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Corn-Soybean and Alternative Cropping Systems Effects on NO3-N Leaching Losses in Subsurface Drainage Water

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Abstract

Alternative cropping systems can improve resource use efficiency, increase corn grain yield, and help in reducing negative impacts on the environment. A 6-yr (1993 to 1998) field study was conducted at the Iowa State University's Northeastern Research Center near Nashua, Iowa, to evaluate the effects of non-traditional cropping systems [strip inter cropping (STR)-corn (Zea mays L.)/soybean (Glycine max L.)/oats (Avina sativa L.)]; alfalfa rotation (ROT)-3-yr (1993 to 1995) alfalfa (Medicago sativa L.) followed by corn in 1996, soybean in 1997, and oats in 1998), and traditional cropping system (corn after soybean (CS) and soybean after corn (SC) on the flow weighted average nitrate-nitrogen (NO3-N) concentrations and NO3-N leaching losses with subsurface drainage water. The soils at the research site are loamy with 3% to 4% organic matter and are underlain by subsurface drainage system. The data collected from four experimental treatments were analyzed as an unbalanced incomplete block design using F-test and T-test among treatments and within treatments, respectively. When averaged across 6-yr, non-traditional cropping systems reduced flow weighted average NO3-N concentrations in subsurface drain water with highly significantly effect ($P < 0.01$) in comparison with traditional cropping system (6.5 vs. 11.2 mg L-1). Similarly, the strip inter cropping system increased corn grain yields by 5% (9.03 vs. 8.6 Mg ha-1) and reduced NO3-N leaching losses by 6% (12.6 vs. 13.5 kg-N ha-1) and showed no difference in soybean yields when compared with traditional cropping system. Results of the study indicate that strip inter cropping and alfalfa rotation systems have the potential to reduce NO3-N leaching into the shallow groundwater system and possibly can become one of the better sustainable farming systems in Midwestern agriculture.

Keywords

Statistics, Strip cropping, Subsurface drainage, Nitrate leaching, Yield, Water quality

Disciplines

Agriculture | Bioresource and Agricultural Engineering | Biostatistics | Soil Science | Water Resource Management

Comments

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CORN–SOYBEAN AND ALTERNATIVE CROPPING SYSTEMS EFFECTS ON NO_3–N LEACHING LOSSES IN SUBSURFACE DRAINAGE WATER

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ABSTRACT. *Alternative cropping systems can improve resource use efficiency, increase corn grain yield, and help in reducing negative impacts on the environment. A 6-yr (1993 to 1998) field study was conducted at the Iowa State University's Northeastern Research Center near Nashua, Iowa, to evaluate the effects of non-traditional cropping systems [strip inter cropping (STR)-corn (*Zea mays *L.)/soybean (*Glycine max *L.)/oats (*Avina sativa *L.)]; alfalfa rotation (ROT)-3-yr (1993 to 1995) alfalfa (*Medicago sativa *L.) followed by corn in 1996, soybean in 1997, and oats in 1998), and traditional cropping system (corn after soybean (CS) and soybean after corn (SC) on the flow weighted average nitrate-nitrogen (NO_3-N) concentrations and NO_3-N leaching losses with subsurface drainage water. The soils at the research site are loamy with 3% to 4% organic matter and are underlain by subsurface drainage system. The data collected from four experimental treatments were analyzed as an unbalanced incomplete block design using F-test and T-test among treatments and within treatments, respectively. When averaged across 6-yr, non-traditional cropping systems reduced flow weighted average NO_3-N concentrations in subsurface drain water with highly significantly effect ($P < 0.01$) in comparison with traditional cropping system (6.5 vs. 11.2 mg L^{-1}). Similarly, the strip inter cropping system increased corn grain yields by 5% (9.03 vs. 8.6 Mg ha^{-1}) and reduced NO_3-N leaching losses by 6% (12.6 vs. 13.5 kg-N ha^{-1}) and showed no difference in soybean yields when compared with traditional cropping system. Results of the study indicate that strip inter cropping and alfalfa rotation systems have the potential to reduce NO_3-N leaching into the shallow groundwater system and possibly can become one of the better sustainable farming systems in Midwestern agriculture.*

Keywords. *Strip cropping, Subsurface drainage, Nitrate leaching, Yield, Water quality.*

Nonpoint source contamination of surface and groundwater bodies with nitrate-nitrogen (NO_3-N) has been linked to agricultural production systems in the Midwestern United States (Kanwar et al., 1999; Jaynes et al., 1999; Cambardella et al., 1999; Hatfield et al., 1998). Moreover, the increased spread and severity of the hypoxia zone within the Gulf of Mexico has been attributed to the accelerated NO_3-N loading to the Mississippi River (Rabalais et al., 1999). Elevated NO_3-N concentrations in the Mississippi River have been associated with the extensive drainage system in the upper Mississippi River Basin (Randall et al., 2000; Randall and Mulla, 2001). More than 30% of the croplands in the Midwest need subsurface drainage to maintain the productivity of these poorly drained soils. The subsurface drainage system not only removes the excess water from the root zone but also transports NO_3-N from the root zone to the edge of the field (Tan et al., 2002; Hatfield et al., 1998; Drury et al., 1993). Many studies have reported increased NO_3-N concentrations in subsurface drainage water from the fields receiving typical nitrogen application rates (Baker and Johnson, 1981; Kanwar et al., 1988, 1997, 1999). In this context, the management of nitrogen application to plants is important to reduce the NO_3-N leaching losses with subsurface drainage water (Bakhsh et al., 2000a).

The management of nitrogen using intercropping practice is another approach to reduce NO_3-N leaching into the subsurface drainage water. The intercropping practice has been reported to improve resource use efficiency, increase crop yield, and reduce the negative effects on the environment (Exner et al., 1999; Pederson et al., 1999; Fortin et al., 1994). Intercropping is a type of farming practice in which two or more crops are grown simultaneously on the same field. Strip inter cropping is the production of more than one crop simultaneously on the same field in different strips that are narrow enough for the crops to interact and wide enough to permit independent cultivation of different crops (Wigham, 1985). Narrow strips of crops compatible with the farm machinery can improve crop yield and biological efficiency with no additional out-of-pocket cost, though more time and management may be required of farmers (Exner et al., 1999; Smith and Carter, 1998).

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Research on strip inter cropping systems in the Midwest has included corn or sorghum (*Sorghum bicolor* (L.) *Moench*) C_4 species that readily respond to higher light intensities (Crookston and Hill, 1979). The taller C_4 crop more efficiently utilizes intense sunlight in border positions, while C_3 crop carbon exchange rate under partial shading remains high relative to that of C_4 crops (Ghaffarzadeh et al., 1997). Soybean strips also will be sheltered by taller crop strips, serving as wind barriers to improve water use efficiency and canopy temperature of the soybean (Radke and Hagstrom, 1976). Another approach to strip cropping, practiced by some farmers in the upper Midwest (Cramer, 1991; Mangold, 1992; Tonneson and Houtsma, 1991; Walter, 1991), introduced a small grain crop such as oats or wheat (*Triticum aestivum* L.) into the traditional two-crop system. Including a small grain crop between corn and soybean can reduce the negative border effects on adjacent soybean rows without sacrificing small grain yields (Iragavarapu and Randall, 1996). The spatial diversity of the system may also be improved by including a crop, such as oats, with a different life cycle. Including an oat crop in the rotation adds temporal diversity that improves corn and soybean grain yields (Ghaffarzadeh et al., 1997; Crookston et al., 1991).

The strip inter cropping system has been reported to increase corn grain yields. Francis et al. (1986) reported that corn grain yields were 10% to 40% higher and soybean yields were 10% to 30% lower than yields in mono crops fields in the Eastern and Midwestern parts of the United States. Alexander and Genter (1962), studying corn and soybean in alternate pairs of rows in Indiana, found that corn yields were 30% higher than corn planted alone, while soybean yields were similar in both methods. Lesser soybean yields, when they occur, have been attributed to competition between corn and soybean for water, light, and nutrients due to similarities in growth habits of the crops (Crookston and Hill, 1979). All the above mentioned research studies have reported the effects of strip cropping on the corn and soybean yields but no such study has been conducted to evaluate the effects of strip cropping systems on the leaching of NO_3-N to subsurface drainage water.

It was hypothesized that a strip inter cropping system will increase corn grain yields through more resource use efficiency and thus will reduce the NO_3-N leaching losses with subsurface drainage water. The objective of this study was to evaluate the effects of two alternative cropping systems [strip inter cropping configuration that included corn, soybean, and oats followed by an N-fixing berseem clover (*Trifolium alexandrinum*) crop and a 3-yr rotation of alfalfa followed by corn, soybean, and oats] and one traditional (corn-soybean rotation system with preplant single N-application to corn) on the leaching losses of NO_3-N in subsurface drainage water.

MATERIALS AND METHODS

Field experiments were conducted at Iowa State University's Northeastern Research Center near Nashua, Iowa. The soils at the site include Floyd loam (fine-loamy, mixed, mesic Aquic Hapludolls), Kenyon loam (fine-loamy, mixed, mesic Typic Hapludolls), and Readlyn loam (fine-loamy, mixed, mesic Aquic Hapludolls) with 3% to 4% organic matter (Kanwar et al., 1997). These soils have a seasonally high water table and benefit from a subsurface drainage system. Subsurface drains at this site were installed in 1979 at 1.2-m depth and with 28.5-m spacing.

The site has 36, 0.4-ha plots (58.5 × 67 m) with fully documented tillage and cropping records for the past 22 years. In addition to these 36 plots, which were under traditional farming practices (corn-soybean rotation), four other plots were established in two blocks at the same site (each plot of about 1 ha in size) for conducting research on alternative or non-traditional farming practices [strip inter cropping (STR)-corn/soybean/oats interseeded with berseem clover and rotation (ROT)-consecutively grown alfalfa for three years followed by corn, soybean, and oats]. For the STR treatment, a complete set of crop strips (fig. 1) comprised one of the two alternative system treatments and therefore resided in one plot in each of the two blocks. These strips were rotated each year so that strips under corn in the previous year produced soybean in the following year and similarly strips under soybean in the previous year produced oats in the following year. An oat crop interseeded with alfalfa (forage) was grown on all four plots in 1993, first year of the experiment. The ROT treatment, also replicated two times, included a forage crop grown for three years (1993, 1994, 1995) and followed by corn in 1996, soybean in 1997, and oats in 1998. The strips of corn/soybean/oats (from east to west) were 4.56 m wide and 140 m long having six rows of corn and soybean with a row spacing of 0.76 m and oats with a row spacing of 0.19 m (fig. 1). The same varieties of corn (Golden Harvest 2343[1]) and soybean (Sands of Iowa 237[1]) were grown in these plots during the study period (Bakhsh et al., 2000b). Traditional cropping system treatments were

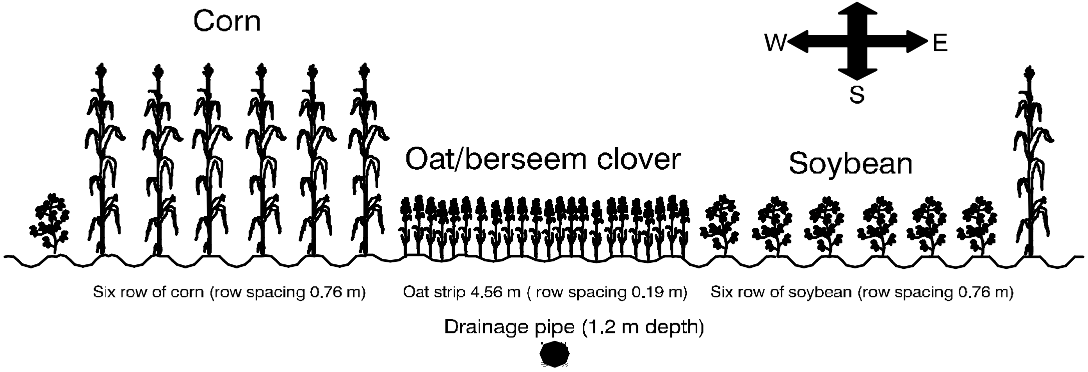
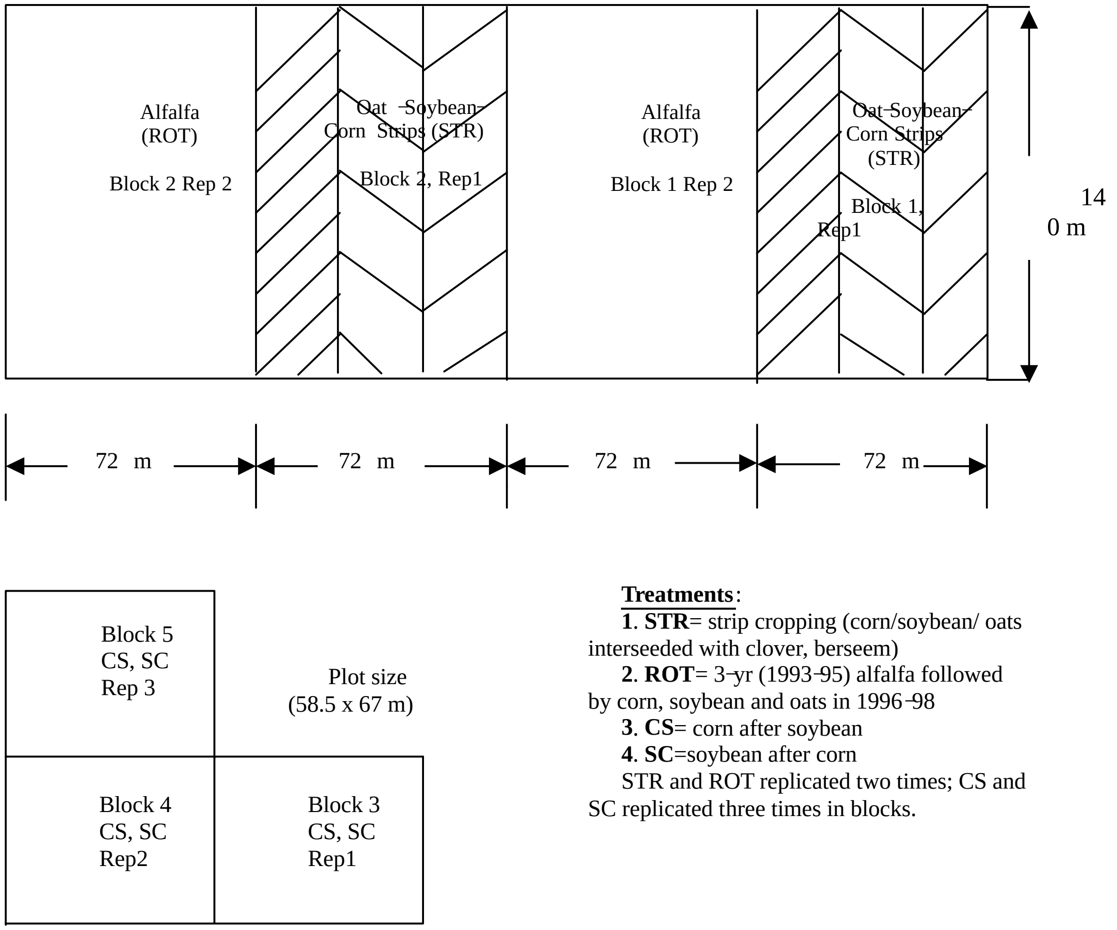


Figure 1. Schematic diagram of strip inter cropping, showing strip direction, crop orientation, row spacing, and location of drainage pipe.



Treatments:

1. **STR**= strip cropping (corn/soybean/ oats interseeded with clover, berseem)

2. **ROT**= 3-yr (1993-95) alfalfa followed by corn, soybean and oats in 1996-98

3. **CS**= corn after soybean

4. **SC**=soybean after corn

STR and ROT replicated two times; CS and SC replicated three times in blocks.

Figure 2. Experimental layout showing blocks, replications, and treatments.

corn after soybean (CS) and soybean after corn (SC), each replicated three times. Six plots out of 36 in three blocks (fig. 2) for CS and SC treatments were selected for comparison purposes with STR and ROT treatments data on subsurface drainage, flow weighted average NO_3-N concentrations, NO_3-N leaching loss with subsurface drainage water, and the corn-soybean yields.

Each plot at the site has an independent drainage sump with flow meter for recording subsurface drain flows and collecting water samples for NO_3-N analysis. Drainage water sampling frequency averaged three times a week if subsurface drains were flowing. Subsurface drainage water samples were collected and refrigerated at 4°C until NO_3-N analyses were made at the National Soil Tilth Laboratory in Ames, Iowa. A complete detail of the automated subsurface drainage system installed at this site can be found in Kanwar et al. (1999). The annual subsurface drainage flow volume, NO_3-N loss with subsurface drainage water and the flow weighted average annual NO_3-N concentrations (FWANC) from each plot were computed for analysis. The FWANC (mg L^{-1}) were calculated by dividing the cumulative NO_3-N leaching loss (kg-N ha^{-1}) by the drainage effluents (cm) for that period and multiplying by 10 (conversion factor).

The average N fertilizer application rate applied to corn under STR treatment was 95 kg-N ha^{-1} and no N fertilizer was applied to soybean and oat strips (tables 1 and 2). The amount of N-applied to STR treatment varied from zero in 1994 to 185 kg-N ha^{-1} in 1996. The late spring urea ammonium nitrate solution fertilizer (UAN) application rates to STR were determined based on the late spring NO_3-N test (LSNT), developed for Iowa soils (Blackmer et al., 1989), in addition to 30 kg N ha^{-1} applied with the corn planter. Based on LSNT, UAN was injected to increase the soil NO_3-N concentrations in the top 300 mm of the soil profile to

Table 1. Schedule of cropping activities at the study site at the Northeast Research Center, Nashua, Iowa.

Field Operations	1993	1994	1995	1996	1997	1998
Preplant fertilizer application	14 May	24 April	12 May	3 May	12 May	1 May
Corn planting	17 May	2 May	16 May	21 May	12 May	5 May
Soybean planting	26 May	17 May	22 May	30 May	16 May	18 May
Sidedress fertilizer application (LSNT)	7 July	17 June	22 June	24 June	19 June	15 June
Cultivation (corn plots)	21 July	2 June	14 June	24 June	19 June	4 June
Approx. corn maturity	1 September	2 September	7 September	5 October	30 September	10 September
Corn harvest	25 October	28 September	22 September	21 October	10 October	22 September
Soybean harvest	7 October	6 October	11 October	8 October	2 October	1 October
Primary tillage (chisel plow)	20 November	15 November	20 November	17 November	12 November	17 November

Table 2. Nitrogen application rates (kg-N ha^{-1}) for various cropping systems from 1993 to 1998 at the study site.

Application Rates	1993	1994	1995	1996	1997	1998	Average
Strip (STR)[a]	0	0	98	185	157	131	95
Single (CS)	110	110	110	110	110	110	110

[a] LSNT= late spring nitrate fertilizer application rates (kg N ha^{-1}) for corn under STR treatment, includes 30 kg N ha^{-1} applied with planter.
CS = single pre plant N applied to corn plots only in corn after soybean rotation plots under traditional (CS & SC) treatments.
No fertilizer was applied to ROT treatment plots (fig. 2).

25 mg kg^{-1}. The traditional CS treatment received single preplant N-application at the rate of 110 kg N ha^{-1} and fall chisel plowing was conducted after corn harvest (table 2). Corn was planted into a seedbed prepared by fall chiseling and spring field cultivation. Soybean was drilled directly into corn stover from the previous year, and no fertilizer was applied. A single UAN application of 110 kg N ha^{-1} occurred before planting with a spoke injector (Baker et al., 1989), which injected UAN at about a 200-mm depth. Corn and soybean yields were measured from each plot using a modified commercial combine.

The study consisted of four treatments conducted over a 6-yr period (1993 to 1998): (1) ROT (alfalfa for three years followed by corn, soybean, and oats in the following three years); (2) STR (corn/soybean/oats strips); (3) CS (corn after soybean); (4) SC (soybean after corn). The data were analyzed as an unbalanced incomplete block design (figs. 1 and 2). The PROC MIXED procedure of SAS was used to analyze the data collected from a total of 10 plots. The F-test was used to test the treatment effects and T-test was used to test the difference between treatment means on subsurface drainage, NO_3-N leaching loss, and the flow weighted average NO_3-N concentrations in subsurface drainage water. The statistical analyses were conducted separately for corn and soybean yield data.

RESULTS AND DISCUSSION

RAINFALL PATTERN AND SUBSURFACE DRAIN FLOWS

The differences in the amount of rainfall over the study period of six years (1993-1998) provided a highly diverse environment for evaluating the effects of these alternative-cropping systems on NO_3-N leaching losses in subsurface drainage water. The analysis of data showed that subsurface drainage, flow weighted average NO_3-N concentrations in subsurface drainage water, and NO_3-N leaching losses changed from year to year. This was due to changing rainfall patterns, which also affected the subsurface drainage flow volume from year to year. The growing season (March through November) rainfall varied from a low of 680 mm in 1996 to a high of 1030 mm in 1993 (fig. 3). A significant ($P < 0.05$) correlation ($R^2 = 0.88$) between annual subsurface drainage flow volume and growing season rainfall during the 6-yr period was found for the study area (fig. 4). The year 1993 was extremely wet, with rainfall 23% greater than the 30-yr average annual rainfall of 840 mm (Voy, 1995). All other years, except one, had rainfall amounts lower than the 30-yr average. There was 750 mm of rainfall for 1994, 800 mm for 1995, and 750 mm for 1997. In 1998 there was 980 mm of rainfall, which was 17% greater than the 30-yr

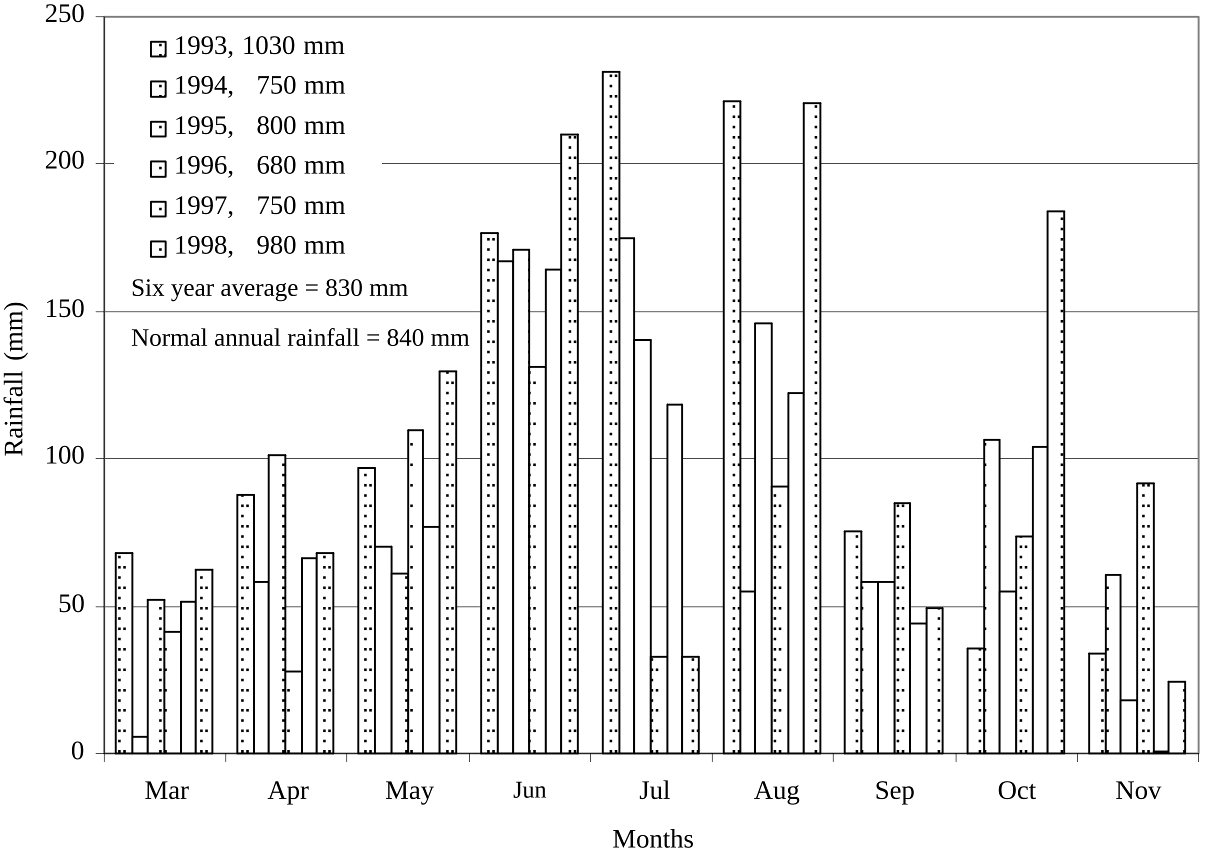


Figure 3. Monthly rainfall for the growing seasons (March through November) from 1993 through 1998.

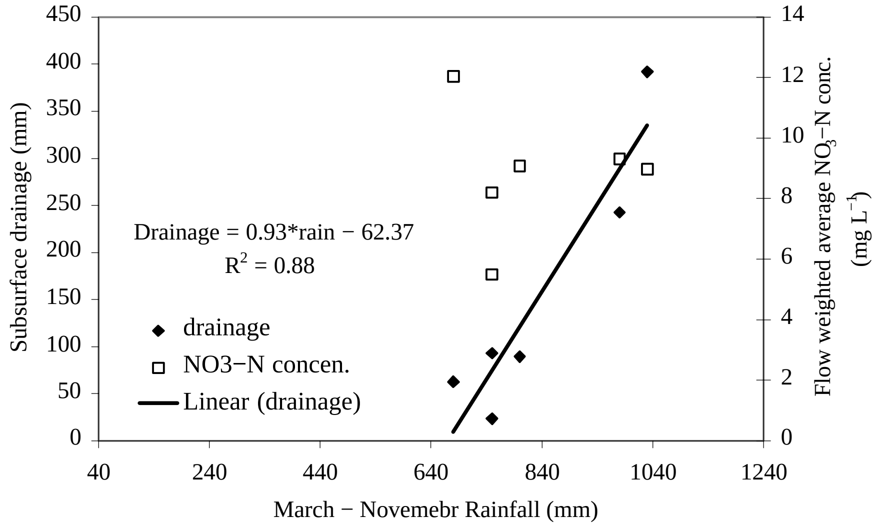


Figure 4. Relationship between rainfall, annual subsurface drainage, and flow weighted average NO_3-N concentrations in subsurface drainage water when averaged across cropping systems.

average. The 6-yr average subsurface drainage flow for this experiment showed that about 18% of the average growing season rainfall (832 mm) exited the system as subsurface drainage flow (150 mm) (table 3).

The subsurface drainage flows, averaged across systems, also varied considerably over years and ranged from a low of 23 mm in 1994 to a high of 392 mm in 1993 (table 3). The STR and ROT treatments generally resulted in greater drainage volumes in comparison with CS and SC treatments in the wet year of 1993 and lower drainage volume in dry year of 1994 probably due to their temporal diversity and the associated effects on evapotranspiration for both the systems. Overall, the non-traditional treatments (ROT and STR), however, resulted in significantly ($P < 0.01$) greater drainage by 46% (178 vs. 122 mm) (table 4) when compared with traditional treatments (CS and SC). This difference can be attributed to the fact that ROT and STR treatments might have produced deeper roots, and macropores with greater biomass, which accelerated the percolation in comparison to corn-soybean rotation system (Tan et al., 2002).

NO_3-N LEACHING LOSSES WITH SUBSURFACE DRAINAGE WATER

Growing season rainfall during the study period significantly ($P < 0.05$) affected annual NO_3-N leaching losses in subsurface drainage water. The nitrate leaching losses, averaged across systems, varied considerably among years and ranged from a low of 1.6 kg N ha^{-1} in 1994 to a high of 33.5 kg N ha^{-1} in 1993 (table 3). The NO_3-N leaching losses were mainly governed by the amount of subsurface drainage

Table 3. Cropping system effects on subsurface drainage data.

	Years[a]						Average
Systems[b]	1993	1994	1995	1996	1997	1998	(1993-1998)
	Average subsurface drainage (mm)						
CS	352a	29b	67b	49b	50b	187a	122a
SC	283a	56a	95ab	38b	55b	206a	122a
ROT	478a	3c	59b	83a	161a	291a	179a
STR	453a	6c	137a	81a	105b	286a	178a
Average	392	23	89	63	93	243	150
$LSD_{(0.05)}$	208	23	69	24	55	152	74
	Flow weighted average NO_3−N concentrations (mg L^{-1})						
CS	9.3ab	9.3a	15.5a	13.0ab	12.4a	12.7a	12.0a
SC	11.5a	6.1b	10.9b	15.1a	6.8b	11.9a	10.4b
ROT	7.1b	4.9bc	1.9c	12.1ab	6.3b	6.1b	6.4c
STR	8.0b	1.6c	8.1b	8.0b	7.3b	6.6b	6.6c
Average	8.9	5.5	9.1	12.0	8.2	9.3	8.9
$LSD_{(0.05)}$	3.4	3.1	4.5	6.4	3.8	3.3	1.5
	Average NO_3−N drainage loss (kg−N ha^{-1})						
CS	32.8a	2.7a	10.5a	6.3b	6.3b	23.6a	13.7a
SC	32.3a	3.4a	10.2a	5.7b	3.7c	24.5a	13.3a
ROT	32.8a	0.1b	0.9b	9.8a	9.9a	17.5a	11.8a
STR	36.2a	0.2b	11.2a	6.3b	7.5b	18.3a	13.3a
Average	33.5	1.6	8.2	7.0	6.8	20.9	13.0
$LSD_{(0.05)}$	12.0	1.5	6.9	2.7	1.5	9.9	4.8

[a] Treatment means followed by different letters are significantly ($P < 0.05$) different.

[b] CS = corn after soybean; SC = soybean after corn; ROT = rotation; STR = strip cropping.

Table 4. Traditional vs. non−traditional treatment means comparison.

Systems[a]	Years 1993	1994	1995	1996	1997	1998	Average (1993−98)
	Average subsurface drainage (mm)						
Non−traditional	466	4	98	82	133	288	178
Traditional	317	43	81	43	53	196	122
Difference	149	−39	17	38	80	92	56
P−value	<0.05	<0.01	>0.10	<0.01	<0.01	>0.10	<0.01
	Flow weighted average NO_3−N concentrations (mg/L)						
Non−traditional	7.6	3.3	4.9	10.0	6.8	6.3	6.5
Traditional	10.4	7.8	13.2	14.0	9.6	12.3	11.2
Difference	−2.8	−4.5	−8.2	−4.0	−2.8	−6.0	−4.7
P−value	<0.05	<0.05	<0.05	<0.10	>0.10	<0.01	<0.01
	Average NO_3−N leaching loss (kg/ha)						
Non−traditional	34.5	0.2	6.0	8.1	8.7	17.9	12.6
Traditional	32.5	3.1	10.4	6.0	4.9	24.1	13.5
Difference	2.0	−2.9	−4.3	2.0	3.8	−6.2	−0.9
P−value	>0.10	<0.01	>0.10	<0.10	<0.05	<0.10	>0.10

[a] Non−traditional = strip cropping and rotation; Traditional = corn after soybean and soybean after corn; P−value = Probability value.

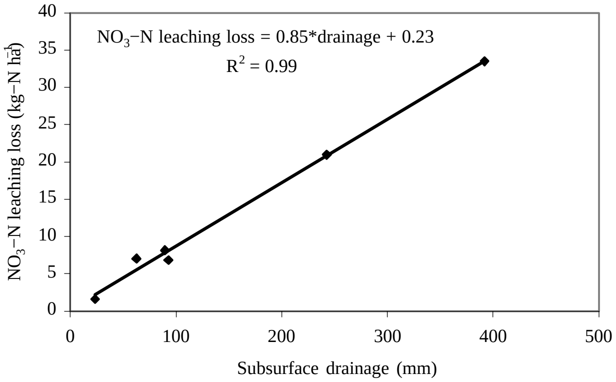


Figure 5. Relationship between annual subsurface drainage and annual NO_3−N leaching losses in subsurface drainage water, averaged across all cropping systems.

volumes. A strong linear relationship (fig. 5) was observed between NO_3-N leaching loss and the seasonal drainage effluents ($R^2 = 0.99$). Treatment effects on NO_3-N leaching losses also varied from year to year (table 3).

An oat crop interseeded with alfalfa (forage) was established in 1993 (wet year) on all four plots of the non-traditional cropping systems, i.e. strip (STR) and rotation (ROT). In 1996 and 1997, the ROT treatment resulted in the greatest NO_3-N leaching loss compared to the rest of the treatments (table 3), which could be largely due to greater drainage effluents under this treatment during these two years and due to the release of fixed atmospheric N through decay of the alfalfa roots (Tan et al., 2002). This treatment had alfalfa grown for three consecutive years (1993-95) and no N-fertilizer was applied to corn in 1996 and soybeans in 1997. Also, this shows the complex interactions among climatic effects on drainage effluents and N-mineralization rates through root decay on the NO_3-N leaching loss with subsurface drainage water.

The treatments effects on NO_3-N leaching losses were found to be significant ($P < 0.05$) in 1994, dry year. The non-traditional (STR and ROT) treatments resulted in 6% (0.2 vs. 3.1 kg N ha^{-1}) as much NO_3-N leaching loss as the traditional systems in 1994 (table 4). The non-traditional treatments, however, showed less NO_3-N leaching losses in comparison with the traditional treatment (6.0 vs. 10.4 kg N ha^{-1}) in 1995 (table 4). In 1996 and 1997, traditional treatments showed lower NO_3-N leaching losses probably because of their significantly ($P < 0.05$) lower drainage volumes for these years (table 4). In 1998, non-traditional treatment resulted in 74% (17.9 vs. 24.1 kg N ha^{-1}) as much NO_3-N leaching loss as the traditional treatments, which was significant at the 10% probability level.

When averaged across six years, the non-traditional treatments showed 94% of the NO_3-N leaching loss observed under traditional treatments (12.6 vs. 13.5 kg N ha^{-1}), and these differences were not significantly different (table 4). Although there could be effects of the crops on the NO_3-N leaching losses, these effects seem to be suppressed with seasonal drainage effects due to rainfall variability and significant season effects. The flow weighted average NO_3-N concentrations, however, have been reported to be a better indicator to assess the NO_3-N loadings particularly if the stream is joining the reservoir or lake that serves as a drinking water source (Jaynes et al., 1999).

Flow Weighted Average NO_3-N Concentrations

The analysis of variance showed significant ($P < 0.05$) effects of cropping systems on the flow weighted average NO_3-N concentrations (FWANC) in subsurface drainage water. These effects varied from year to year probably because of the changing weather conditions (fig. 6). The FWANC values for non-traditional cropping systems were lower with high significance level ($P < 0.01$) than for traditional cropping system when averaged over years (table 4). The FWANC values, however, were also affected by the rainfall variability. The year with the lowest rainfall (680 mm in 1996) showed the maximum FWANC value of 14 mg/L for the traditional system. The non-traditional cropping systems always showed lower FWANC values than the traditional cropping systems and clear differences in FWANC were observed between the two systems throughout the study period (fig. 6). The FWANC values varied from a low of 4.9 mg L^{-1} in 1995 to a high of 10.0 mg L^{-1} in 1996 under the non-traditional cropping system, whereas the traditional cropping system showed values that ranged from 7.8 mg L-^{1} in 1994 to a high of 14.0 mg L^{-1} in 1996. The variation in FWANC values from year to year can be attributed partly to the dilution effects resulting from variable drainage effluents and the residual effects from the previous crop, especially the root decay of the alfalfa. When averaged across 6 years, non-traditional cropping system showed significantly ($P < 0.01$) lower FWANC values compared to

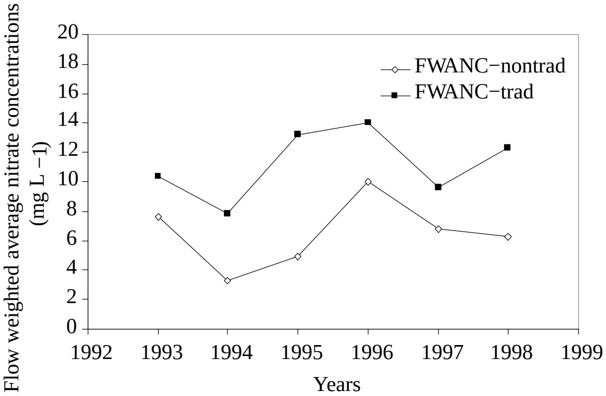


Figure 6. Flow weighted average NO_3−N concentrations in subsurface drainage water for non−traditional and traditional cropping systems throughout the study period.

the traditional cropping system by 42% (table 4). On average, the strip inter cropping system showed FWANC values less than 7 mg/L, which is well below the drinking water standard of 10 mg/L. This shows that the strip inter cropping system has the potential to reduce the NO_3-N contamination of surface and groundwater bodies.

CORN-SOYBEAN YIELDS

The cropping system effect on corn and soybean yields varied from year to year. The strip inter cropping system showed greater corn grain yields for all years except 1995 when a hail storm severely damaged the crops (Bjorneberg et al., 1998). The corn grain yield varied from year to year as seasonal effects on yield were found to be highly significant ($P < 0.01$). The year-to-year yield variability can be attributed partly to the changing weather conditions and its associated effects on the drainage effluents, as well as on the N-mineralization rates in soils, especially from root decay of alfalfa and soybean crops (Tan et al., 2002; Bakhsh et al., 2001). When averaged over 6 years, strip cropping gave significantly ($P < 0.05$) 5% greater yield (9.03 vs. 8.58 Mg ha^{-1}) in comparison with corn after soybean cropping system (table 5). This analysis shows that strip inter cropping system has the potential to increase corn grain yields in comparison with the corn-soybean rotation system. The strip inter cropping system resulted in soybean yields (3.80 vs. 3.76 Mg ha^{-1}) similar to the traditional system.

Table 5. Crop yield comparison.

Systems[a]	Years				Average (1993−98)
	1995	1996	1997	1998	
	Corn yield (Mg/ha)				
CS	6.02	8.81	9.76	9.73	8.58
STR	4.39	9.34	11.28	11.09	9.03
Difference	1.64	−0.53	−1.51	−1.36	−0.44
P−value	>0.10	<0.10	<0.10	>0.10	<0.05
	Soybean yield (Mg/ha)				
SC	3.25	4.14	3.64	4.03	3.76
STR	2.82	3.89	4.17	4.32	3.80
Difference	0.43	0.25	−0.53	−0.29	−0.04
P−value	<0.10	<0.05	>0.10	>0.10	>0.10

[a] CS = corn after soybean.
STR = strip cropping.
P−value = Probability value.

CONCLUSIONS

Field experiments were conducted at the Iowa State University's Northeastern Research Center near Nashua, Iowa, to evaluate the effects of non-traditional cropping systems (strip inter cropping-corn/soybean/oats; rotation 3-yr alfalfa followed by corn, soybean, and oats) and traditional cropping systems (corn after soybean and soybean after corn) on the flow weighted average NO_3-N concentrations and NO_3-N leaching losses with subsurface drainage water. Results from this 6-yr study indicate that the non-traditional cropping system reduced the flow weighted average NO_3-N concentrations in subsurface drainage water with high significance level ($P < 0.01$) in comparison with traditional cropping system (6.5 vs. 11.2 mg L^{-1}). This study also showed that non-traditional cropping system decreased NO_3-N leaching losses to subsurface drain water and increased corn grain yields by 5% (9.03 vs. 8.58 Mg ha^{-1}). The results of the study support the hypothesis that the strip inter cropping system can be an environmentally sustainable farming practice in Midwestern parts of the United States when compared with corn after soybean cropping system.

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