WINTER COVER CROP EFFECTS ON SOIL HEALTH IN SLOPING CROPLAND

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OBJECTIVE

Healthy soils are critical for high and stable productivity of wheat and other crops grown in Kentucky. Growing cover crops is one way to improve soil health. However, research findings about cover crop impacts on soil health and sustainability are derived mainly from flat research plots that are not representative of the rolling cropland that is common in Kentucky. These existing datasets may overlook the disproportionate benefits that cover crops can provide on sloping land. The objective of this study is to determine the effects of cereal rye and mixed cereal rye-crimson clover cover crops on soil organic C and N and other soil health indicators at three different landscape positions. We expected to find that cover crops would have greater benefits for soil health on sloping land than flat land.

METHODS & MATERIALS

The winter cover crop effects on soil health were investigated using an existing field study at University of Kentucky's Spindletop Farm. The study includes two fields that rotate between corn and soybeans. The study was established in the first field 2018 and in the second field in 2019. Each field includes three landscape positions – top of hill (summit), side of hill (backslope), and bottom of hill (toeslope). At each of those positions, three winter cover crop treatments – cereal rye, cereal rye-crimson clover mixture, and winter fallow were established. The project involves routine sampling for soil moisture, soil inorganic nitrogen (N), cover crop biomass and N uptake, corn N uptake, and crop yields. Cover crop biomass and crop yield data from this study are summarized in Tables 1 and 2.

On April 19, 2021 just before cover crop termination, soil samples were taken at 0-10 and 10-20 cm (0-4 and 4-8 inches) in the first field. The second field was sampled in the same way on April 28, 2022. The samples were air-dried, sieved through a 2 mm screen, and analyzed for soil C, total N, potential respiration, potential N mineralization, and wet aggregate stability. Soil C and N were measured using the dry combustion method. We subtracted the inorganic C from total C to determine organic C; however, inorganic C results from the second field are still in process. Potential respiration was measured using a soil incubation in which 100 g (first field) or 20 g (second field) of air-dried soil were brought to 60% water-holding capacity and carbon dioxide concentrations were measured in the incubation jars after 0, 24, 48, and 72 hours of incubation. We calculated potential respiration as the average daily rate of CO_2-C production over the three-day period per kg of dry soil. Potential N mineralization was measured using a soil incubation in which 8 g of air-dried soil were brought to 60% water-holding capacity and inorganic N was measured after 0 and 7 days of incubation. The difference in inorganic N between these two timepoints was divided by 7 days to determine the average rate of N mineralization per day. Wet aggregate stability was determined as the portion of 1-2 mm aggregates that remained on a 0.250 mm sieve following three minutes of oscillation in water and correction for sand content. For statistical analysis, we evaluated the interactive effects of cover crop and landscape position using analysis of variance and considered p values ≤ 0.05 to be significant.

RESULTS

Soil organic C and N are key components of soil organic matter. In the first field, we found that the backslope position had significantly greater soil organic C and total N than the toeslope and summit positions for the 0-10 cm depth (Figure 1). The landscape position effect was not observed for 10-20 cm. Although we did not detect statistical differences among cover crop treatments, it is possible to observe a trend toward higher soil organic C for the rye and mixture treatments than the fallow treatment that was most pronounced in the surface soil on the backslope (Figure 1). In the second field, we found no significant effects of landscape position or cover crop for the soil surface (Figure 2). However, for the depth of 10-20 cm we found that the backslope had significantly greater total N than the toeslope, while the summit was not different than the backslope or toeslope in total N concentration (Figure 2).

Potential soil respiration is an indicator of microbial activity and fast-turnover soil organic matter. For the first field, in the surface 0-10 cm, potential soil respiration was greater on the toeslope than the backslope position, while the summit had an intermediate potential respiration rate (Figure 3). In addition, potential soil respiration was 15% greater with a mixture or rye cover crop than winter fallow. The effect of cover crop use was similar across landscape positions. The 10-20 cm had generally lower potential respiration than the 0-10 cm layer. While the toeslope and summit had higher soil potential respiration than the backslope at 10-20 cm, there was no cover crop effect at that depth (Figure 3). In the second field, in terms of landscape position effects, the backslope had greater potential soil respiration than the summit and toeslope positions in the 0-10 cm increment (Figure 4). In terms of cover crop, we found that the rye resulted in 34% more potential soil respiration than the mix and fallow treatments in the surface soil (Figure 4). Considering the depth of 10-20 cm, the backslope position produced greater potential soil respiration than the summit. Besides that, there were no differences in view of cover crop effects for 10-20 cm (Figure 4).

Potential N mineralization is an indicator of the soil's ability to supply plant-available N. For the first field, in the surface 0-10 cm, potential N mineralization was greater with a rye cover crop than winter fallow on the toeslope position. However, the cover crop effect on the toeslope was reversed in the 10-20 cm depth, where the cover crop mixture led to significantly lower potential N mineralization than fallow (Figure 5). The rye cover crop increased variation in potential N mineralization among landscape positions at 10-20 cm, with significantly greater N mineralization on the summit and toeslope than on the backslope in the rye cover crop treatment (Figure 5). Potential N mineralization was overall higher in the second field, but no effects of landscape position or cover crop were observed (Figure 6).

Soil aggregate stability is an indicator of soil structure and tilth. For the first field, all three landscape positions had very high percentages of water-stable aggregates, and the cover crop treatments tended to increase the aggregate stability, though the effect was not statistically significant (Figure 7). Due to the lack of treatment effects at the soil surface, we decided not to measure aggregate stability on the second depth. For the second field, soil aggregate stability was also high and a significant statistical effect of cover crops was found, in which rye and mix led to 3% greater aggregate stability than the fallow treatment for each landscape position (Figure 8).

DISCUSSION

The mixture and rye cover crops increased potential respiration in the top 10 cm across all landscape positions relative to the winter fallow treatment in the first field (Figure 3), but in the second field only the rye cover crop showed a pronounced difference compared with the fallow treatment (Figure 4). These results suggest that the cover crop treatments contributed to enhancing the fast-turnover, easily decomposable soil organic matter that is responsible for feeding the soil microbial community. However, in this relatively small study, the rye cover crop was more consistent in increasing the potential respiration than the mixture treatment. This was surprising because the rye and mixture cover crops produced similar cover crop biomass (Tables 1 and 2). Perhaps the cereal rye cover crop depleted inorganic N to a greater extent than the mixture, causing a 'N mining' response in which microbes increased their rate of decomposition to make N more available.

The greater potential mineralization of the cover crop treatments may be an early indication of soil organic C buildup. Indeed, the soil organic C and N concentrations showed a similar trend in response to cover crop treatments as the potential respiration in the surface depth of each field (Figures 1-4), even though cover crop effects on soil organic C and N were not significant. Soil organic C often takes five years or more to show statistically significant changes, while potential respiration can change more quickly because it represents a fast-turnover fraction of soil organic matter. It is also important to highlight that soil organic C and N concentrations varied much more between landscape positions than among cover crop treatments, emphasizing that natural variability in soil organic matter can outweigh management impacts.

It was observed that the backslope position in the first field had the lowest potential respiration despite having the highest soil organic C concentration (Figures 1 and 3). In contrast, the backslope position had the highest potential respiration among landscape positions in the second field (Figure 4), aligning with the slightly higher total N found at that position in field #2 (Figure 2). The higher organic C and total N concentrations on the backslope in both fields may reflect the relatively shallow soil profiles on the backslope, resulting in a limited mass of soil in which to store organic inputs, and thus enrichment of organic matter in that shallow soil. The potential respiration reflects only the easily decomposable forms of organic matter, such as cash crop and cover crop residues. In the first field, the backslope position is the least productive position in terms of crop yield and thus has the lowest crop residues and lowest potential respiration despite its high soil organic C concentration (Table 1). However, in the second field, the backslope is more similar to the other positions in terms of productivity and residue inputs (Table 2), which may explain why the potential soil respiration generally aligned with the total N concentrations.

Easily decomposable organic matter is thought to contribute to nutrient release. However, the effect of cover crops on potential N mineralization was less consistent than their effect on potential respiration. The rye cover crop increased potential N mineralization in the top 10 cm on the toeslope of the first field, but the mixture cover crop decreased potential N mineralization in the 10-20 cm layer on the toeslope. Considering the second field, no significant effects of cover crop or landscape position were detected at either depth. In this study, the C:N ratio of aboveground cover crop biomass ranges from 25 to 35, meaning that the residues contain about as much N as the microbes need to decompose the residue. With a moderate C:N ratio, the cover crop residues are not expected to release N quickly. Since the soil was sampled immediately after cover crop termination, it is possible that the cover crop residue had not decomposed enough to cause significant N mineralization. The C:N ratio of cover crop roots ranges from 35 to 60, and it is possible that the high abundance of roots at 10-20 cm depth led to N immobilization on the toeslope position of field #1 with the cover crop mixture.

The easily decomposable organic matter is also thought to promote aggregate stabilization. While it was not found that the cover crop treatments increased aggregate stability in the first field, we did observe significantly greater wet aggregate stability for the rye and mixture cover crops than the winter fallow in the second field. It is important to note that the aggregate stability was quite high in both fields even in the no cover crop treatment, which suggests that the soils have favorable structure with a possible minimal opportunity for improvement in this property.

CONCLUSION

This research suggests that cereal rye and cereal rye-crimson clover mixtures were effective in increasing soil potential respiration across landscape positions, with rye providing more consistent benefits across fields. The increased soil potential respiration is an early indication that the cover crops are contributing to buildup of soil organic C. In the first field, it was observed that potential respiration increased with crop yield among the landscape positions, suggesting that cover crops and productive cash crops are beneficial for soil health. The cover crops had inconsistent effects on potential N mineralization. The cover crops were generally beneficial for aggregate stability, with significant impacts observed in one of two fields.

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TABLES

Table 1. Average winter biomass production, corn yield, and soybean yield for field #1 of the landscape position project averaged across years. Corn yields are for the plots that received 240 lb N/acre. Winter biomass production for the fallow treatment was derived from winter weeds. Standard errors are shown in parentheses.

Cover crop	Summit	Backslope	Toeslope
Winter biomass, lb/acre (2019-2021)			
Fallow	226 (48)	413 (94)	204 (156)
Mix	4110 (470)	3520 (327)	3700 (634)
Rye	3710 (305)	3010 (281)	3160 (327)
Corn yield, bu/acre (2019, 2021)			
Fallow	210 (22)	152 (19)	239 (19)
Mix	220 (25)	136 (25)	237 (16)
Rye	201 (23)	131 (19)	212 (20)
Soybean yield, bu/acre (2020)			
Fallow	55 (0.6)	39 (2.3)	61 (2.1)
Mix	55 (1.0)	38 (1.6)	62 (0.6)
Rye	52 (3.2)	40 (1.2)	59 (1.0)

Table 2. Average winter biomass production, corn yield, and soybean yield for field #2 of the landscape position project averaged across years. Corn yields are for the plots that received 240 lb N/acre. Winter biomass production for the fallow treatment was derived from winter weeds. Standard errors are shown in parentheses.

Cover crop	Summit	Backslope	Toeslope
Winter biomass, lb/acre (2020-2022)			
Fallow	861 (135)	1050 (220)	1160 (187)
Mix	3230 (402)	2870 (462)	3310 (315)
Rye	3500 (389)	3200 (350)	3200 (228)
Corn yield, bu/acre (2020, 2022)			
Fallow	231 (10)	219 (18)	225 (12)
Mix	247 (10)	183 (17)	239 (13)
Rye	239 (20)	211 (16)	230 (15)
Soybean yield, bu/acre (2021)			
Fallow	60 (3.7)	53 (3.0)	78 (3.1)
Mix	60 (2.7)	51 (2.7)	68 (4.7)
Rye	52 (3.1)	48 (2.4)	66 (3.7)

FIGURES

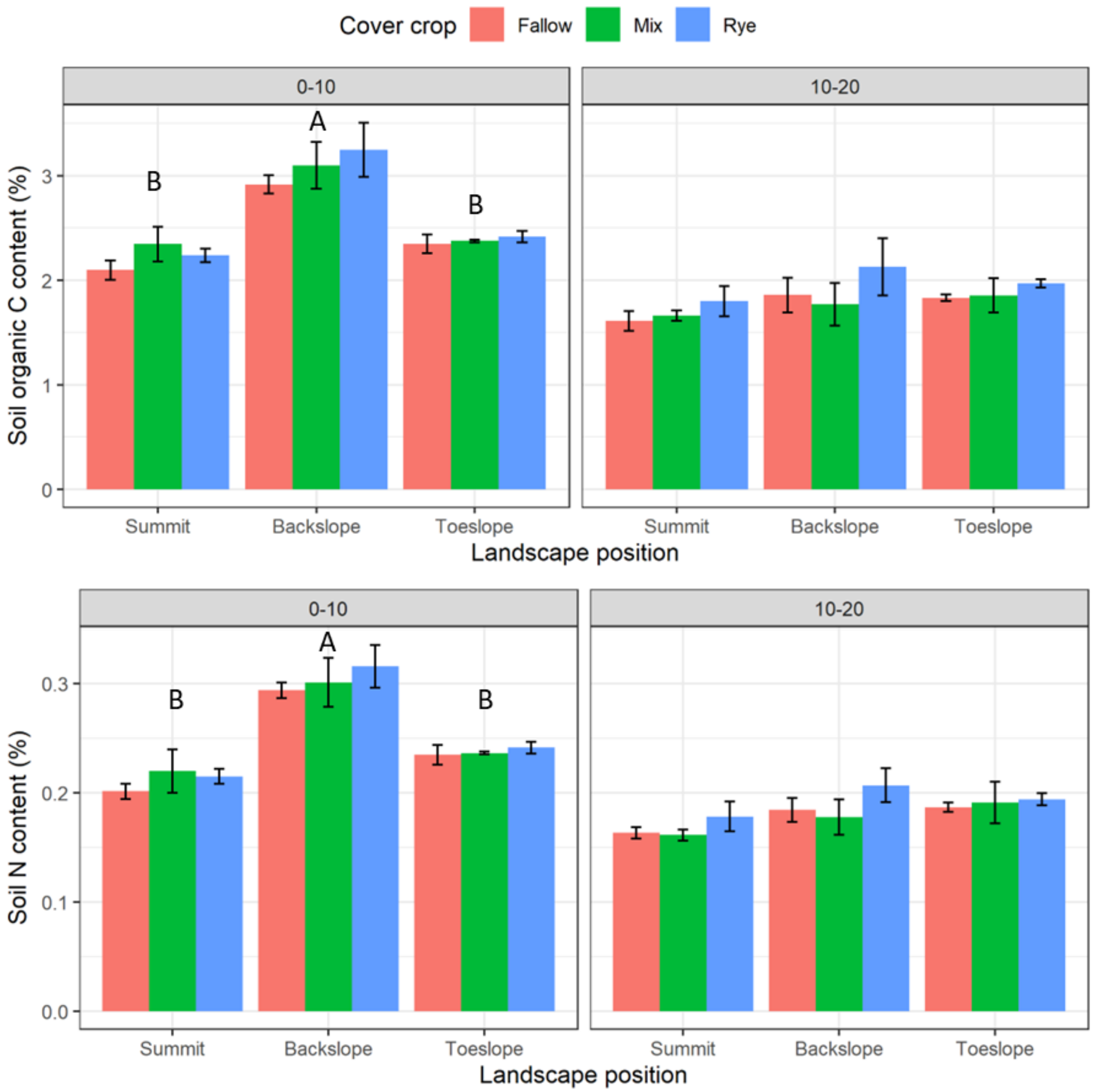

Figure 1. Soil organic C concentrations (top) and N concentrations (bottom) for 0-10 cm (left) and 10-20 cm (right) by landscape position measured in spring 2021 following three years of cover crop treatments in a corn-soybean rotation (Field #1). Different capital letters show differences among landscape positions averaged across cover crop treatments. There were no significant effects of cover crop treatment on soil organic C at 0-10 or 10-20 cm, and no significant effect of landscape position at 10-20 cm. Error bars are ± one standard error.

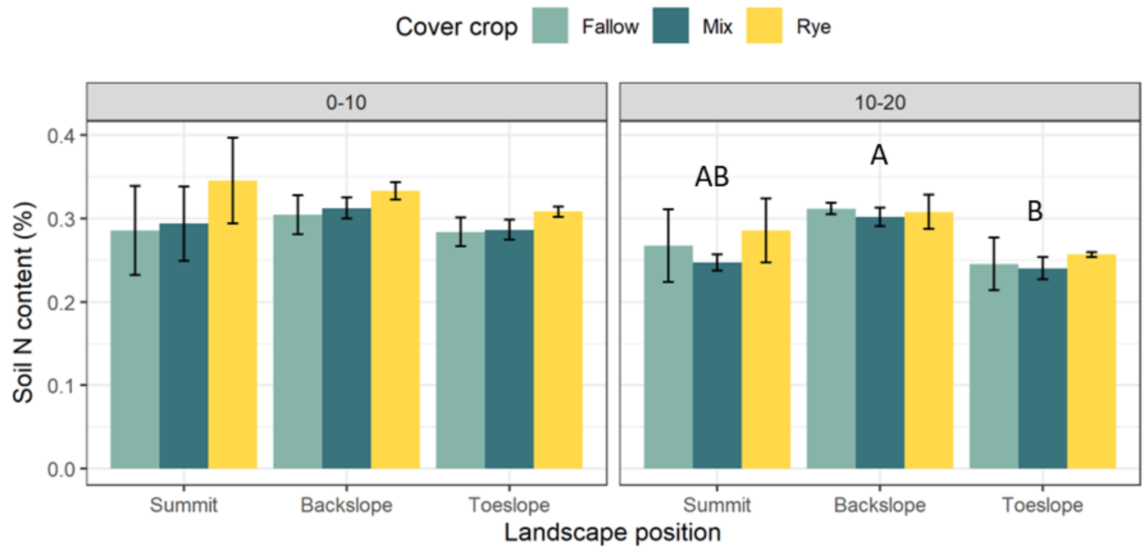

Figure 2. Soil total N content for 0-10 cm (left) and 10-20 cm (right) by landscape position measured in spring 2022 following three years of cover crop treatments in a corn-soybean rotation (Field #2). Different capital letters show differences among landscape positions averaged across cover crop treatments. There were no significant effects of landscape positions and cover crop treatment on soil total N at 0-10 cm, while at 10-20 cm there was a significant effect of landscape position but no difference among cover crop treatments within each landscape position. Error bars are ± one standard error.

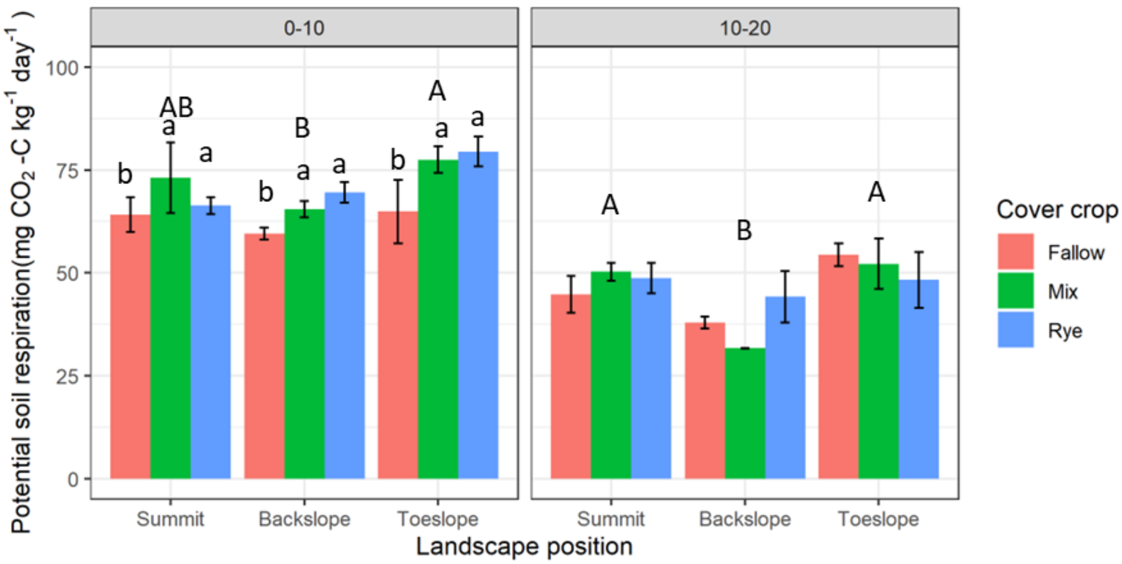

Figure 3. Potential soil respiration for 0-10 cm (left) and 10-20 cm (right) by landscape position measured in spring 2021 following three years of cover crop treatments in a corn-soybean rotation (Field #1). Different capital letters show differences among landscape positions averaged across cover crop treatments, while different lowercase letters show differences among cover crop treatments within each landscape position. There were no significant effects of cover crop treatment on potential soil respiration at 10-20 cm. Error bars are ± one standard error.

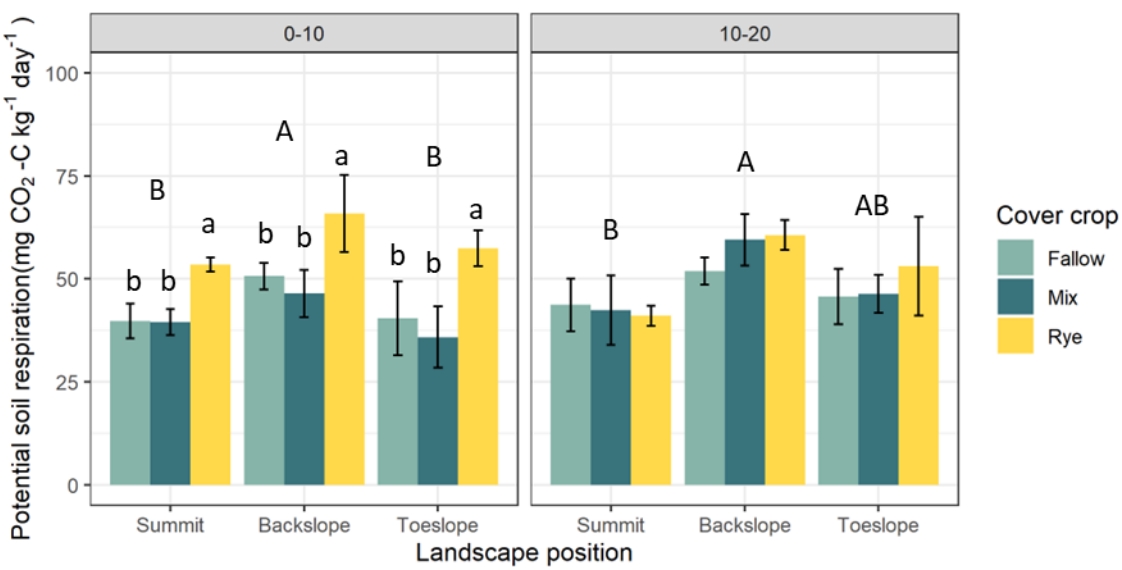

Figure 4. Potential soil respiration for 0-10 cm (left) and 10-20 cm (right) by landscape position, measured in spring 2022 following three years of cover crop treatments in a corn-soybean rotation (Field #2). Different capital letters indicate differences among the landscape positions averaged across cover crops, and different lowercase letters show differences among cover crop treatments within each landscape position. There were no significant effects of cover crop treatment on potential soil respiration at 10-20 cm. Error bars are ± one standard error.

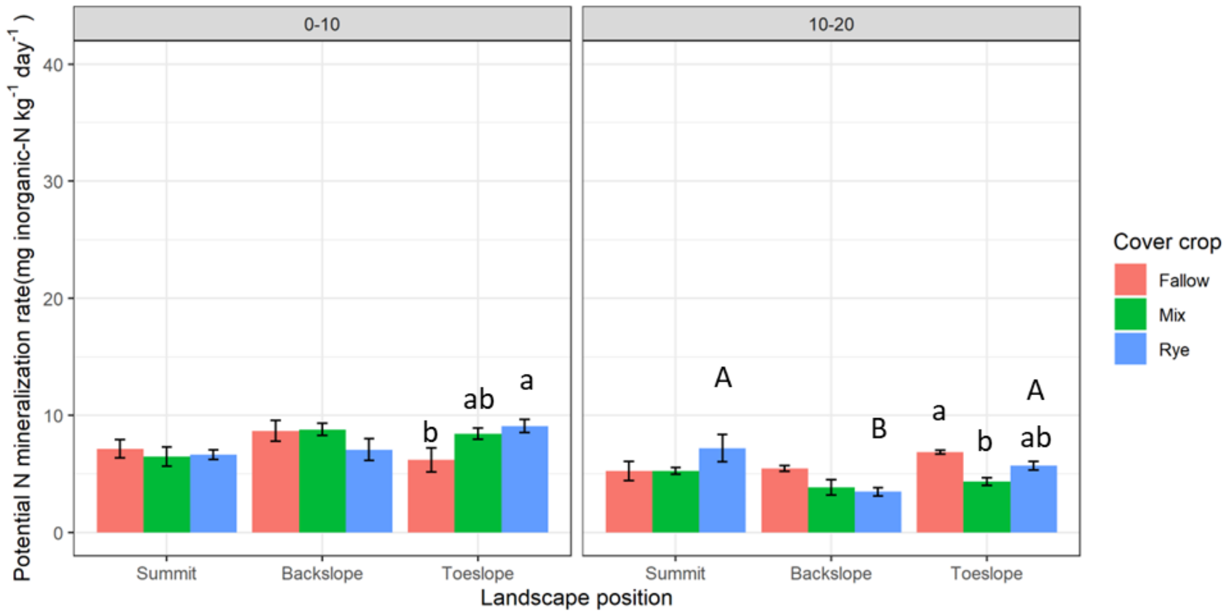

Figure 5. Soil potential N mineralization for 0-10 cm (left) and 10-20 cm (right) by landscape position measured in spring 2021 following three years of cover crop treatments in a corn-soybean rotation (Field #1). Different capital letters show differences among landscape positions for a particular cover crop treatment while different lowercase letters show differences among cover crop treatments within a particular landscape position. There was no effect of landscape position on potential N mineralization at 0-10 cm and no effect of cover crop treatment on the summit and backslope position at either depth. Error bars are ± one standard error.

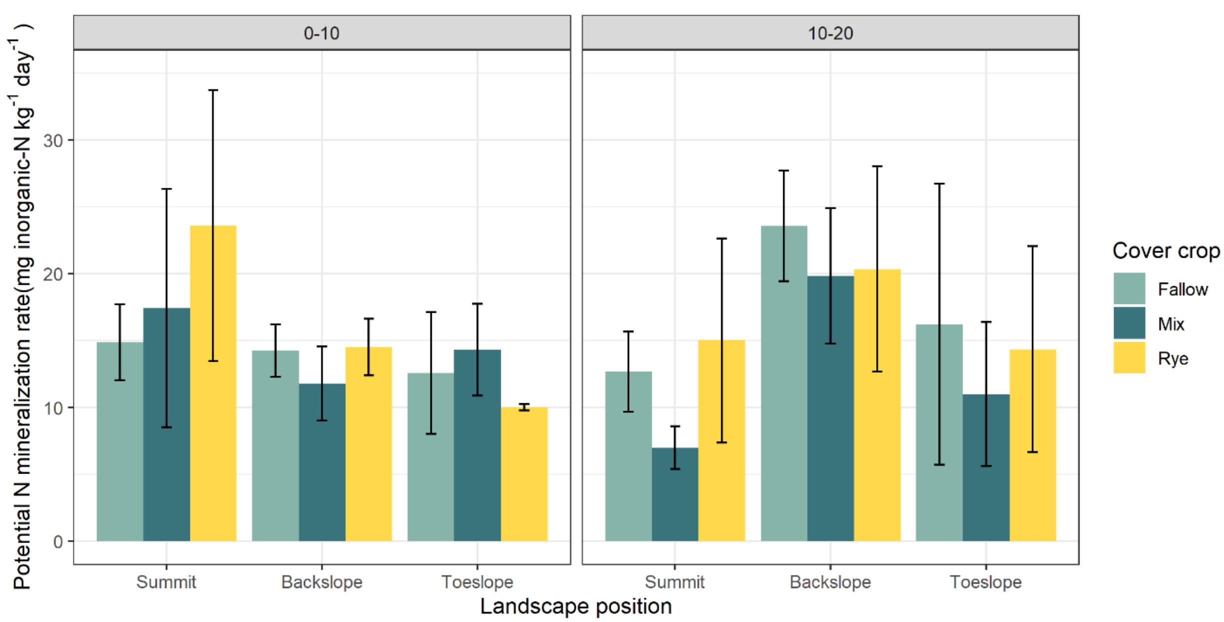

Figure 6. Soil potential N mineralization for 0-10 cm (left) and 10-20 cm (right) by landscape position measured in spring 2022 following three years of cover crop treatments in a corn-soybean rotation (Field #2). There were no effects of cover crop or landscape position on potential N mineralization for either depth. Error bars are ± one standard error.

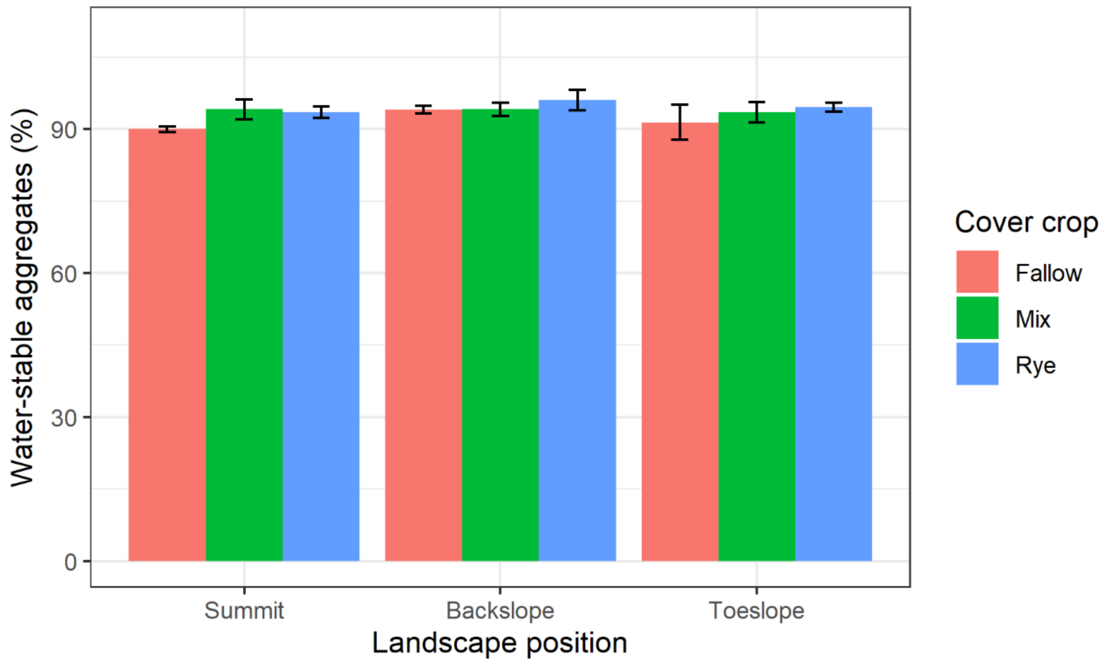

Figure 7. Percentage water-stable aggregates for 0-10 cm by landscape position measured in spring 2021 following three years of cover crop treatments in a corn-soybean rotation (Field #1). There were no significant effects of landscape position or cover crop treatment on percentage water-stable aggregates. Error bars are ± one standard error.

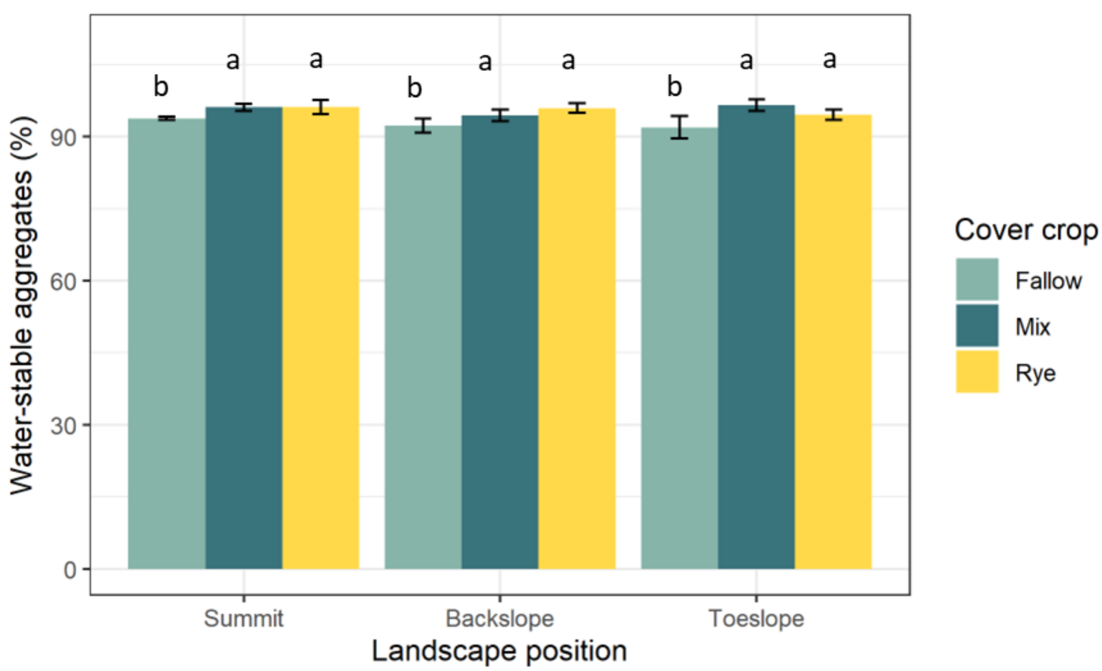

Figure 8. Percentage water-stable aggregates for 0-10 cm by landscape position measured in spring 2022 following three years of cover crop treatments in a corn-soybean rotation (Field #2). Different lowercase letters show significant differences among cover crop treatments within each landscape position. Error bars are ± one standard error.