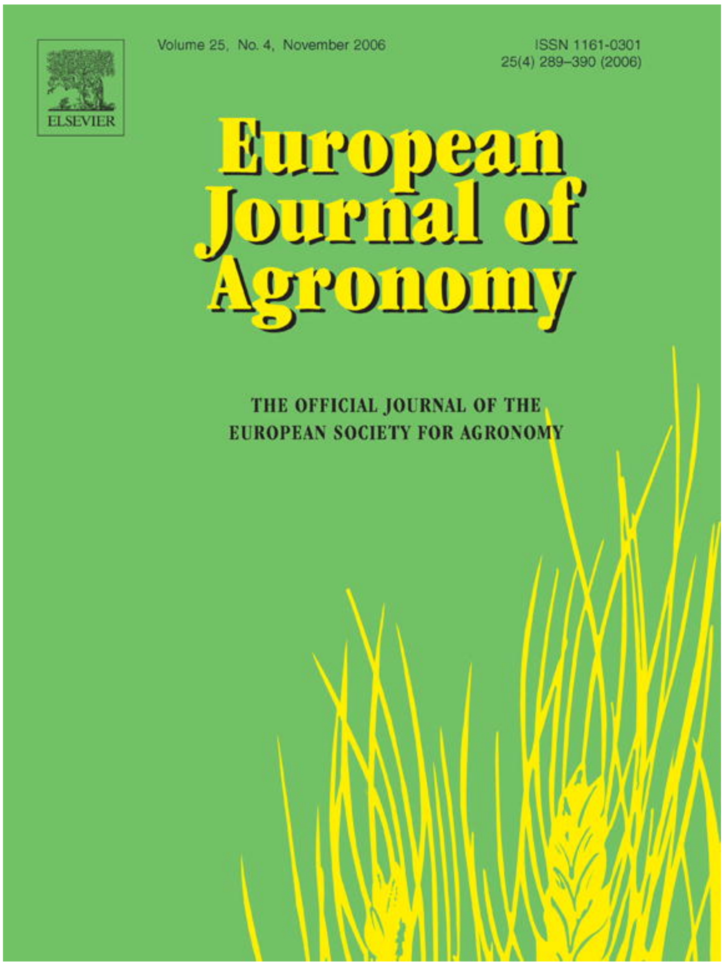
Volume 25, No. 4, November 2006
ISSN 1161-0301
25(4) 289–390 (2006)
ELSEVIER
European Journal of Agronomy
THE OFFICIAL JOURNAL OF THE
EUROPEAN SOCIETY FOR AGRONOMY

Available online at www.sciencedirect.com
ScienceDirect
Europ. J. Agronomy 25 (2006) 372–382
European Journal of Agronomy
www.elsevier.com/locate/eja

Tillage, cover crops, and nitrogen fertilization effects on soil nitrogen and cotton and sorghum yields

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Received 20 August 2005; received in revised form 7 July 2006; accepted 27 July 2006

Abstract

Sustainable soil and crop management practices that reduce soil erosion and nitrogen (N) leaching, conserve soil organic matter, and optimize cotton and sorghum yields still remain a challenge. We examined the influence of three tillage practices (no-till, strip till and chisel till), four cover crops {legume [hairy vetch (*Vicia villosa* Roth)], nonlegume [rye (*Secaele cereale* L.)], vetch/rye biculture and winter weeds or no cover crop}, and three N fertilization rates (0, 60–65 and 120–130 kg N ha^{-1}) on soil inorganic N content at the 0–30 cm depth and yields and N uptake of cotton (*Gossypium hirsutum* L.) and sorghum [*Sorghum bicolor* (L.) Moench]. A field experiment was conducted on Dothan sandy loam (fine-loamy, siliceous, thermic, Plinthic Paleudults) from 1999 to 2002 in Georgia, USA. Nitrogen supplied by cover crops was greater with vetch and vetch/rye biculture than with rye and weeds. Soil inorganic N at the 0–10 and 10–30 cm depths increased with increasing N rate and were greater with vetch than with rye and weeds in April 2000 and 2002. Inorganic N at 0–10 cm was also greater with vetch than with rye in no-till, greater with vetch/rye than with rye and weeds in strip till, and greater with vetch than with rye and weeds in chisel till. In 2000, cotton lint yield and N uptake were greater in no-till with rye or 60 kg N ha^{-1} than in other treatments, but biomass (stems + leaves) yield and N uptake were greater with vetch and vetch/rye than with rye or weeds, and greater with 60 and 120 than with 0 kg N ha^{-1}. In 2001, sorghum grain yield, biomass yield, and N uptake were greater in strip till and chisel till than in no-till, and greater in vetch and vetch/rye with or without N than in rye and weeds with 0 or 65 kg N ha^{-1}. In 2002, cotton lint yield and N uptake were greater in chisel till, rye and weeds with 0 or 60 kg N ha^{-1} than in other treatments, but biomass N uptake was greater in vetch/rye with 60 kg N ha^{-1} than in rye and weeds with 0 or 60 kg N ha^{-1}. Increased N supplied by hairy vetch or 120–130 kg N ha^{-1} increased soil N availability, sorghum grain yield, cotton and sorghum biomass yields, and N uptake but decreased cotton lint yield and lint N uptake compared with rye, weeds or 0 kg N ha^{-1}. Cotton and sorghum yields and N uptake can be optimized and potentials for soil erosion and N leaching can be reduced by using conservation tillage, such as no-till or strip till, with vetch/rye biculture cover crop and 60–65 kg N ha^{-1}. The results can be applied in regions where cover crops can be grown in the winter to reduce soil erosion and N leaching and where tillage intensity and N fertilization rates can be minimized to reduce the costs of energy requirement for tillage and N fertilization while optimizing crop production.

Keywords: Tillage; Cover crop; Nitrogen fertilization; Inorganic nitrogen; Cotton yield; Sorghum yield

1. Introduction

Sustainable management practices, such as conservation tillage and cover cropping, which can increase soil organic matter and reduce soil erosion and nitrogen (N) leaching, still remain a challenge for cotton (*Gossypium hirsutum* L.) and sorghum [*Sorghum bicolor* (L.) Moench] production systems. Soils in the Piedmont region of the southeastern USA, where most of cotton and sorghum are grown, are highly weathered, erodible, and infertile in nature and contain lower organic matter than in the northern regions (Franzluebbers et al., 1999). In such areas, conservation tillage increases the amount of crop residue left in the soil after harvest, thereby reducing soil erosion and increasing organic matter, aggregation, water infiltration, and water holding capacity compared with conventional tillage (Daniel et al., 1999; Franzluebbers et al., 1999; Baughman et al., 2001). Similarly, cover crops cover soil during fallow, thereby reducing soil erosion and N leaching, improving soil organic matter, aggregation, and water holding capacity, and influencing crop yields compared with no cover crop (McVay et al., 1989; McCracken

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doi:10.1016/j.eja.2006.07.005

et al., 1994; Kuo et al., 1997a). While legumes may supply N and increase crop yields, nonlegumes may reduce N leaching compared with no cover crops (Kuo et al., 1997b; Sainju and Singh, 1997). Increasing cost of N fertilization due to increase in the cost of petroleum and increased N leaching due to higher N fertilization rates suggests that the rate of N fertilization should be reduced while maintaining crop yields.

The effect of tillage on cotton and sorghum yields had been variable. Some studies have shown that cotton and sorghum yields were similar to or greater in no-tillage than in conventional tillage (Bordovsky et al., 1998; Daniel et al., 1999; Nyakatawa et al., 2000). Others have reported lower cotton yields in no-tillage than in conventional tillage (Ishaq et al., 2001; Pettigrew and Jones, 2001; Schwab et al., 2002). Still others have found that enhanced cotton yields with conservation tillage were observed only after several years (Triplett et al., 1996). While increased soil moisture resulting from the accumulation of surface residue in no-tillage has been reported to increase cotton seed germination, root growth, and lint yield compared with conventional tillage (Bordovsky et al., 1994; Nyakatawa and Reddy, 2000; Nyakatawa et al., 2000), poor root penetration and difficulties in obtaining adequate stands and weed control have been observed to reduce cotton and sorghum yields in no-tillage (Schertz and Kemper, 1994; Triplett et al., 1996). However, lower production cost and greater environmental benefits of reduced soil erosion and N leaching and increased C sequestration in no-tillage than in tilled system makes conservation tillage more promising for improving soil quality and sustaining crop production (Varco et al., 1987; Smart and Bradford, 1999; Paxton et al., 2001).

Sustainability of the farming system can be improved by combining winter cover cropping with conservation tillage. Cotton and sorghum yields are often improved by planting winter cover crops in conservation tillage systems (Hutchinson et al., 1995; Schwenke et al., 2001). This is because cover crops provide additional residues that act as mulch in conservation tillage, thereby improving soil moisture and germination of cotton seedlings (Nyakatawa and Reddy, 2000; Boquet et al., 2004a). Furthermore, improved soil physical, chemical, and biological properties associated with cover cropping helps to increase the growth and production of cotton and sorghum (Hutchinson et al., 1995; Schwenke et al., 2001). Biomass residue production can be further increased, soil organic matter be enriched, and crop yields be optimized by using a mixture of legume and nonlegume cover crops compared with either of species alone (Mutch and Martin, 1998; Snapp et al., 2003; Sainju et al., 2005), but the effect of cover crop mixture on soil nitrogen and crop yields is little known.

The rate of N fertilization for optimizing cotton and sorghum yields can vary with the type of tillage and cover crop. Boquet et al. (2004b) reported that cotton yields were lower in no-tillage than in surface tillage without applied N, but with optimum N rate, yields were higher in no-tillage. They also found that higher N rate was required to optimize cotton yield following wheat (*Triticum aestivum* L.) or no cover crop in no-tillage and surface tillage but no N rate was required following hairy vetch (*Vicia villosa* Roth) in either tillage practice. Similarly, N fertilization rates to cotton and sorghum can be reduced or eliminated by using legume cover crops, such as red clover (*Trifolium pratense* L.) and hairy vetch, regardless of tillage practices (Hargrove, 1986; Blevins et al., 1990; Sweeney and Moyer, 2004).

Little information is available about the combined effects of tillage, cover crops, and N fertilization rates on soil mineral N and cotton and sorghum yields and N uptake. We hypothesized that a combination of conservation tillage, such as no-tillage or strip tillage, with a mixture of legume and nonlegume cover crops, and reduced rate of N fertilization may optimize soil N availability at crop planting, reduce residual N accumulation after harvest, and sustain cotton and sorghum yields and N uptake compared with conventional tillage with no cover crop and high rate of N fertilization. Our objectives were to: (1) examine the amount of N supplied by legume and nonlegume cover crops in various tillage practices and N fertilization rates applied to cotton and sorghum and (2) determine the effects of tillage, cover crops, and N fertilization rates on soil inorganic N content at the 0–30 cm depth and cotton and sorghum yields and N uptake from 2000 to 2002 in Georgia, USA.

2. Materials and methods

2.1. Experimental site and treatments

The experiment was conducted at the Agricultural Research Station Farm, Fort Valley State University, Fort Valley, Georgia, USA. The soil was a Dothan sandy loam (fine-loamy, kaolinitic, thermic, Plinthic Kandiudults), with pH of 6.5–6.7 and sand content of 650 g kg^{-1}, silt 250 g kg^{-1} and clay 100 g kg^{-1} soil at the 0–30 cm depth. The clay content increased to 350 g kg^{-1} below 30 cm. The soil sampled in October 1999 before cover crop planting had organic C of 8.8 g kg^{-1} and organic N 620 mg kg^{-1} at the 0–30 cm depth. Previous crops from 1995 to 1999 were tomato (*Lycopersicum esculentum* Mill) and silage corn (*Zea mays* L.). Temperature and rainfall data were collected from a weather station, 20 m from the experimental site.

Treatments consisted of three tillage practices (no-till, strip till and chisel till), four cover crops {legume [hairy vetch (*Vicia villosa* Roth)], nonlegume [rye (*Secale cereale* L.)], legume and nonlegume (hairy vetch/rye) biculture, and winter weeds or no cover crop}, and three N fertilization rates (0, 60–65 and 120–130 kg N ha^{-1}). In strip till (or reduced till), cropping rows were subsoiled to 35 cm depth in a narrow strip of 30 cm width, thereby leaving 60 cm strip between rows undisturbed. The surface tilled zone is leveled by coulters behind the subsoiler. Chisel till (or conventional till) consisted of plowing the soil with disc harrow and chisel plow to a depth of 15–20 cm, followed by leveling with a S-tine harrow. No-till soil was left undisturbed, except for planting cover crops, cotton and sorghum. The 120 kg N ha^{-1} is the recommended rate of N fertilization for cotton and 130 kg N ha^{-1} for sorghum in central Georgia, USA (University of Georgia, 1999, 2001). Treatments were laid out in a split plot arrangement in randomized complete block, with tillage as the main plot factor, cover crop as the split plot factor, and N fertilization rate as the split-split plot factor. Each treatment had three replications. The split-split plot size was 7.2 m × 7.2 m.

2.2. Cover crop management

Cover crops were planted in October–November, 1999–2001, in the same plot every year to examine their long-term influence on soil quality and crop production. Hairy vetch seeds were drilled at 28 kg ha^{-1} after inoculating with *Rhizobium leguminosarum* (bv. viceae) and rye at 80 kg ha^{-1}, using a row spacing of 15 cm. In the hairy vetch/rye biculture, hairy vetch was drilled at 19 kg ha^{-1} (68% of monoculture), followed by rye at 40 kg ha^{-1} (50% of monoculture) in between vetch rows. The rates of hairy vetch and rye in the biculture were used based on the recommendation of Clark et al. (1994). Cover crops were drilled in plots without any tillage because previous studies have shown that cover crop aboveground biomass yields and N accumulation were not significantly influenced by tillage practices (Sainju and Singh, 2001; Sainju et al., 2005). No fertilizers, herbicides or insecticides were applied to cover crops.

In April 2000–2002, cover crop biomass yield was determined by hand harvesting plant samples from two 1 m^2 areas randomly within each plot and weighed in the field. A subsample (≈100 g) was collected for determinations of dry matter yield and N concentration and the remainder of the plant samples was returned to the harvested area where it was spread uniformly by hand. In plots without cover crop, winter weeds, dominated by henbit (*Lamium amplexicaule* L.) and cut-leaf evening primrose (*Oenolthera laciniate* Hill), were collected using the same procedure. Plant samples were oven-dried at 60 °C for 3 days, weighed, and ground to pass a 1-mm screen. After sampling, cover crops and weeds were mowed with a rotary mower to prevent residues from dragging while operating tillage and seeding. In no-till and strip till, cover crops were killed by spraying 3.36 kg ha^{-1} a.i. (active ingredient) of glyphosate [*N*-(phosphonomethyl)glycine]. In chisel till, cover crops were killed by disc harrowing and chisel plowing. Residues were allowed to decompose in the soil for 2 weeks prior to cotton and sorghum planting.

2.3. Cotton and sorghum management

At the time of planting cotton and sorghum in May 2000–2002, P {as triple superphosphate [$Ca(H_2PO_4)_2$]} fertilizer at 36 kg ha^{-1} for cotton and 40 kg ha^{-1} for sorghum and K [as muriate of potash (KCl)] fertilizer at 75 kg ha^{-1} for cotton and 80 kg ha^{-1} for sorghum were broadcast in all plots based on the soil test and crop requirement. At the same time, B [as boric acid (H_3BO_3)] fertilizer at 0.23 kg ha^{-1} for cotton was also broadcast. Nitrogen fertilizer as ammonium nitrate (NH_4NO_3) was applied at three rates (0, 60 and 120 kg N ha^{-1}) for cotton in 2000 and 2002, half of which was broadcast at planting and other half broadcast 6 weeks later. Similarly, NH_4NO_3 was applied at three rates (0, 65 and 130 kg N ha^{-1}) for sorghum in 2001, two-third of which was broadcast at planting and other one-third broadcast 6 weeks later. The fertilizers were left at the soil surface in no-till, partly incorporated into the soil in strip till, and completely incorporated in chisel till by plowing.

Following tillage, glyphosate-resistant cotton [cv. DP458BR (Delta Pine Land Co., Hartsville, SC, USA)] at 8 kg ha^{-1} in 2000 and 2002 and sorghum [cv. 9212Y (Pioneer Hi-Bred Int. Inc., Huntsville, AL, USA)] at 12 kg ha^{-1} in 2001 were planted in eight-row (each 7.2 m long) plots (0.9 m spacing) with a no-till equipped unit planter. Although the experiment was planned to plant continuous cotton from 2000 to 2002, sorghum was planted in 2001 to reduce the incidence of weeds, diseases and pests. Cotton was sprayed with glyphosate at 3.36 kg a.i. ha^{-1} in 2000 and 2002 to control weeds immediately after planting and during cotton growth. For sorghum, atrazine [6-chloro-*N*-ethyl-*N*′-(1-methylethyl)-1,3,5-triazine-2,4-diamine] at 1.5 kg a.i. ha^{-1} and metolachlor [2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl)acetamide] at 1.3 kg a.i. ha^{-1} were applied within a day after planting to control post-emergence of weeds. Aphids (*Aphis gossypii* Glover) in cotton was controlled by spraying endosulfan (6,7,8,9,10,10-hexachloro-1,5,5a,6,9,9a-hexahydro-6,9-methano-2,4,3-benzodioxathiepin-3-oxide) at 0.6 kg a.i. ha^{-1}. Cotton was also sprayed with the growth regulator, pix (1,1-dimethyl-piperdinium chloride), at 0.8 kg a.i. ha^{-1} at 2 month after planting to control vegetative growth. Similarly, the defoliant, Cottonquik [1-aminomethanamide dihydrogen tetraoxosulfate ethephon-(2-chloroethyl)phosphoric acid], at 2.8 L ha^{-1} was sprayed to cotton a day after biomass collection and 2–3 weeks before seed and lint harvest to defoliate leaves. Irrigation (equivalent to 25 mm using reel rain gun) was applied immediately after planting and fertilization and during dry periods to prevent moisture stress.

2.4. Plant and soil sample collection

In October–November, 2000 and 2002, aboveground cotton biomass samples containing stems, leaves and lint (including seeds) were hand harvested from two 1.8 m× 1.8 m areas randomly in places next to yield rows within the plot a week prior to the determination of lint yield. After removing lint and seeds, biomass samples containing stems and leaves were weighed, chopped to 2.5 cm length, and mixed thoroughly, from which a representative subsample of 100 g was collected, oven-dried at 60 °C for 3 days, and ground to 1 mm for N analysis. Lint yield was determined by hand harvesting lint-containing seeds from two central rows (6.2 m × 1.8 m), separating lint from seeds after ginning, and weighing them separately. Similarly, in November 2001, aboveground sorghum biomass containing stems and leaves (after removing grains) were collected from two 1.8 m × 1.8 m areas randomly in places next to yield rows within the plot, a week prior to the determination of grain yield. These were weighed, chopped to 2.5 cm length, and mixed thoroughly, from which a subsample of 100 g was oven-dried at 60 °C for 3 days and ground to 1 mm for N analysis. Grain yield was determined by hand harvesting heads from two central rows (6.2 m × 1.8 m), separating grains from heads, and weighing. Grain yield was adjusted to 15% moisture after drying a subsample in the oven at 60 °C. After collecting samples, cotton lint containing seeds and sorghum grains were removed from the remaining plants within the plot from 2000 to 2002 using a combine harvester and biomass residues containing stems and leaves were returned to the soil.

Within 2 weeks after returning cover crop, cotton, and sorghum residues to the soil, soil samples were collected from the 0 to 30 cm depth from each plot using a hydraulic probe (5 cm inside diameter) attached to a tractor. Samples were collected from four places, two in rows and two in between, from middle rows in each plot. The soil core from the probe was divided into 0–10 and 10–30 cm segments to represent their respective soil depths. Samples from four cores in a plot were composited within a depth, air-dried, ground, and sieved to 2 mm. Samples were collected in April to measure the effect of cover crop residues and in November to determine the effect of cotton and sorghum residues on soil inorganic N (NH_4-N + NO_3-N) content in each year from 2000 to 2002. For measuring bulk density, a separate undisturbed soil core (5 cm inside diameter) was collected from the 0 to 30 cm depth in November 2002, divided into two segments as above, oven-dried at 105 °C and weighed.

2.5. Laboratory analysis

The NH_4-N and NO_3-N concentrations (g kg^{-1} soil) in the soil were determined by steam distillation after extracting the soil with 2 M KCl for 1 h (Mulvaney, 1996). Total C and N concentrations (g C and N kg^{-1} plant dry weight) in cover crops and N concentrations in cotton lint, sorghum grain, and their biomass (stems + leaves) were determined by using the dry combustion C and N analyzer (LECO Co., St. Joseph, MI, USA). Soil inorganic N content (kg ha^{-1}) at a particular depth was determined by summing the NH_4-N and NO_3-N concentrations multiplied by bulk density (for that depth) and soil depth. Soil inorganic N content at the 0–30 cm depth was determined by summing contents at the 0–10 and 10–30 cm depths. Bulk density in November 2002 was significantly influenced by tillage at the 0–10 cm but not at the 10–30 cm depth. Therefore, bulk density values of 1.41, 1.51 and 1.42 Mg m^{-3} for no-till, strip till, and chisel till, respectively, averaged across cover crops and N fertilization rates, were used for calculating inorganic N content at the 0–10 cm depth. At the 10–30 cm depth, bulk density value of 1.53 Mg m^{-3}, averaged across treatments, was used for calculation. Carbon and N contents (kg ha^{-1}) in cover crops and N uptake in cotton and sorghum were determined by multiplying their dry matter weights by total C and N concentrations.

2.6. Data analysis

Data for biomass yields and C and N contents in cover crops, yields and N uptake by cotton and sorghum, and soil inorganic N content were analyzed using the MIXED procedure of SAS after testing for homogeneity of variance (Littell et al., 1996). Tillage, cover crop, N rate, and their interactions were considered as fixed effects and replication and tillage × cover crop × replication interaction were considered as random effects. For soil inorganic N, date of soil sampling was considered as the split-split-split plot treatment for analysis. Tillage, cover crop, N rate, date of soil sampling and their interactions were considered as fixed effects and replication and tillage × cover crop × replication interaction were considered as random effects. Means were separated by using the least square means test when treatments and their interactions were significant. Statistical significance was evaluated at $P \leq 0.05$, unless otherwise stated. Regression analysis was done between N fertilization rates, cotton and sorghum yields and N uptake, and soil inorganic N to determine the N fertilizer equivalence of cover crops for crop yields, N uptake and soil N.

3. Results

3.1. Cover crop biomass yield and carbon and nitrogen contents

Although cover crops were planted without tillage and N fertilization from 1999 to 2001, biomass yield and C and N contents in cover crops were not significantly ($P \leq 0.05$) influenced by tillage and N fertilization rates applied to cotton and sorghum in 2000 and 2001. Averaged across tillage and N fertilization rates, biomass yield was higher in rye than in hairy vetch in 2000 and 2001, but was higher in vetch than in rye in 2002 (Table 1).

Table 1
Biomass (stems + leaves) yield, N content, and C/N ratio of cover crops averaged across tillage and N fertilization rates from 2000 to 2002

Year	Cover crop	Biomass yield (Mg ha^{-1})	N content (kg ha^{-1})	C/N ratio
2000	Winter weeds	1.65 d[a]	25 d	24 b
	Rye	6.07 b	68 c	29 a
	Hairy vetch	5.10 c	165 b	12 c
	Hairy vetch/rye	8.18 a	310 a	10 c
2001	Winter weeds	0.75 d	15 b	20 c
	Rye	3.81 b	32 b	57 a
	Hairy vetch	2.44 c	76 a	12 c
	Hairy vetch/rye	5.98 a	84 a	32 b
2002	Winter weeds	1.25 c	23 b	21 b
	Rye	2.28 b	25 b	40 a
	Hairy vetch	5.16 a	167 a	10 c
	Hairy vetch/rye	5.72 a	186 a	11 c

[a] Numbers followed by different letter within a column of a set are significantly different at $P \leq 0.05$ by the least square means test.

Biomass yield was higher in vetch/rye biculture than in vetch and rye monocultures in 2000 and 2001 and higher in vetch/rye than in rye in 2002. Carbon content in cover crops followed trends similar to biomass yield (data not shown). Nitrogen content was higher in vetch and vetch/rye than in rye and weeds in all years. Nitrogen content was also higher in rye than in weeds and higher in vetch/rye than in vetch in 2000. It was not surprising to observe higher biomass yield and C and N contents in cover crops than in winter weeds. The C/N ratio was higher in rye than in other cover crops. The C/N ratio was similar between vetch and vetch/rye in 2000 and 2002 but was higher in vetch/rye than in vetch in 2001.

3.2. Soil inorganic nitrogen

Soil inorganic N content was significantly ($P \leq 0.05$) influenced by cover crop, N fertilization, and date of soil sampling. Interactions were significant ($P \leq 0.05$) for tillage × cover crop and cover crop × date of soil sampling.

Soil inorganic N at 0–10 and 0–30 cm depths, averaged across tillage, N fertilization, and date of sampling was higher with hairy vetch and hairy vetch/rye biculture than with rye and winter weeds (Table 2). At 10–30 cm, inorganic N was higher with vetch than with other cover crops. Inorganic N, averaged across tillage, cover crop, and date of sampling was also higher with 120–130 than with 0 kg N ha^{-1} at all depths. Averaged across tillage and N rates, inorganic N at 0–10 cm was higher with vetch than with rye and weeds in April 2000 and higher with vetch and vetch/rye than with rye and weeds in April 2002 (Fig. 1A). At 10–30 cm, inorganic N was higher with vetch than with rye and weeds in April 2000 (Fig. 1B). At 0–30 cm, inorganic N was higher with vetch than with rye and weeds in April 2000 and 2002 and higher with vetch and rye than with weeds in November 2002 (Fig. 1C).

Inorganic N also varied with tillage and cover crops. At 0–10 cm, inorganic N, averaged across N rates and date of sampling, was higher with vetch than with rye and vetch/rye in no-till, higher with vetch/rye than with rye and weeds in strip till, and higher with vetch than with rye and weeds in chisel till (Table 3). At 0–30 cm, inorganic N was higher with vetch than with rye and vetch/rye in no-till, higher with vetch than

Table 2
Effects of cover crops and N fertilization rates on soil inorganic (NH_4-N + NO_3-N) N content

Treatment	Soil inorganic N at depth (cm)		
	0–10 (kg ha^{-1})	10–30 (kg ha^{-1})	0–30 (kg ha^{-1})
Cover crop			
Winter weeds	19.6 b[a]	32.9 b	52.5 c
Rye	19.1 b	34.1 b	53.2 c
Hairy vetch	23.6 a	38.4 a	62.0 a
Hairy vetch/rye	21.6 a	34.8 b	56.4 b
N fertilization rate (kg N ha^{-1})			
0	19.6 b	33.5 b	53.1 b
60–65	20.8 b	35.3 ab	56.1 ab
120–130	22.5 a	36.4 a	59.9 a

[a] Numbers followed by different letters within a column of a set are not significantly different at $P \leq 0.05$ by the least square means test.

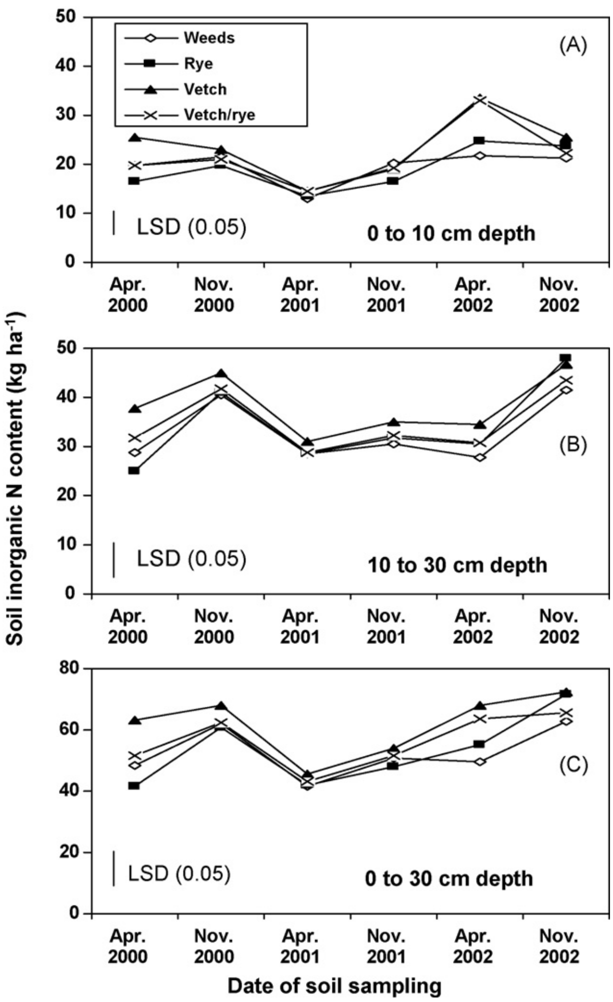

Fig. 1. Effects of cover crops and dates of soil sampling on soil inorganic N (NH_4-N + NO_3-N) content at (A) 0–10 cm, (B) 10–30 cm and (C) 0–30 cm depths averaged tillage and N fertilization rates. Weeds denote winter weeds; rye, cereal rye; vetch, hairy vetch, vetch/rye, hairy vetch and rye biculture. The vertical line denotes least significant difference between cover crops and dates of soil sampling [LSD (0.05)] at $P = 0.05$.

Table 3
Effects of tillage and cover crops on soil inorganic (NH_4-N + NO_3-N) N content averaged across N fertilization rates and dates of soil sampling

Tillage	Cover crop	Soil inorganic N at depth (cm)		
		0–10 kg ha^{-1}	10–30 kg ha^{-1}	0–30 kg ha^{-1}
No-till	Winter weeds	22.2	33.6	55.8
	Rye	17.3	30.5	47.8
	Hairy vetch	24.0	37.0	61.0
	Hairy vetch/rye	20.2	33.5	53.7
Strip till	Winter weeds	18.6	31.9	50.5
	Rye	20.5	36.5	57.0
	Hairy vetch	22.8	39.0	61.8
	Hairy vetch/rye	24.1	36.7	60.8
Chisel till	Winter weeds	17.9	33.3	51.2
	Rye	19.5	35.3	54.8
	Hairy vetch	23.9	39.0	62.9
	Hairy vetch/rye	20.6	34.1	54.7
LSD (0.05)		3.1	–	6.2

Table 4
Effects of interaction of tillage with cover crop and N fertilization rate on cotton lint yield and N uptake in 2000 and 2002

Cover crop	N fertilization rate (kg N ha^{-1})	Tillage practices		
		No-till	Strip till	Chisel till
2000 cotton lint yield (kg ha^{-1})				
Winter weeds		814 bcA[a]	480 bB	802 abA
Rye		1107 aA	674 aC	857 aB
Hairy vetch		661 cA	664 aA	657 bcA
Hairy vetch/rye		978 abA	562 abB	577 cB
	0	837 aA	516 aB	856 aA
	60	1009 aA	645 aB	666 bB
	120	824 aA	594 aB	647 bB
2000 cotton lint N uptake (kg ha^{-1})				
Winter weeds		11 bAB	8 aB	14 aA
Rye		20 aA	11 aB	14 aB
Hairy vetch		11 bA	11 aA	11 abA
Hairy vetch/rye		17 aA	9 aB	9 bB
2002 cotton lint yield (kg ha^{-1})				
	0	692 aB	826 aB	1546 aA
	60	640 aB	774 abB	1525 aA
	120	509 aAB	464 bB	787 bA
2002 cotton lint N uptake (kg ha^{-1})				
	0	14 aB	14 aB	22 aA
	60	12 aB	13 aB	22 aA
	120	12 aA	10 aA	12 bA

[a] Numbers followed by the different lower case letters within a column and upper case letters within a row in a set are significantly different at $P \leq 0.05$ by the least square means test.

with weeds in strip till, and higher with vetch than with other cover crops in chisel till. At 10–30 cm, the tillage × cover crop interaction on inorganic N was not significant.

3.3. Cotton yield and nitrogen uptake in 2000

In 2000, tillage was significant ($P \leq 0.05$) for cotton lint yield, cover crop was significant for lint yield biomass (stems + leaves) yield, and N uptake, and N fertilization was significant for biomass yield and N uptake. The tillage × cover crop interaction was significant for lint yield and N uptake and tillage × N fertilization was significant for lint yield.

Cotton lint yield, averaged across N rates, was higher with rye than with vetch and weeds in no-till, higher with rye and vetch than with weeds in strip till, and higher with rye than with vetch and vetch/rye in chisel till (Table 4). Lint N uptake was higher with rye and vetch/rye than with vetch and weeds in no-till, and higher with rye and weeds than with vetch/rye in chisel till. Lint yield and N uptake were higher with no-till than with strip till and chisel till in rye and vetch/rye. Averaged across cover crops and N rates, lint yield was higher in no-till than in chisel till (Table 6). Averaged across tillage and N rates, lint yield and lint N uptake were higher with rye than with other cover crops. Biomass yield and N uptake were higher with vetch than with rye and weeds.

Averaged across cover crops, lint yield was higher in no-till with 60 kg N ha^{-1} than in strip till with or without N rate and in chisel till with 60 and 120 kg N ha^{-1} (Table 4). Lint yield was also higher with 0 than with 60 and 120 kg N ha^{-1} in chisel till and higher with no-till than with strip till and chisel till in 60 and 120 kg N ha^{-1}. Averaged across tillage and cover crops, biomass yield and N uptake were higher with 60 and 120 than with 0 kg N ha^{-1} (Table 6).

3.4. Sorghum yield and nitrogen uptake in 2001

Sorghum grain yield, biomass, and N uptake were significantly ($P \leq 0.05$) influenced by tillage, cover crops, and N fertilization rates in 2001. Grain yield, biomass and N uptake, averaged across cover crops and N rates, were higher in strip till and chisel till than in no-till (Table 6). Grain yield was higher with vetch/rye than with rye and weeds, grain N uptake and biomass yield were higher with vetch and vetch/rye than with rye, and biomass N uptake was higher with vetch than with rye. Similarly, grain yield and N uptake were higher with 130 than with 0 and 65 kg N ha^{-1}, biomass yield was higher with 130 than with 0 kg N ha^{-1}, and biomass N uptake was higher with 65 and 130 than with 0 kg N ha^{-1}.

Interaction of cover crop × N fertilization was also significant ($P \leq 0.05$) for sorghum grain and biomass yield in 2001. Grain yield, averaged across tillage, was higher with 130 than with 65 kg N ha^{-1} in weeds, and higher with 130 than with 0 and 65 kg N ha^{-1} in rye (Table 5). Grain yield was higher with vetch and vetch/rye than with rye in 0 and 65 kg N ha^{-1}. Grain yield was also higher in vetch/rye with 130 kg N ha^{-1} than in rye and weeds with or without N and in vetch without N. Biomass yield was higher with 130 than with 0 kg N ha^{-1} in rye and weeds, and higher with vetch and vetch/rye than with rye in

Table 5
Effect of the interaction of cover crop and N fertilization rate on sorghum grain and biomass yield (stems + leaves) in 2001 and cotton lint yield and N uptake in 2002

N fertilization rate (kg N ha^{-1})	Cover crop			
	Winter weeds	Rye	Hairy vetch	Hairy vetch/rye
2001 sorghum grain yield (kg ha^{-1})				
0	2700 abA[a]	1500 bB	3300 aA	3500 aA
65	2200 bB	2200 bB	3700 aA	4100 aA
130	3400 aB	3300 aB	3600 aAB	4400 aA
2001 sorghum biomass yield (kg ha^{-1})				
0	10600 bB	7100 bC	14800 aA	13800 aA
65	11200 abBC	9400 abC	14300 aAB	14600 aA
130	14300 aA	11700 aA	13200 aA	14100 aA
2002 cotton lint yield (kg ha^{-1})				
0	1275 aA	1058 abA	920 aA	833 aA
60	1228 aA	1188 aA	827 abAB	676 aB
120	739 bA	575 bA	377 bA	625 aA
2002 cotton lint N uptake (kg ha^{-1})				
0	19 aA	15 abA	18 aA	15 aA
60	16 aAB	20 aA	15 aAB	12 aB
120	14 aA	10 bAB	7 bB	14 aA
2002 cotton biomass N uptake (kg ha^{-1})				
0	69 bB	59 bB	109 aA	82 bAB
60	69 bB	73 abB	81 aB	123 aA
120	85 aA	100 aA	104 aA	100 abA

[a] Numbers followed by the different lower case letters within a column and upper case letters within a row in a set are significantly different at $P \leq 0.05$ by the least square means test.

0 and 65 kg N ha^{-1}. Biomass yield was also higher in vetch with 0 kg N ha^{-1} than in rye and weeds with 0 and 65 kg N ha^{-1}.

3.5. Cotton yield and nitrogen uptake in 2002

Similar to 2000, cotton yield and N uptake were significantly ($P \leq 0.05$) influenced by tillage, cover crops, and N fertilization in 2002. Interactions were significant for tillage × N rate (lint yield and lint N uptake) and cover crop × N rate (lint yield, lint N uptake and biomass N uptake).

Cotton lint yield and lint N uptake, averaged across cover crops and N fertilization rates, were higher with chisel till than with no-till and strip till but biomass yield and N uptake were higher with strip till than with no-till (Table 6). Similarly, lint yield was higher with weeds than with vetch and vetch/rye, lint yield and N uptake were higher with 0 and 60 than with 120 kg N ha^{-1}, and biomass N uptake was higher with 120 than with 0 and 60 kg N ha^{-1}. Lint yield, averaged across cover crops, was higher with 0 than with 120 kg N ha^{-1} in strip till, and higher with 0 and 60 than with 120 kg N ha^{-1} in chisel till (Table 4). Similarly, lint N uptake was higher with 0 and 60 than with 120 kg N ha^{-1} in chisel till. Lint yield and lint N uptake were also higher in chisel till with 0 and 60 kg N ha^{-1} than in no-till and strip till with and without N rates.

Lint yield, averaged across tillage, was higher with 0 and 60 than with 120 kg N ha^{-1} in weeds, higher with 60 than with 120 kg N ha^{-1} in rye, and higher with 0 than with 120 kg N ha^{-1} in vetch (Table 5). Lint yield was also higher in weeds with 0 and 60 kg N ha^{-1} than in rye and vetch with 120 kg N ha^{-1} and in vetch/rye with 60 and 120 kg N ha^{-1}. Lint N uptake was higher in rye with 60 kg N ha^{-1} than in rye with 120 kg N ha^{-1}, vetch with 120 kg N ha^{-1}, and in vetch/rye with 60 kg N ha^{-1}. Biomass N uptake was higher with 120 than with 0 and 60 kg N ha^{-1} in weeds, higher with 120 than with 0 kg N ha^{-1} in rye, and higher with 0 than with 60 kg N ha^{-1} in vetch/rye. Biomass N uptake was also higher with vetch than with rye and weeds in 0 kg N ha^{-1} and higher with vetch/rye than with other cover crops in 60 kg N ha^{-1}.

4. Discussion

The higher soil inorganic N content with hairy vetch and hairy vetch/rye biculture than with rye and winter weeds (Table 2) was probably due to greater amount of N supplied by them (Table 1). Hairy vetch, because of its higher N concentration and lower C/N ratio, decomposes rapidly in the soil, and enriches soil N more than rye (Kuo et al., 1997b; Sainju and Singh, 2001). The significant enrichment of soil N by vetch and vetch/rye, however, occurred immediately after their biomass residues were returned to the soil in the spring, as shown by higher soil N levels with them in April 2000 and 2002 (Fig. 1). Hairy vetch releases about half of its N within 2–4 weeks after the residue is incorporated into the soil (Stute and Posner, 1995; Kuo et al., 1997b). Since soil samples were taken 2 weeks after cover crop residues were returned to the soil in April, N could have released in larger amounts from vetch and vetch/rye than from rye and weeds during this period. The significant differences in inorganic N between cover crops, however, disappeared by November, except in November 2002. The lower inorganic N content in April 2001 than in April 2000 and 2002 could be due to differ-

Table 6
Effects of tillage, cover crops, and N fertilization rates on yield and N uptake by cotton lint, sorghum grain, and their biomass (stems + leaves) from 2000 to 2002

Treatment	2000 cotton lint ($kg\,ha^{-1}$)		2000 cotton biomass ($kg\,ha^{-1}$)		2001 sorghum grain ($kg\,ha^{-1}$)		2001 sorghum biomass ($kg\,ha^{-1}$)		2002 cotton lint ($kg\,ha^{-1}$)		2002 cotton biomass ($kg\,ha^{-1}$)	
	Yield	N uptake	Yield	N uptake	Yield	N uptake	Yield	N uptake	Yield	N uptake	Yield	N uptake
Tillage[a]												
NT	890 a[b]	15 a	7600 a	174 a	2200 b	34 b	8300 b	85 b	614 b	13 b	3133 b	71 b
ST	595 ab	10 a	6600 a	203 a	3400 a	52 a	13900 a	154 a	688 b	12 b	4466 a	102 a
CT	423 b	12 a	6000 a	145 a	3900 a	58 a	15100 a	155 a	1286 a	19 a	4067 ab	91 a
Cover crop[c]												
WW	699 b	11 b	5200 c	124 b	2800 bc	43 ab	12000 ab	133 ab	1091 a	16 a	3667 a	74 a
R	879 a	15 a	6300 bc	138 b	2300 c	32 b	9400 b	81 b	940 ab	15 a	3567 a	77 a
HV	660 b	11 b	8200 a	239 a	3500 ab	60 a	14100 a	175 a	708 b	13 a	4067 a	98 a
HV/R	706 b	12 b	7300 ab	194 a	4000 a	58 a	14100 a	138 ab	711 b	14 a	4233 a	102 a
N fertilization rate ($kg\,N\,ha^{-1}$)												
0	736 a	12 a	5700 b	135 c	2800 b	41 b	11600 b	108 b	1021 a	17 a	3700 a	80 b
60–65	783 a	13 a	7000 a	178 b	3100 b	46 b	12400 ab	135 a	980 a	16 a	3900 a	86 b
120–130	689 a	11 a	7600 a	209 a	3700 a	57 a	13300 a	152 a	587 b	11 b	4000 a	97 a

[a] Tillage is CT, chisel till; NT, no-till; ST, strip till.
[b] Numbers followed by the different lower case letters within a column in a set are significantly different at $P \leq 0.05$ by the least square means test.
[c] Cover crops are HV, hairy vetch; HV/R, hairy vetch/rye; R, rye; WW, winter weeds.

Table 7
Total monthly rainfall from 2000 to 2002 at the experimental site

Months	2000 (mm)	2001 (mm)	2002 (mm)	41-Year average (mm)
January	93	47	49	143
February	8	23	46	124
March	111	179	70	119
April	18	44	59	79
May	15	52	40	95
June	137	159	145	121
July	81	51	122	131
August	82	39	88	90
September	82	53	127	69
October	18	2	98	62
November	90	51	99	77
December	48	28	123	123
December–April[a]	278	341	252	588
May–November	505	407	719	645

[a] Includes total rainfall from December of the previous year to April of the following year.

ences in the amount of N supplied by cover crops and the rainfall pattern between years. The amount of cover crop N was lower in 2001 than in 2000 and 2002 (Table 1). The December–April rainfall was 63 mm higher in 2000–2001 than in 1999–2000 and 89 mm higher than in 2001–2002, although it was 247 mm lower than the normal (Table 7). Also, total rainfall in March 2001 was 68 and 109 mm higher than in March 2000 and 2002, respectively. While higher rainfall in December–April, 2000–2001, could have increased the leaching loss of NO_3–N from the soil, lower N content in cover crop residues could have reduced the amount of N returned to the soil. A cold temperature in December 2000 (4.3 °C) compared with December 2001 (11.9 °C) and the 41-year average (9.6 °C) reduced plant stand of vetch, thereby decreasing its biomass yield and N content in 2001 compared with 2000 and 2002. As a result, soil inorganic N content was lower in April 2001 than in April 2000 and 2002. Similarly, lower total rainfall in May–November (Table 7), followed by lower amount of cover crop N in 2001 than in 2000 and 2002 could have reduced N mineralization from crop residue and soil, thereby resulting in lower soil inorganic N in November 2001 than in November 2000 and 2002. The differences in soil inorganic N contents between cover crops in April and November in each year was probably resulted from the variations in N mineralization from soil and crop residues, N fertilization, N uptake by cotton and sorghum, and N loss due to leaching, volatilization and denitrification.

It is not surprising to observe higher soil inorganic N with increasing N fertilization rates, because crops are unable to take 100% of the applied N (Bergstrom and Kirchmann, 2004; Bundy and Andraski, 2005). Unlike cover crops, the effect of N fertilization on inorganic N, however, disappeared with time, since N fertilization × date of soil sampling interaction was not significant. Probably crop N uptake and N loss due to leaching and/or volatilization occurred more rapidly with N fertilization than with cover crops where the rate of N mineralization is slower (Sainju and Singh, 2001; Bergstrom and Kirchmann, 2004). Similar levels of inorganic N at 0–30 cm between 60–65 and

120–130 kg N ha^{-1}, regardless of tillage, cover crops and date of soil sampling (Table 2), suggests that N fertilization rates to cotton and sorghum probably can be decreased to reduce the cost of N fertilization and the potential for N leaching.

Tillage modified inorganic N by influencing the rate of mineralization of cover crop residues in the soil (Table 3). While inorganic N level with vetch was almost constant in all tillage practices, the levels with rye and vetch/rye normally increased with increased tillage intensity. This shows that tillage has little effect on mineralization of vetch residue in the soil but higher tillage intensity was required to increase the mineralization of rye residue. This could be related to residue quality, such as C/N ratio of the residue, as discussed above. This is consistent with those reported in the literature that tillage influences the mineralization of cover crop residue and the resulting soil N level (Varco et al., 1987; Sainju and Singh, 2001).

Soil N availability as influenced by tillage, cover crops, and N fertilization was reflected on cotton and sorghum yields and N uptake (Tables 4, 5 and 6). Greater soil N availability with vetch and vetch/rye than with rye and weeds and increased rates of N fertilization increased sorghum grain yield, cotton and sorghum biomass yields, and N uptake but had adverse effects on cotton lint yield and lint N uptake. Increased soil N availability probably increased cotton biomass yield at the expense of lint yield. Boquet et al. (2004b) reported that cotton lint yield and N uptake increased with increasing N fertilization rates from 0 to 118 kg N ha^{-1} with wheat cover crop or native cover but decreased with hairy vetch. The tolerance of cotton lint yield following rye to high N rates was probably related to N immobilization caused by high C/N ratio of rye residue (Dabney et al., 2001). It may also be possible that unidentified factors retard cotton's vegetative growth in rye residue (Hicks et al., 1989). High rate of N fertilization can produce excessive vegetative growth that delays maturity and harvest and reduces cotton lint yield and N uptake (McConnell et al., 1993; Hutchinson et al., 1995; Howard et al., 2001). In contrast, increased sorghum grain and biomass yields and N uptake with vetch and vetch/rye compared with rye and weeds or with increasing rates of N fertilization suggests that both sorghum grain and stalk respond equally to N application in increasing yield and N uptake. Increases in sorghum grain and biomass yields and N uptake with legume cover crop and N fertilization compared with nonlegume or no cover crop and N fertilization were reported by several researchers (Hargrove, 1986; McVay et al., 1989; Sweeney and Moyer, 2004). Reduced cotton lint yield and lint N uptake with vetch and vetch/rye compared with rye and weeds or with 120 compared with 0 and 60 kg N ha^{-1} suggests that N supplied by hairy vetch or 120 kg N ha^{-1} could have been excessive and that the recommended N fertilization rate to cotton can be reduced by half to sustain cotton lint yield and N uptake and to reduce the cost of N fertilization and the potential for N leaching. Similar levels of sorghum grain yield and N uptake between vetch, vetch/rye, and 130 kg N ha^{-1} suggests that both vetch and vetch/rye can supply full N requirement for sorghum, which can replace N fertilization for optimum grain yield and N uptake. Similarly, vetch can be replaced by vetch/rye biculture to sustain cotton and sorghum yields and N uptake and to reduce the potential for N leaching.

Increased cotton lint yield and lint N uptake in no-till with rye or 60 kg N ha^{-1} compared with other management practices in 2000 (Table 4) suggests that conservation till with nonlegume cover crop and reduced rate of N fertilization can sustain cotton lint yield better than conventional till with full rate of N fertilization. Cotton lint yield and N uptake were as good as or better in no-till than in strip till and chisel till (Table 6). However, in 2002, cotton lint yield and lint N uptake were higher in chisel till than in no-till and strip till (Table 6) or higher in chisel till with 0 and 60 kg N ha^{-1} than in other tillage and N rates (Table 4). The effect of tillage on cotton lint yield has been reported to be variable, with some observing higher yields in conservation than in conventional till (Bordovsky et al., 1998; Daniel et al., 1999; Nyakatawa et al., 2000), while others finding higher yields in conventional till than in no-till (Ishaq et al., 2001; Pettigrew and Jones, 2001; Schwab et al., 2002). In contrast, increased sorghum yield and N uptake with increased tillage intensity (Table 5) suggests that tillage favors growth and development of sorghum, probably due to increased N mineralization, since soil inorganic N content increased from April to November in 2001 (Fig. 1B).

The lower or negative response of cotton lint yield and lint N uptake and higher response of sorghum yield and N uptake to N fertilization could also be related to differences in soil residual N levels between years. Soil inorganic N content at the 0–30 cm depth, averaged across tillage, cover crops, and N fertilization rates, was 51–59 kg ha^{-1} in April 2000 and 2002 compared with 43 kg N ha^{-1} in April 2001 (Fig. 1). Probably soils with lower N levels respond more to crop yields with N fertilization than with higher N levels. Because of lower soil N level, sorghum grain yield and N uptake responded more positively to N fertilization in 2001 than cotton lint yield and lint N uptake in 2000 and 2002. Similarly, because of lower soil N level in April 2000 than in April 2002, slightly positive response with 0–60 kg N ha^{-1} in cotton lint yield and lint N uptake was observed in 2000 compared to negative response in 2002. To sustain cotton lint yield and lint N uptake, N fertilization rate needs to be increased from 0 to 60 kg N ha^{-1} following rye or no-till, but no N fertilization would be needed following vetch, vetch/rye, strip till or chisel till. Similarly, to sustain sorghum yield and N uptake, N fertilization rate of 130 kg N ha^{-1} would be needed following rye or weeds, but no N rate would be needed following vetch or vetch/rye.

Because of the variable response of cover crops and N fertilization rates in soil inorganic N and cotton and sorghum yields and N uptake, N fertilizer equivalence of cover crops in response to crop yields and N uptake can be calculated (Touchton et al., 1984; Hargrove, 1986; Sweeney and Moyer, 2004). Except for cotton lint yield and lint N uptake, sorghum grain yield, cotton and sorghum biomass yields, N uptake, and soil inorganic N increased linearly with N fertilization rate (Table 8). The N fertilizer equivalence of cover crops calculated from this relationship for cotton and sorghum yields and N uptake and soil inorganic N were positive for vetch and vetch/rye and mostly negative for rye and winter weeds. The positive values indicate similar response

Table 8
Nitrogen fertilizer equivalence (kg N ha^{-1}) of cover crops for soil inorganic (NH_4-N + NO_3-N) N content at the 0–30 cm depth in November 2000–2002, and cotton and sorghum yields and N uptake

Parameter	Cover crop				Regression analysis[a]	
	Winter weeds	Rye	Hairy vetch	Hairy vetch/rye	R^2	P
2000 cotton						
Lint yield	–	–	–	–	0.25	0.67
Lint N uptake	–	–	–	–	0.25	0.67
Biomass yield	−13	30	149	93	0.96	0.13
Biomass N uptake	−21	2	165	92	0.99	0.06
Soil inorganic N	−60	−190	220	140	0.64	0.40
2001 sorghum						
Grain yield	7	−64	107	179	0.96	0.12
Grain N uptake	25	−67	167	150	0.96	0.14
Biomass yield	32	−168	194	194	0.99	0.02
Biomass N uptake	69	−84	192	83	0.98	0.08
Soil inorganic N	59	12	116	71	0.86	0.25
2002 cotton						
Lint yield	–	–	–	–	0.28	0.82
Lint N uptake	–	–	–	–	0.24	0.87
Biomass yield	−21	−61	139	205	0.96	0.12
Biomass N uptake	−35	−13	134	160	0.97	0.11
Soil inorganic N	−74	5	176	160	0.70	0.37

[a] Regression analysis of N fertilization rates vs. cotton and sorghum yields and N uptake and soil inorganic N.

of cover crops and N fertilization to crop yields due to N mineralization from cover crops residues in the soil while negative values indicate opposite response due to N immobilization. The values shows that vetch and vetch/rye increased soil inorganic N similar to that increased by fertilizer N rates of 116–220 and 71–160 kg N ha^{-1}, respectively. The increase in sorghum grain yield, cotton and sorghum biomass yields, and N uptake with vetch and vetch/rye were similar to that increased by fertilizer N rates of 107–194 and 83–205 kg N ha^{-1}, respectively. The N fertilizer equivalence values of hairy vetch for cotton and sorghum yields and N uptake were similar to or greater than the reported values for cotton (67–101 kg N ha^{-1}) (Touchton et al., 1984; Brown et al., 1985) and for sorghum (41 to >135 kg N ha^{-1}) (Hargrove, 1986; Sweeney and Moyer, 2004). The variations in the values of N fertilizer equivalence of vetch and vetch/rye from 2000 to 2002 were probably resulted from differences in cover crop N accumulations and their rate of mineralization in the soil between years. The N fertilizer equivalence of cover crops may be somewhat overestimated because N fertilization rates did not exceed 130 kg N ha^{-1} and that the relationships between soil N accumulation or crop yield and N uptake with N fertilization rate may not be linear above the N rates used for cotton and sorghum in this experiment. Furthermore, N accumulation in the soil and response by cotton and sorghum may be partially masked by soil potential N mineralization (Sweeney and Moyer, 2004).

5. Conclusions

Results of this study showed that tillage, cover crops, and N fertilization rates influenced soil N availability and cotton and sorghum yields and N uptake due to variations in the amount of N returned to the soil by cover crop, cotton and sorghum residues, their rates of mineralization in the soil, and N supplied by variable N rates. Because of higher N supply, soil inorganic N, sorghum grain yield, cotton and sorghum biomass yields, and N uptake were higher with vetch and vetch/rye than with rye and weeds and higher with 120–130 than with 0 kg N ha^{-1}. In contrast, cotton lint yield and lint N uptake were higher with rye than with vetch and vetch/rye and higher with 0 and 60–65 than with 120–130 kg N ha^{-1}. Increased tillage intensity increased soil inorganic N and sorghum yield and N uptake but had variable effect on cotton yield and N uptake. Because of similar soil inorganic N, cotton and sorghum yields, and N uptake, hairy vetch and 130 kg N ha^{-1} can be replaced by hairy vetch/rye biculture to reduce the potential for N leaching and sustain cotton and sorghum yields. Conservation till, such as no-till and strip till, with hairy vetch/rye cover crop and 60–65 kg N ha^{-1} can be used to sustain cotton and sorghum yields, increase N-use efficiency, and reduce the potentials for soil erosion and N leaching compared with conventional till with no cover crop and 120–130 kg N ha^{-1}. These management practices can be applied to control soil erosion and reduce N leaching in the regions where cover crops can be grown in the winter and costs for energy requirement for tillage and N fertilization are a major concern.

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