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# Conservation of Residual Nitrate Nitrogen with Winter Cover Crops

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*ABSTRACT. Non–legume winter cover crops effectively scavenge residual soil N between major cropping cycles. Their high C:N ratio often prevents tissue–incorporated N from becoming available in spring, thereby potentially increasing early season fertilizer requirements for summer crops. Field trials were conducted at Hermiston in North central Oregon, USA to investigate the effectiveness of various winter cover crops in recycling residual nitrate nitrogen ($NO_3$-N) following cultivation of potato (Solanum tuberosum L.). Six cover crops namely, winter wheat (Triticum aestivum L. cv. Stephens), winter barley (Hordeum vulgare L. cv. Hesk), spring barley (Hordeum vulgare L. cv. Steptoe), cereal rye (Secale cereal L. cv. Wheeler), triticale (*X *triticosecale Wittm. cv. Whitman), and rape (Brassica napus L. cv. Humus) were compared against a winter fallow check in 1992–1993 and 1993–1994 following potato.*

*Cover crops conserved substantial amounts of residual $NO_3$-N primarily through N uptake. However, they did not decompose and release conserved N concurrently. Thus, immobilization was evident in the following season. Effects of cover crops on $NO_3$-N content of soil in early spring depended on climatic conditions. After a wet, cold winter followed by a decomposition period, $NO_3$-N levels increased relative to the fallow in spring barley incorporated plots. Accordingly, soils incorporated with spring barley had 93 kg of $NO_3$-N $ha^{-1}$ and fallow plots had 49 kg of $NO_3$-N $ha^{-1}$ in the 0–0.6 m depth. After a dry mild winter followed by a decomposition period, plots incorporated with cereal rye had 9 kg of $NO_3$-N $ha^{-1}$ and fallow plots had 45 kg of $NO_3$-N $ha^{-1}$ in the 0–0.6 m zone. Thus, N immobilization was evident in rye incorporated plots. However, N accumulation in rye exceeded the predicted nitrogen losses. Thus, rye may be able to reduce $NO_3$-N leaching, but immobilization is a limiting factor.*

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## INTRODUCTION

Management of nutrient cycling has gained importance as winter cover cropping becomes more widely used for reduction of $NO_3$-N leaching (Hargrove, 1986; Meisinger *et al.*, 1991). It is possible to trap residual N from the previous season by using some winter cover crops and recycling it for growing crops during the following season (Evanylo, 1991). However, immobilization of residual nitrogen due to high C:N ratios often delays decomposition and release of N to the following crop. This would enhance early-season fertilizer N requirements (Hargrove, 1986; Tyler *et al.*, 1987; Holderbaum *et al.*, 1990).

Little information is available on the effectiveness of winter cover crops in recovering residual $NO_3$-N and its subsequent release to spring crops in the Columbia Basin of the U.S.A. Thus, this study was carried out at the Hermiston Agricultural Research and Extension Center (HAREC) of the Oregon State University, U.S.A., to evaluate the effectiveness of fall-planted non-legume cover crops in recycling residual $NO_3$-N to the succeeding crop.

## MATERIALS AND METHODS

### Field plots

Experiments were conducted from September, 1992 to May, 1993 (first season) and September, 1993 to April, 1994 (second season) at HAREC in the lower Columbia Basin of the U.S.A. Trials were established under a centre pivot irrigation system on Adkins fine sandy loam (coarse-loamy, mixed mesic Xerollic Camborthid). Potato *(Solanum tuberosum* L. *cv.* Russet Burbank) was grown in an open field in both years and cover crop plots were prepared soon after harvesting potato. Thus, in each season the potato crop preceded the winter cover crops. The recommended rate of nitrogen for potato totaling 392 kg $ha^{-1}$ was applied and crop was grown under irrigation.

Six cover crop species namely, winter wheat *(Triticum aestivum L. cv.* Stephens*),* winter barley (*Hordeum vulgare* L. *cv.* Hesk), spring barley (*Hordeum vulgare* L. *cv.* Steptoe), cereal rye (*Secale cereal* L. *cv.* Wheeler), triticale (X *triticosecale* Wittm. *cv.* Whitman), and rape (Brassica napus L. *cv.* Humus) were compared against a fallow check. Plot size was 3 m × 10.2 m, and seeds were sown in rows 25 cm apart. Cover crops were not fertilized. These seven treatments were arranged in a randomized complete block design with four replicates.

Supplementary irrigation was provided for the cover crop to simulate an average high rainfall season based on long term values (1961–1990), but irrigation was not continued beyond November due to freezing winter temperatures in both seasons.

### Soil and plant sampling

Soil $NO_3$-N concentration was measured in 0.3 m increments to a depth of 0.6 m in both seasons. Soil was sampled from each plot soon after harvesting of potato. Cover crops were planted on the same day (18 September, 1992 and 20 September, 1993). The second set of soil samples were taken from each plot one month after cover crop incorporation (7 May, 1993 and 9 April, 1994). Plant samples for dry matter and nitrogen determinations were taken from a 0.5 $m^2$ area in the centre of each plot in March.

### Soil analysis

The KCl extraction method outlined by Keeney and Nelson (1982) with a modification outlined by Horneck *et al.* (1989) was used for determining $NO_3$-N. In this method, 75 ml of KCl and 20 g of soil were used instead of 100 ml KCl and 10 g soil. Ammonium and organic–N contents were also analysed in the initial soil samples using the KCl extraction method and micro Kjeldahl procedure, respectively.

### Plant total nitrogen

Micro Kjeldahl procedure was followed for digestion of the plant samples (Bremner and Mulvaney, 1982). The $NH_4$-N content in the digest was determined with an ALPKEM rapid flow analyzer which relies on ammonium to complex with salicylate to form indophenol blue.

### Statistical analyses

Soil nitrate and total plant nitrogen data were analysed by using ANOVA and orthogonal contrasts of interest were determined using the general linear model procedure of SAS (SAS, 1991).

## RESULTS AND DISCUSSION

Cover crops were soil-incorporated on 5 April, 1993 and on 15 March, 1994. Cover crop incorporation in the first season was delayed due to wet weather. When nitrate data from both seasons were combined, cover crop × season interactions were statistically significant. Therefore, data for the two seasons were not combined.

### Weather conditions

The 1992–1993 experimental plots received 307 mm of water (irrigation plus precipitation) between planting of the cover crops and final soil sampling. Long term mean precipitation was 180 mm, and the long term maximum was 522 mm for the experimental period. In 1993–1994, plots received 150 mm of water. Long term mean and maximum precipitation levels for this period were 162 mm and 454 mm, respectively.

### Soil nitrate nitrogen

After the potato harvest, most of the nitrogen in the 0–0.6 m soil layer occurred in the organic form; $NO_3$-N was the primary form of inorganic nitrogen available for immediate plant uptake (Table 1). Residual $NO_3$-N concentration in the 0–0.6 m layer was higher in 1992 than in 1993 ($P<0.0001$). It was 160 kg $ha^{-1}$ $NO_3$-N in September, 1992 and 62 kg $ha^{-1}$ $NO_3$-N in September, 1993. These amounts represent only 4.6 and 1.9 % of the total nitrogen pool, respectively. Nitrate leaching is a concern in the Columbia Basin (McMorran, 1994). However, the results of the present study show that residual $NO_3$-N represents a very small fraction of the total nitrogen pool in the root zone (0–0.6 m) (Pumphrey and Rusmussen, 1983). Further, $NO_3$-N is concentrated in the top 30 cm and varies with the season (Table 1).

Due to N uptake by cover crops and the leaching that occurred during September, 1992 to May, 1993. The amounts of $NO_3$-N decreased in the 0–0.3 m zone in all treatments ($P< 0.01$), but no differences were evident among treatments (Table 2).

From September, 1993 to April, 1994, soil $NO_3$-N in all treatments were reduced in the 0–0.3 m zone. Due to the early decomposition, this reduction was not significant in plots incorporated with spring barley ($P=0.09$) (Table 2). Due to the N immobilization by rye, in April, 1994 soil

$NO_3$-N was lower in plots incorporated with rye than in spring barley, rape, and fallow plots (Meisinger *et al.*, 1991).

**Table 1.** **Nitrogen concentrations in the soil profile between 0–0.6 m after harvesting of potato in September.**

| | 18 September, 1992 | | | 20 September, 1993 | | |
|---|---|---|---|---|---|---|
| Depth, m. | +Nit. | Ammo. | O.N | Nit. | Ammo. | O.N |
| | mg N $kg^{-1}$ | | | mg N $kg^{-1}$ | | |
| 0-0.3 | 31.0 | 5.0 | 508 | 12.0 | 3.0 | 467 |
| 0.3-0.6 | 6.0 | 3.0 | 246 | 2.0 | 2.0 | 237 |
| % | 4.6 | 1.0 | 94 | 1.9 | 0.7 | 97 |

The amount of $NO_3$-N in kg $ha^{-1}$ for these soils can be calculated by multiplying the $NO_3$-N (ppm) concentration by a conversion factor of 4.48 (Schepers and Mosier, 1991; McMorran, 1994). +Nit. - Nitrate-N, Ammo.- Ammonium-N, O.N - Organic-N.

All treatments showed a decrease of soil $NO_3$-N between 0.3–0.6 m zone during September, 1992 and May, 1993. However, this was not statistically significant ($P>0.05$) in fallow, and spring barley and triticale incorporated soils (Table 3). Nitrate–N concentrations in May, 1993 differed among treatments. Due to leaching from the 0–0.3 m zone, fallow plots had more $NO_3$-N than plots incorporated with rape, but the rye incorporated plots had less $NO_3$-N than the other cereals due to the greater immobilization (Meisinger *et al.*, 1991).

By the end of the 1993–1994 season, $NO_3$-N concentrations in the soil between 0.3-0.6 m depth had increased in fallow and rape incorporated plots ($P<0.03$). This is mainly due to that rape showed a poor growth and conserved less N in the second season. In April, 1994, cereals had lower $NO_3$-N concentrations than fallow and rape incorporated plots. There were no differences in soil $NO_3$-N among plots incorporated with cereals. In May, 1993, rape had lower $NO_3$-N than fallow, but the two were similar in April, 1994. In contrast, rye was always lower in $NO_3$-N than the fallow. This may

**Table 2.** **Effects of winter cover crops on the content of nitrate nitrogen in the soil profile between 0–0.3 m.**

| | 1992–1993 | | | 1993-1994 | | |
|---|---|---|---|---|---|---|
| Cover crops | 18 Sep. | 7 May | $^{\dagger}$P | 20 Sep. | 9 Apr. | $^{\dagger}$P |
| | mg N kg$^{-1}$ | | | mg N kg$^{-1}$ | | |
| None (fallow) | 23.6 | 8.2 | 0.003 | 12.1 | 5.5 abc | 0.002 |
| Winter wheat | 25.0 | 10.2 | 0.003 | 10.3 | 3.9 bcd | 0.003 |
| Winter barley | 40.6 | 16.2 | 0.0001 | 12.7 | 4.4 abcd | 0.0003 |
| Spring barley | 29.5 | 16.5 | 0.01 | 10.9 | 7.7 a | 0.09 |
| Cereal rye | 33.8 | 13.0 | 0.0002 | 13.4 | 1.9 d | 0.0001 |
| Triticale | 30.4 | 15.6 | 0.003 | 13.6 | 3.3 cd | 0.0001 |
| Rape | 30.7 | 8.9 | 0.0001 | 11.2 | 7.1 ab | 0.04 |
| Pr>F | ns | ns | | ns | * | |
| LSD(P=0.05) | - | - | | - | 3.4 | |
| **Orthogonal contrasts:** | | | | | | |
| Fallow × C. crops | | ns | | | ns | |
| Cereals × Rape | | * | | | * | |
| Cereals × Fallow | | * | | | ns | |
| Fallow × Rape | | ns | | | ns | |
| Rye × Cereals | | ns | | | * | |
| Rye × Wheat | | ns | | | ns | |

In a column means followed by a common letter are not statistically significant at P=0.05 by LSD. * Significant at the 0.05 level of probability. ns = nonsignificant at the 0.05 level of probability. $^{\dagger}$P value for the concentration difference between 18 September, 1992 to 7 May, 1993 and 20 September, 1993 to 9 April, 1994.

be due to the N immobilization ( Meisinger *et al.*, 1991). As a result of the cold winter of 1992, more than 50% of the spring barley vegetation was dead in early March, 1993, which allowed these materials to decompose and release N to the soil earlier than the other crops. This decomposition may have contributed to the high $NO_3$-N in the soil zone between 0.3–0.6 m depth in plots incorporated with spring barley in May, 1993. During the 1993–1994 season, spring barley began to die in late December, and by early January resembled a surface mulch. This dried plant material decomposed much earlier than other species and released more $NO_3$-N to the 0–0.3 m soil layer.

Rye lead all treatments in total seasonal N uptake, followed in descending order by winter barley, rape, wheat, triticale, and spring barley in May, 1993 (Table 4). In the second season, all treatments except spring barley incorporation significantly decreased $NO_3$-N levels ($P<0.05$) in soil between 0–0.3 m during September, 1993 to April, 1994. The spring barley vegetation was dead in early spring and thus it released N to the soil earlier than the other crops. On the other hand, rape incorporated and fallow plots significantly increased $NO_3$-N concentrations in soil between 0.3–0.6 m in depth. This was not evident in the plots incorporated with cereals (Tables 2 and 3). This could be due to that the cereal crops conserved N through uptake while leaching continued in fallow and rape incorporated plots in soil between 0–0.3 m.

All treatments reduced $NO_3$-N in the 0–0.6 m zone between September, 1992 and May, 1993 ($P<0.01$) (Tables 2 and 3). By May, 1993 total $NO_3$-N in the 0–0.6 m zone was higher with spring barley than with the wheat, fallow, and rape treatments; none of the other cover crops differed from the fallow plot. Thus, spring barley tended to increase $NO_3$-N concentration over the fallow treatment at spring plow–down.

Between September, 1993 and April, 1994, $NO_3$-N in the 0–0.6 m layer of soil was significantly depleted by the incorporation of wheat, winter barley, rye, and triticale ($P < 0.01$). Plots incorporated with rye, triticale, and winter wheat had lower $NO_3$-N concentrations than those of fallow, rape, and spring barley (Tables 2 and 3). Rye incorporated plots had low $NO_3$-N but did not differ from triticale, wheat, or winter barley. Rye, triticale, winter wheat, and winter barley reduced soil $NO_3$-N when compared to a fallow (Meisinger *et al.*, 1991). In orthogonal contrasts, cereals were different from fallow ($P=0.004$) in April, 1994.

Final soil $NO_3$-N concentrations differed among treatments in May, 1993 ($P=0.04$) (Table 2 and 3). Plots incorporated with spring barley, which was killed by cold weather in early March, 1993, had more $NO_3$-N than the

Table 3. **Effects of winter cover crops on the content of nitrate nitrogen in the soil profile between 0.3–0.6 m.**

| Cover crops | 1992-1993 | | | 1993-1994 | | |
|---|---|---|---|---|---|---|
| | 18 Sep. | 7 May. | ᵗP | 20 Sep. | 9 Apr. | ᵗP |
| | mg N kg$^{-1}$ | | | mg N kg$^{-1}$ | | |
| None (fallow) | 4.6 | 2.8 ab | 0.1 | 1.6 | 4.5 a | 0.02 |
| Winter wheat | 5.8 | 1.3 bc | 0.002 | 1.7 | 0.1 b | 0.2 |
| Winter barley | 6.5 | 2.0 bc | 0.002 | 1.6 | 0.4 b | 0.3 |
| Spring barley | 5.3 | 4.3 a | 0.4 | 2.3 | 1.0 b | 0.3 |
| Cereal rye | 5.8 | 1.0 c | 0.001 | 1.4 | 0.1 b | 0.2 |
| Triticale | 4.5 | 2.2 bc | 0.07 | 2.0 | 0.3 b | 0.1 |
| Rape | 6.8 | 0.9 c | 0.0001 | 2.1 | 4.8 a | 0.03 |
| Pr>F | ns | ** | | ns | ** | |
| LSD(P=0.05) | - | 1.8 | | - | 2.8 | |
| **Orthogonal contrasts:**<br>Fallow x C. crops | | ns | | | ** | |
| Cereals x Rape | | ns | | | *** | |
| Cereals x Fallow | | ns | | | *** | |
| Fallow x Rape | | * | | | ns | |
| Rye x Cereals | | * | | | ns | |
| Rye x Wheat | | ns | | | ns | |

In a column means followed by a common letter are not statistically significant at P=0.05 by LSD. *,**,*** Significant at the 0.05, 0.01 and 0.001 levels of probability, respectively. ns = nonsignificant at the 0.05 level of probability. ᵗP value for the concentration difference between 18 September to 7 May, 1993 and 20 September, 1993 to 9 April, 1994.

fallow treatment. The other cereal incorporated plots had higher $NO_3$-N than in the fallow plots in May, 1993. The 1993–1994 season experienced a mild,

**Table 4.** **The nitrogen uptake, nitrogen percentage, and C:N ratio of cover crops.**

| Cover crop | March, 1993 | | | March, 1994 | | |
|---|---|---|---|---|---|---|
| | N kg ha$^{-1}$ | N% | C:N | N kg ha$^{-1}$ | N% | C:N |
| Winter wheat | 98 bc | 2.8 b | 14.7 a | 76 a | 2.5 c | 16.4 b |
| Winter barley | 116 ab | 3.1 b | 13.1 ab | 65 b | 2.4 cd | 16.5 b |
| Spring barley | 74 c | 2.8 b | 14.6 a | 45 b | 2.4 ab | 13.7 c |
| Cereal rye | 133 a | 3.0 b | 13.4 a | 71 a | 2.1 d | 19.3 a |
| Triticale | 95 bc | 2.9 b | 13.9 a | 76 a | 2.6 bc | 15.9 b |
| Rape | 100 bc | 3.5 a | 11.5 b | 35 b | 3.2 a | 12.6 c |
| Pr>F | * | ** | ** | *** | *** | *** |
| LSD(P=0.05) | 33 | 0.4 | 1.8 | 18 | 0.4 | 2.22 |
| **Orthogonal contrasts:**<br>Cereal × Rape | ns | *** | * | *** | *** | *** |
| Wheat × Cereals | ns | ns | ns | ns | ns | ns |
| Rye × Cereals | ** | ns | ns | ns | ** | ** |
| Wheat × Rye | * | ns | ns | ns | * | ** |
| Wheat × W.barley | ns | ns | ns | ns | ns | ns |

In a column means followed by a common letter are not statistically significant at P=0.05 by LSD. *,**,*** Significant at the 0.05, 0.01 and 0.001 levels of probability, respectively. ns = nonsignificant at the 0.05 level of probability.

dry winter followed by a dry, cool decomposition period. In April, 1994 wheat, triticale, rye, and winter barley had lower $NO_3$-N concentrations than rape or fallow plots. Thus, cereal cover crop incorporation after a mild, dry winter can deplete soil $NO_3$-N when compared to a fallow (Hargrove, 1986).

## Biomass nitrogen

In March, 1993, rye contained more N in the above-ground biomass than either spring barley, winter wheat, triticale, or rape (Table 4). However, in March, 1994, triticale, wheat, and rye showed similar biomass N uptake. The C:N ratios of the cereal cover crops were similar in March, 1993, however, except for winter barley, all were higher than rape. Rape and spring barley had lower C:N ratios than the other crops in March, 1994, whereas triticale, wheat, and winter barley had similar C:N ratios which were lower than that of rye (Holderbaum *et al.*, 1990). Rye accounted for 133 kg ha$^{-1}$ of inorganic N uptake in March, 1993, but only 71 kg ha$^{-1}$ in March, 1994.

## CONCLUSIONS

Results of this study suggest that effects of winter cover crops on early spring soil $NO_3$-N in the 0–0.6 m zone is strongly dependant on the species of the cover crop and climatic conditions. After a wet, cold winter followed by a decomposition period, $NO_3$-N content in soil increased relative to the fallow in spring barley, winter barley, and triticale incorporated plots through early mineralization. In contrast, after a dry mild winter followed by a decomposition period, rye incorporated plots contained less $NO_3$-N than fallow plots due to the large volume of persistent mulch produced by rye. Although cover crop species may have similar C:N ratios, they do not decompose and release N compounds concurrently. Nitrogen release can be further complicated by differences in the timing of crop kill and soil incorporation.

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