Impacts of long-term no-tillage and conventional tillage management of spring wheat-lentil cropping systems in dryland Eastern Montana, USA, on fungi associated to soil aggregation

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Abstract
Lentil (*Lens culinaris* Medikus CV. Indianhead) used to replace fallow in spring-wheat (*Triticum aestivum*) rotation in the semi-arid Eastern Montana USA, may improve soil quality. We evaluate the 14 years influence of continuous wheat under no-tillage (WNT), fallow-wheat under conventional tillage (FCT) and no-tillage (FNT), lentil-wheat under tillage (LCT) and no-tillage (LNT) on soil formation and stability, and on the amount of immunoreactive easily-extractable glomalin (IREEG) and soil aggregating basidiomycete fungi in the 4.75-2.00, 2.00-1.00, 1.00-0.50, 0.50-0.25, and 0.25-0.00 mm aggregate-size classes, at 0-5 cm soil depth. The 4.75-2.00 mm aggregate proportion was higher in LNT than FNT and higher in LT than FT treatments and mean weight diameter (MWD) was higher when lentil was used to replace fallow under NT. No-till systems had higher glomalin and basidiomycete amount than CT in all aggregate-size classes and glomalin was higher in LNT than FNT in aggregate-size classes less than 0.50 mm. We conclude that residue input in NT systems triggers fungal populations which are involved in soil binding in aggregates, and that replacing fallow by lentil in spring wheat rotation in dryland seems to favor aggregate formation/stability under NT probably by increasing N fertility during the course of 14 years.

Key Words
Tillage, soil aggregation, lentil, fallow, spring wheat, glomalin, basidiomycete fungi.

Introduction
Wheat-fallow rotations commonly practiced in the semiarid Northern Great Plains of the United States, resulted in substantial soil erosion, deterioration of the quantity and quality of soil organic matter, and increased greenhouse gas emissions (Sainju *et al.* 2008; 2009). By using a legume to replace fallow in a wheat-fallow rotation, there has been a gradual reduction in fertilizer-N requirement after about 6 years (Campbell *et al.* 1992). Legume-based cropping systems will not only reduce nitrogen losses, but they may also increase the proportion of crop residue carbon that is sequestered in stable soil organic matter (Drinkwater *et al.* 1998). It appears that rotations containing grain legumes will also result in greater microbial activity (Biederbeck *et al.* 2005). However, the effects of legume cropping in dryland spring wheat rotations on soil aggregation and fungal population involved in soil binding is not known. Our objective was to study aggregate formation and stability, and the populations of fungi associated to soil aggregation in different aggregate-size classes in lentil spring wheat systems in comparison to fallow spring wheat and continuous spring wheat as influenced by tillage.

Methods
The study was located in Culbertson, Montana, USA on a Williams loam (fine-loamy, mixed Typic Argiboroll). Annual precipitation is 340 mm. The experimental design is detailed in Pikul *et al.* (1997). Treatments consist of two tillage systems (conventional tillage, CT, and no-tillage, NT) and five cropping systems (no-tilled continuous wheat, CWNT, no-tilled wheat-fallow, FNT, conventional tilled wheat-fallow, FCT, no-tilled wheat-lentil, LNT, conventional tilled wheat-lentil, LCT) as split-plot treatments in a randomized block design with four replications. Indianhead lentil (*Lens culinaris* Medikus CV. Indianhead) was grown as green manure (L) and terminated either mechanically (LCT) or by herbicides (LNT) using a mixture of glyphosate (2.3 L/ha) and 2,4-D (0.54 kg/ha). Indianhead lentil was used in this study because this legume has intermediate topgrowth N yield and the seed was available at low cost. Soil samples collected to a depth of 5 cm were processed within 24-48 h for determinations of soil aggregation. Aggregates were separated by dry sieving and the aggregate proportion (g aggregate/kg soil) was measured in 4.75-2.00, 2.00-

1.00, 1.00-0.50, 0.50-0.25, and 0.25-0.00 mm aggregate-size classes. Mean weight diameter (MWD), used as an index of aggregate stability, was calculated according to the procedure described by Kemper and Rosenau (1996). The immonoreactive fraction of the easily extractable glomalin (IREEG) produced by arbuscular mycorrhizal fungal hyphae was determined by methods previously described (Wright and Upadhyaya, 1998). An enzyme-linked immunosorbent assay was used to quantify the amount of soil aggregating basidiomycete fungi (Caesar-TonThat *et al.* 2001).

Results and discussion

The aggregate proportion and MWD significantly differed among treatments at 0-5 cm soil depth (Table 1). No-tilled continuous spring-wheat (WNT) and wheat-lentil (LNT) treatments had the highest proportion of 4.75-2.00 mm aggregate-size class compared to the other treatments with a subsequent decrease in the 0.25-0.00 mm aggregate-size class. Regardless of tillage, wheat-lentil treatments had higher proportions of 4.75-2.00 mm aggregate-size class compared to wheat-fallow treatments. Mean-weight diameter (MWD) was higher in LNT than in FNT and FT, and was the highest in WNT and the lowest in FCT among the treatments. These results suggest that continuous spring-wheat and wheat-lentil treatments under NT practice are more suitable in dryland Montana USA than wheat-fallow treatments in improving aggregate formation and stability. The increase of aggregate stability in LNT compared to FNT could be attributed to lentil incorporation of readily decomposable and N-rich substrate which provides a better environment for microbial growth and activities that are involved in the production of soil binding agents. These data are consistent with Biederbeck *et al*. (1998) who had found an increase in soil aggregation in lentil system compared to wheat fallow systems at the top soil surface layer (0-10 cm) in the semiarid climate of the Canadian prairie.

Table 1. Effects of tillage and cropping systems on the proportion of soil aggregates and mean weight diameter (MWD) at 0-5 cm soil depth.

	Aggregate proportion in size class (g aggregate/kg soil)					
Treatments*	4.75-2.00 mm	2.00-1.00 mm	1.00-0.50 mm	0.50-0.25 mm	0.25-0.00 mm	MWD*** (mm)
WNT	394.21a**	134.07a	106.29ab	135.90b	215.60c	0.51a
FCT	96.94c	94.67b	109.77ab	203.48a	495.30a	0.39c
FNT	188.06b	110.09ab	96.27b	205.27a	411.44b	0.43c
LCT	151.14b	104.70ab	132.63a	205.19a	406.67b	0.44bc
LNT	354.69a	111.02ab	104.87ab	189.12ab	240.31c	0.48ab
Means						
NT	308.85a	118.48a	102.48a	181.40a	289.12b	0.48a
CT	124.042b	99.65b	121.20b	204.33a	450.99a	0.42b

*Tillage and cropping systems are WNT, no-tilled continuous wheat, FCT, conventional tilled wheat-fallow, FNT, no-tilled wheat-fallow, LCT, conventional tilled wheat-lentil, and LNT, no-tilled wheat-lentil.

**Numbers followed by different letters within a column are significantly different at $P \leq 0.05$ by the Honestly Significant Difference procedure of Tukey-Kramer.

***MWD, mean weight diameter.

Treatments had significantly different concentrations of immunoreactive easily extractable glomalin (IREEG) and soil aggregating basidiomycete fungi in the different aggregate-size classes (4.75-2.00, 2.00-1.00, 1.00-0.50, and 0.50-0.25 mm) (Figures 1 and 2). Figure 1 indicates that IREEG was higher in all NT treatments compared to CT in all aggregate-size classes. Continuous spring wheat under NT (WNT) had the highest concentration of IREEG compared to the other treatments in aggregate-size classes (4.75-2.00, 2.00-1.00, and 1.00-0.50 mm) but was lower than LNT in the 0.50-0.25 mm aggregate-size class. There was significant higher glomalin concentration in aggregate-size classes 1.00-0.50 and 0.50-0.25 mm in LNT than FNT. The quantification of the soil aggregating basidiomycete fungi indicated that in general WNT had the largest amount of basidiomycetes than the other treatments (Fig. 2). There was no difference in the amount of fungi between FNT and LNT and between FCT and LCT, but FNT and LNT were significantly higher than FCT and LCT. The data indicated that regardless of cropping systems, NT in the Northern Plains dryland favor the concentrations of IREEG and soil aggregating basidiomycete fungi on the top soil surface (0-5 cm) because mycorrhizal and basidiomycete fungi are known to be sensitive to soil disturbance caused by tillage (Caesar-TonThat *et al.* 2001; Wright and Upadhyaya, 1998), and plant residue input resulted from

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NT systems favor the survival and growth of these fungi. Results showing a higher amount of IREEG in LNT compared to FNT are consistent with Doubs *et al*. (1997) who have reported that that organic matter increased AM fungal hyphae growth.

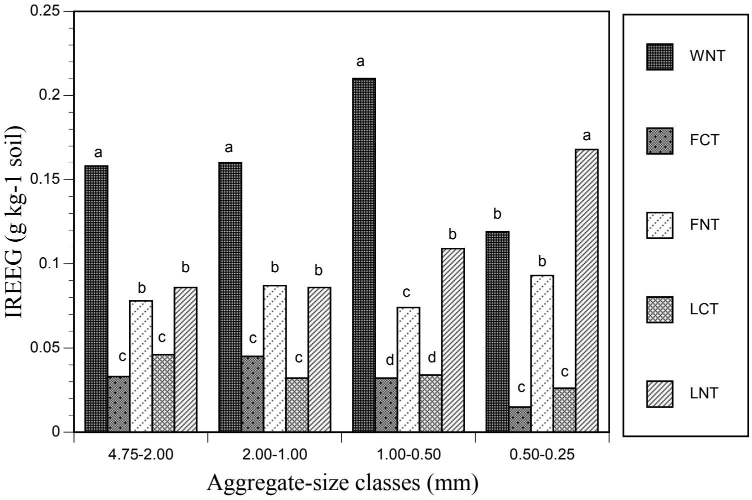

Figure 1. Concentrations of immunoreactive easily extractable glomalin (IREEG) at 0-5 cm soil depth. Tillage and cropping systems are no tilled continuous spring wheat (WNT), conventional tilled wheat-fallow (FCT), no-tilled wheat-fallow (FNT), conventional tilled wheat-lentil (LCT), and no-tilled wheat-lentil (LNT). Bars followed by the same lowercase letters are not significantly different at $P \leq 0.05$.

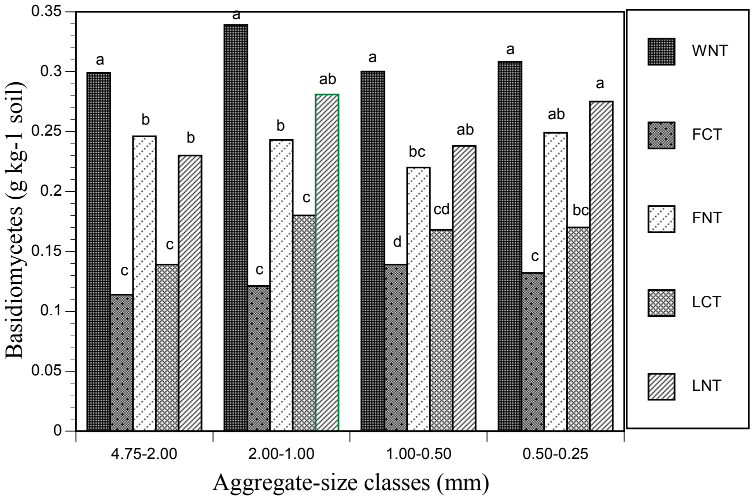

Figure 2. Amount of soil aggregating basidiomycete fungi at 0-5 cm soil depth as detected by ELISA. Tillage and cropping systems are no tilled continuous spring wheat (WNT), conventional tilled wheat-fallow (FCT), no-tilled wheat-fallow (FNT), conventional tilled wheat-lentil (LCT), and no-tilled wheat-lentil (LNT). Bars followed by the same lowercase letters are not significantly different at $P \leq 0.05$.

Conclusion

The use of lentil to replace fallow in spring wheat rotation system improved soil aggregate formation regardless of tillage management and aggregate stability was improved in LNT compared to FNT. Under NT, wheat-lentil rotation improved glomalin concentration when compared to wheat-fallow rotation. Regardless of cropping systems, aggregate stability, glomalin (IREEG) concentrations and basidiomycete fungi were higher under NT than CT.

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