573.

Thiagalingam, K., N.P. Dalgliesh, N.S. Gould, R.L. McCown, A.L. Cogle, and A.L. Chapman. 1996. Comparison of no-tillage and conventional tillage in the development of sustainable farming systems in the semi-arid tropics. Aust. J. Exp. Ag. 36:995-1002.

Torbert, H.A., and D.W. Reeves. 1991. Benefits of a winter legume cover crop to corn: Rotation versus fixed-nitrogen effects. pp. 99–100. In: W.L. Hargrove (ed.) Cover Crops for Clean Water. SWCS. Ankeny, IA.

Touchton, J. T., W. A. Gardner, W. L. Hargrove, and R. R. Duncan. 1982. Reseeding crimson clover as a N source for no-tillage grain sorghum production. Agron. J. 74:283–287.

Triplett, G. B., S. M. Dabney, and J. H. Siefker. 1996. Tillage systems for cotton on silty upland soils. Agron. J. 88:507–512.

Utomo, M., W. W. Frye, R. L. Blevins. 1990. Sustaining soil nitrogen for corn using hairy vetch cover crop. Agron. J. 82:979–983.

Unger, P.W., and M.F. Vigil. 1998. Cover crops effects on soil water relationships. J.Soil Water Cons. 53:241–244

USDA. 1948. Winter legumes for green manure in the cotton belt. Farmers' Bulletin No. 1663. 22 pp.

USDA. 1949. Bur-clover cultivation and utilization. Farmers' Bulletin No. 1741. 12 pp.

USDA. 1951. Harvesting and cleaning grass and legume seed in the western Gulf region. Ag. Handbook No. 24. pp. 83–85.

Varco, J. J., W. W. Frye, M. S. Smith, and C. T. MacKown. 1989. Tillage effects on nitrogen recovery by corn from a nitrogen-15 labeled legume cover crop. Soil Sci. Soc. Am. J. 53:822–827.

Vaughan, J.D. and G.K. Evanylo. 1998. Corn response to cover crop species, spring desiccation time, and residue management. Agron. J. 90:536–544.

Viets, F.G., Jr. and C.L. Crawford. 1950. The influence of nitrogen on the growth and nitrogen fixation of Hairy Vetch. Soil Sci. Soc. Am. Proc. 14:234–237.

Vos, J.G.M. and N. Sumarni. 1997. Integrated crop management of hot pepper (Capsicum spp.) under tropical lowland conditions: effects of mulch on crop performance and production. J. Hort. Sci. 72:415–424.

Wagger, M.G. 1989a. Time of desiccation effects on plant composition and subsequent nitrogen release from several winter annual cover crops. Agron. J.81:236–241.

Wagger, M.G. 1989b. Cover crop management and nitrogen rate in relation to growth and yield of no-till corn. Agron. J. 81:533–538.

Wagger, M.G., M.L. Cabrera, and N.N. Ranells. 1998. Nitrogen and carbon cycling in relation to cover crop residue quality. J. Soil Water Cons. 53: 214–218.

Wagger, M.G. and H.P. Denton. 1989. influence of cover crop and wheel traffic on soil physical properties in continuous no-till corn. Soil Sci. Soc. Am. J. 53:1206–1210.

Wagner-Riddle, C., T.J. Gillespie, L.A. Hunt, and C.J. Swanton. 1997. Modeling a rye cover crop and subsequent soybean yield. Agon. J. 89:208–218.

Walker, T.W., A.F.R. Adams, and H.D. Orchiston. 1956. Fate of labeled nitrate and ammonium nitrogen when applied to grass and clover grown separately and together. Soil Sci. 81:339–351.

Weston, L. A. 1990. Cover crop and herbicide influence on row crop seedling establishment in no-tillage culture. Weed Sci. 38(2):166–171.

Williams, M.M. II, D.A. Mortensen, and J.W. Doran. 2000. No-tillage soybean performance in cover crops for weed management in the western corn belt. J. Soil Water Cons. 55:79–84.

Wilson, D.O., and W.L. Hargrove. 1986. Release of nitrogen from crimson clover residue under two tillage systems. Soil Sci. Soc. Am. J. 50:1251–1254.

Wright, S.F., J.L. Starr, and I.C. Paltineanu. 1999. Changes in aggregate stability and concentration of glomalin during tillage management transition. Soil Sci. Soc. Am. J. 63:1825–1829.

Zak, J.C., B. McMichael, S. Dhillion, and C. Friese. 1998. Arbuscular-mycorrhizal colonization dynamics of cotton (*Gossypium hirsutum* L.) growing under several production systems on the Southern High Plains, Texas. Agric., Ecosystems, & Env. 68:245–254.

Request Permission or Order Reprints Instantly!

Interested in copying and sharing this article? In most cases, U.S. Copyright Law requires that you get permission from the article's rightsholder before using copyrighted content.

All information and materials found in this article, including but not limited to text, trademarks, patents, logos, graphics and images (the "Materials"), are the copyrighted works and other forms of intellectual property of Marcel Dekker, Inc., or its licensors. All rights not expressly granted are reserved.

Get permission to lawfully reproduce and distribute the Materials or order reprints quickly and painlessly. Simply click on the "Request Permission/Reprints Here" link below and follow the instructions. Visit the U.S. Copyright Office for information on Fair Use limitations of U.S. copyright law. Please refer to The Association of American Publishers' (AAP) website for guidelines on Fair Use in the Classroom.

The Materials are for your personal use only and cannot be reformatted, reposted, resold or distributed by electronic means or otherwise without permission from Marcel Dekker, Inc. Marcel Dekker, Inc. grants you the limited right to display the Materials only on your personal computer or personal wireless device, and to copy and download single copies of such Materials provided that any copyright, trademark or other notice appearing on such Materials is also retained by, displayed, copied or downloaded as part of the Materials and is not removed or obscured, and provided you do not edit, modify, alter or enhance the Materials. Please refer to our Website User Agreement for more details.

Order now!

Reprints of this article can also be ordered at
http://www.dekker.com/servlet/product/DOI/101081CSS100104110