# Productivity and N-Fixation of Legume-cereal Intercrops and Their Monocrop Counterparts in Organic Cropping Systems

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## Abstract

In recent years, Western Canada has seen considerable growth in organic production. This is due to heightened environmental awareness, reduced input costs, diversification of market opportunities, and food safety aspects. On the prairies, organic production generally includes the use of annual green manure (GrM) crops, which are plowed under to add nutrients to the soil. However, in a GrM plow-down year, farmers face loss of income. One alternative to growing a traditional GrM could be growing legumes alone or intercropping them with cereals and managing them as green feed forage (GF) for use on-farm or for sale to local livestock producers without compromising soil fertility levels. Intercropping legumes with cereals may be a novel approach to problems of nitrogen (N) supply as the legume may provide N to the current and subsequent crops. It was hypothesized that by intercropping the legume with a cereal, the inorganic N supply would be reduced to levels where N fixation in the legume would be stimulated. This study (i) compared yield in monoculture legume with legume-cereal intercrops (ii) investigated whether increasing cereal density stimulated the legume to fix more N (iii) Compared yield of a cereal grown after the GrM and GF crop treatments. The study included mixtures of feed pea (*Pisum sativum* cv 40-10 silage pea), oat (*Avena sativa* L.cv AC Morgan), and triticale (X *Triticosecale* Wittmack cv Pika). The experiment consisted of 16 treatments and 4 replicates in which feed pea, oat, and triticale were grown alone or in combination and managed as GrM or GF. Wheat and fallow (tillage) served as cropped and uncropped controls respectively. The intercropped oat was seeded at three densities (50, 100, and 150 plants $m^{-2}$). In the second year, wheat was seeded in all plots. In this paper, biomass, total nitrogen (N), and nitrogen derived from the atmosphere (Ndfa) of treatments and subsequent yields of wheat grown after the treatments at the Delisle site are discussed. Results show that the oat (4238 kg $ha^{-1}$) and fieldpea + oat 2 (3630 kg $ha^{-1}$) treatments had the highest biomass whereas the triticale (1357 kg $ha^{-1}$) treatment had the lowest. Among the intercrops, only the fieldpea + oat 2 treatments had higher total nitrogen (91.61 kg $ha^{-1}$) than their monocultures, with the oat treatment being the least (45 kg $ha^{-1}$). The highest %Ndfa was achieved at the highest intercropped cereal density of fieldpea + oat 1 (84%).Wheat grain yield were consistently higher following GrM treatments whereas biomass removal significantly compromised subsequent wheat yields in the GF treatments.

## Introduction

Organic farming mainly depends on soil organic matter and biological activity as major nutrient suppliers in the soil and this in turn is dependant largely on the incorporation of plant biomass. The organic matter decomposes to release nutrients that are taken up by subsequent crops (Hendrix et al. 1986). Green manure (GrM) crops have been used to help maintain soil organic matter, improve soil fertility through nitrogen (N) retention and supply and protect soil against erosion (Zentner et al. 1996; Fowler et al. 2004). In Western Canada, sustainability of cereal-cropping systems may be improved by using legumes as intercrops (Ross et al. 2005). In a study by Izaurralde et al. (1991), barley-field pea intercrops increased N yield when grown under cryoboreal sub-humid conditions. They noted that on average, the amount of N derived from air by pea intercrops was 39% higher than that derived by the single pea crop. They attributed these yield advantages to the mutual complimentary effects of individual crops including better use of available resources such as light, water, and nutrients. Nair et al. (1979) observed a 30% wheat yield increase after a maize-soybean intercrop and a 34% increase after maize-cowpea intercrop compared to maize-wheat rotation.

### *Rationale*

There is evidence that fixed N is available to both current and subsequent cereal crops (Pal and Shehu, 2001; Pappa et al. 2006). However, other studies have shown no evidence for transfer of N from legume to the cereal in the current year (Izaurralde et al. 1991; Ofori and Stern, 1987). Thus, it is thought that N transfer happens under certain conditions depending on factors such as soil temperature, moisture content, available soil N.
Although there are obvious benefits of growing GrM crops either as monocrops or intercrops, farmers face a loss of income in the plow-down year. One option may be to grow crops as GF, so farmers may harvest the crops as hay for their animals or for sell to livestock producers. Currently, there are no studies carried out to evaluate the productivity of different GrM versus GF options.

## Hypotheses

1. Intercropping legumes with cereals increases biomass, yield, and consequent N-benefits to current and subsequent cereal crop.
2. Increasing the cereal density in a legume/cereal intercrop enhances N-fixation.

**Objectives**

1. Compare yield in monoculture legume with legume-cereal intercrops
2. To investigate whether increasing cereal density enhances N-fixation in the intercropped legume
3. Compare yields of wheat grown after crop treatments in green manure and green forage management systems.

**Materials and Methods**

Treatment crops were seeded at Delisle, SK in 2005 and pursued with a wheat (*Triticum aestivum* L.) test crop in 2006 in all plots .The experiment consisted of 16 treatments and 4 replicates (Table 1) in which feed pea (*Pisum sativum* cv 40-10 silage pea), oat (*Avena sativa* L.cv AC Morgan), and triticale (X *Triticosecale* Wittmack cv Pika) were grown alone or in combination and managed as GrM or GF. Wheat and fallow (tillage) served as cropped and uncropped controls respectively. Soil samples were collected prior to seeding for initial characterization.

**Table 1.** Experimental treatments

| Treatment | GrM | GF | Control |
|---|---|---|---|
| **Fallow** | | | X |
| **Wheat** | | | X |
| **F/p + Oat 1*** | X | X | |
| **F/p + Oat 2*** | X | X | |
| **F/p + Oat 3*** | X | X | |
| **Oat** | X | X | |
| **F/p + Trit.** | X | X | |
| **Triticale** | X | X | |

*Oat 1, 2, & 3 = 50, 100, & 150 plants m-2 respectively.

**Seeding Rates**

Monocropped seeding rates were: 157 kg ha$^{-1}$ field pea; 88 kg ha$^{-1}$ oat; 94 kg ha$^{-1}$ triticale; and 90 kg ha$^{-1}$ wheat. These seeding rates provided target populations of 95 plants m$^{-2}$ field pea and 250 plants m$^{-2}$ for oat, triticale and wheat. Where crops were intercropped, seeding rates were adjusted as follows: 100 kg ha$^{-1}$ field pea; 18, 35 and 54 kg ha$^{-1}$ oat, and 150 kg ha$^{-1}$ triticale. The target plant densities were 60 plants m$^{-2}$ field pea; 50, 100 and 150 plants m$^{-2}$ oat; and 150 plants m$^{-2}$ triticale, respectively (Table 2).

**Table 2.** Seeding rates of single and companion crops.

| Crop | Single crop (Plants/$m^2$) | Companion crop (about 60% of single) (Plants/$m^2$) |
|---|---|---|
| Fieldpea | 95 | 60 |
| Oat | 250 | 50; 100; 150 (oat 1, 2, 3 respectively) |
| Triticale | 250 | 150 |
| Wheat | 250 | N/A |

**Sampling**

GrM plots were initially sampled 8 weeks after seeding for biomass production. Aerial biomass plant tissue samples were collected from five 0.5 m rows. The shoots were cut approximately 5 cm above ground. Samples were oven dried (72 h at 60°C). Intercrops were separated before grinding and subsequently weighed for plant tissue analyses. Green manure plots were incorporated using a small plot tractor equipped with tandem disks when the field pea was at full bloom (9 weeks after seeding).

The GF plots were sampled when at least 50 % of the cereals were in the dough stage of development. Prior to harvesting, five 0.5 m rows were sampled and plants cut approximately 5 cm above-ground. Samples were oven-dried for 72 h at 60$^o$C and weighed. Continuous wheat plots were harvested and the above-ground biomass and grain yield were measured.

Biological N fixation was estimated using the $^{15}$N isotope dilution method.
In the subsequent year, wheat plots were sampled five times at a two-week interval during the growing season to assess biomass and N-uptake. Finally all plots were harvested for grain yield analyses. The grain was weighed when it had attained 13% moisture content and yield determined in kg ha$^{-1}$.

**Results and Discussion**

Mean biomass for the GrM was highest in the oat and fieldpea + oat 2 treatments at 4238 kg ha$^{-1}$ and 3630 kg ha$^{-1}$ respectively. Triticale had the lowest biomass (Figure1). Higher available soil N may have resulted in the greatest biomass achieved by the oat treatment as oat is more efficient at extracting soil N, whereas the small stature of triticale compromised its biomass. However, triticale had a higher concentration of N in plant tissue (data not shown) than the oat.

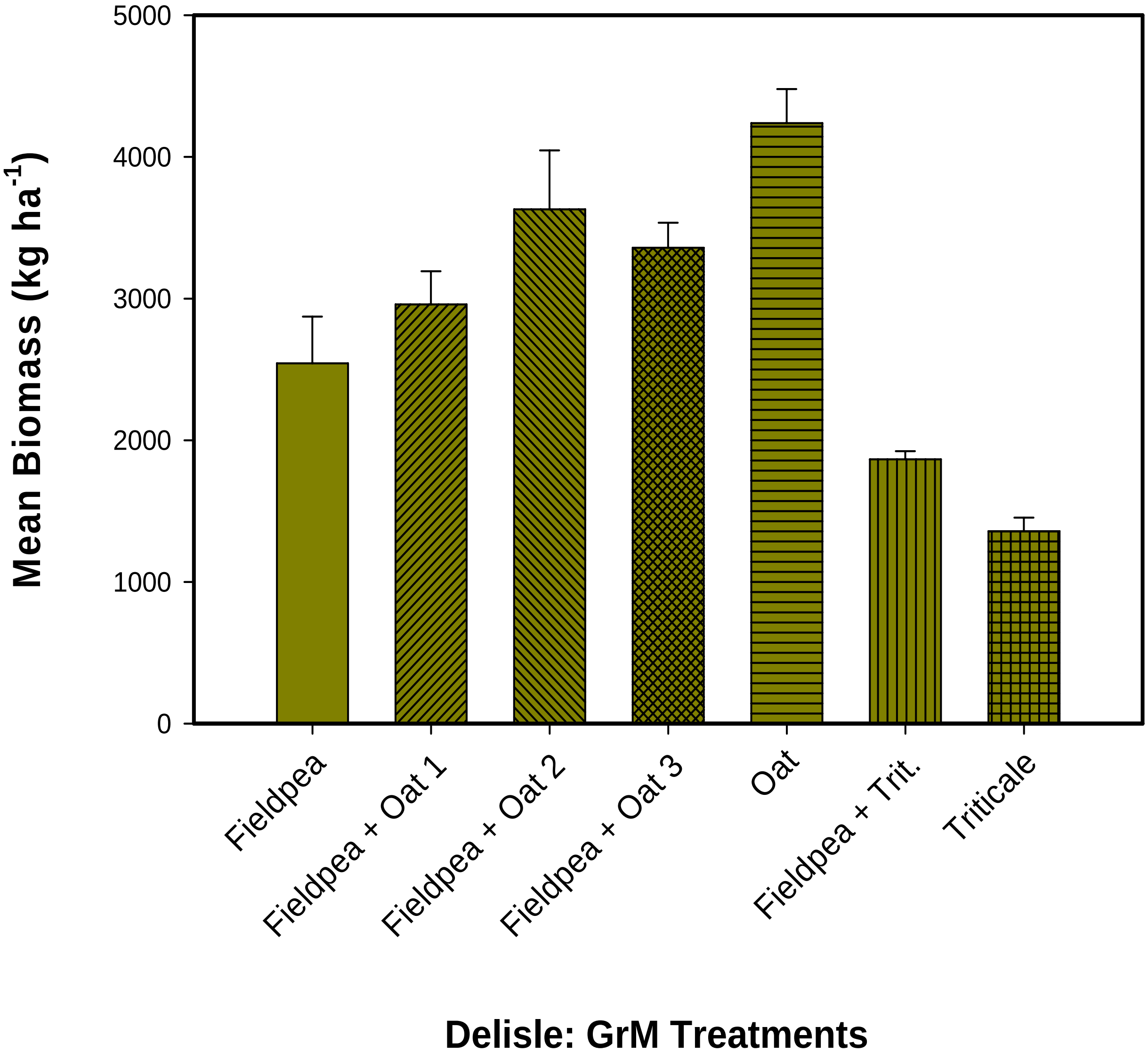


**Figure 1.** Comparison of biomass of different GrM intercrops and their monocure counterparts at the Delisle site in 2005. Error bars are standard errors.

The fieldpea + oat 2 treatment was highest in total nitrogen whereas the rest of the intercrops were not higher than their monocultures. As would be expected, the fieldpea treatment had higher total N than the rest of the intercrops because of its higher %N concentration in the plant tissues by virtue of being a legume.

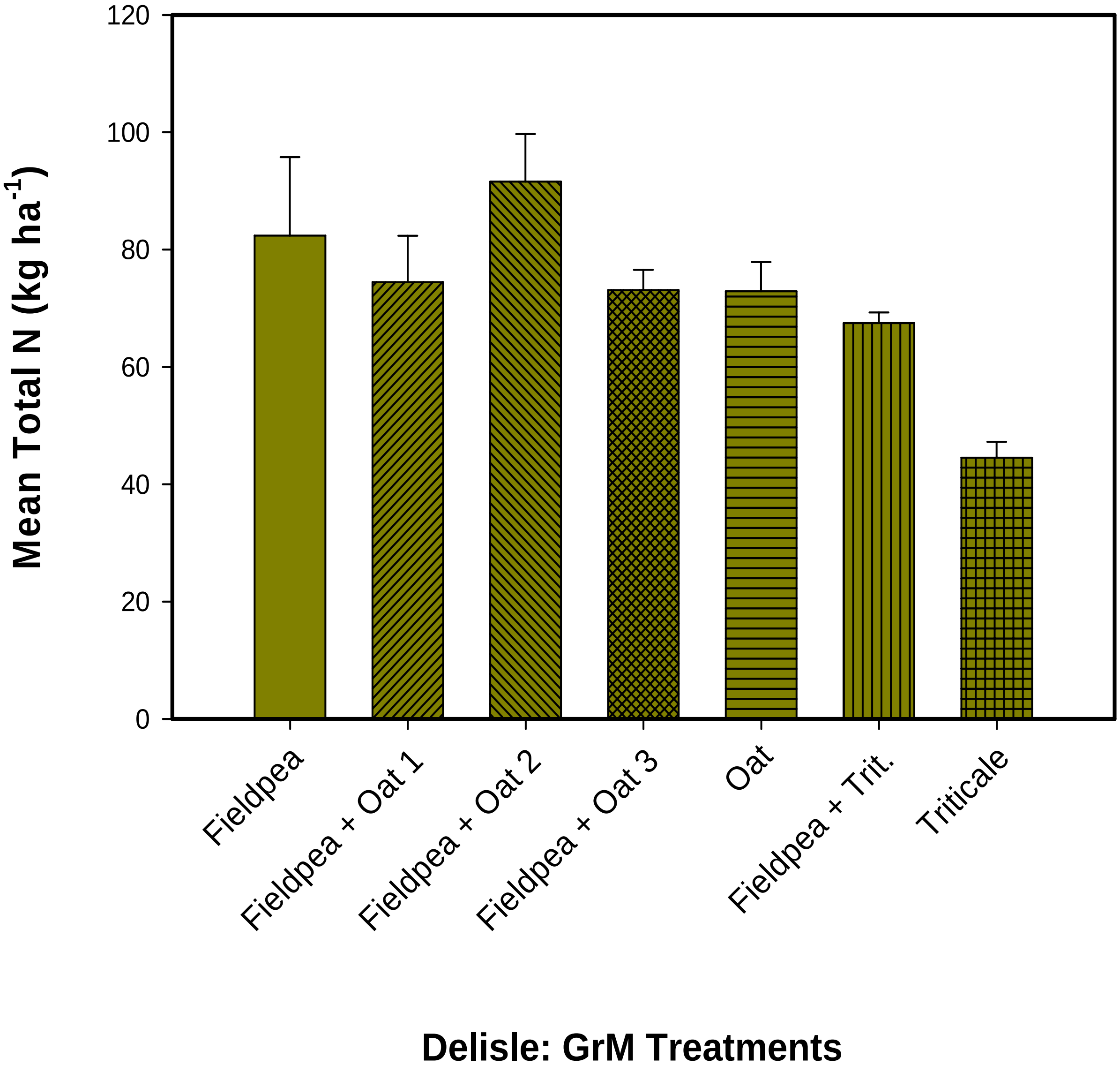


**Figure 2.** Comparison of N-uptake of different GrM intercrops and their monoculture counterparts at the Delisle site in 2005. Error bars are standard errors.

Although figures 1 and 2 above appear to have differences among treatments in both biomass and total N, there were no significant statistical differences among all the treatments (Table 3). The same observation applies for nitrogen fixation on figure 3 below (statistical table not shown). This scenario may have been due to higher levels of soil N and water. Thus, there was not much competition between the cereal and the legume.

**Table 3.** Statistical contrasts of plant biomass and total N for the Delisle site in 2005

| **Contrast** | | |
|---|---|---|
| **Plant Biomass comparison** | | |
| | **———Treatment ID (GrM Treatments)———** | ***P-value*** |
| Fieldpea | Fieldpea + Oat 1, Fieldpea + Oat 2, Fieldpea + Oat 3, Fieldpea + Triticale | 0.66† |
| Oat | Fieldpea + Oat 1, Fieldpea + Oat 2, Fieldpea + Oat 3, Fieldpea + Triticale | 0.64† |
| Triticale | Fieldpea + Oat 1, Fieldpea + Oat 2, Fieldpea + Oat 3, Fieldpea + Triticale | 0.21† |
| Oat | Triticale | 0.18† |
| Fieldpea + Oat 3 | Fieldpea + Triticale | 0.51† |
| Fieldpea + Oat 2 | Fieldpea | 0.88† |
| **Plant Total comparison** | | |
| Fieldpea | Fieldpea + Oat 1, Fieldpea + Oat 2, Fieldpea + Oat 3, Fieldpea + Triticale | 0.84† |
| Oat | Fieldpea + Oat 1, Fieldpea + Oat 2, Fieldpea + Oat 3, Fieldpea + Triticale | 0.62† |
| Triticale | Fieldpea + Oat 1, Fieldpea + Oat 2, Fieldpea + Oat 3, Fieldpea + Triticale | 0.36† |
| Oat | Triticale | 0.74† |
| Fieldpea + Oat 3 | Fieldpea + Triticale | 0.13† |
| Fieldpea + Oat 2 | Fieldpea | 0.97† |

† = Non-significant at 0.05 level

The highest level of N-fixation was achieved at the highest cereal density of fieldpea + oat 3 (Figure 3). This result supports our hypothesis that increasing cereal density in an intercrop triggers more N-fixation due to competition of for soil N between the legume and its cereal companion. Because the cereal crop has a more vigorous root system than the legume, it is more efficient at extraction N and moisture from the soil leaving the legume with the only option of deriving N from the atmosphere.

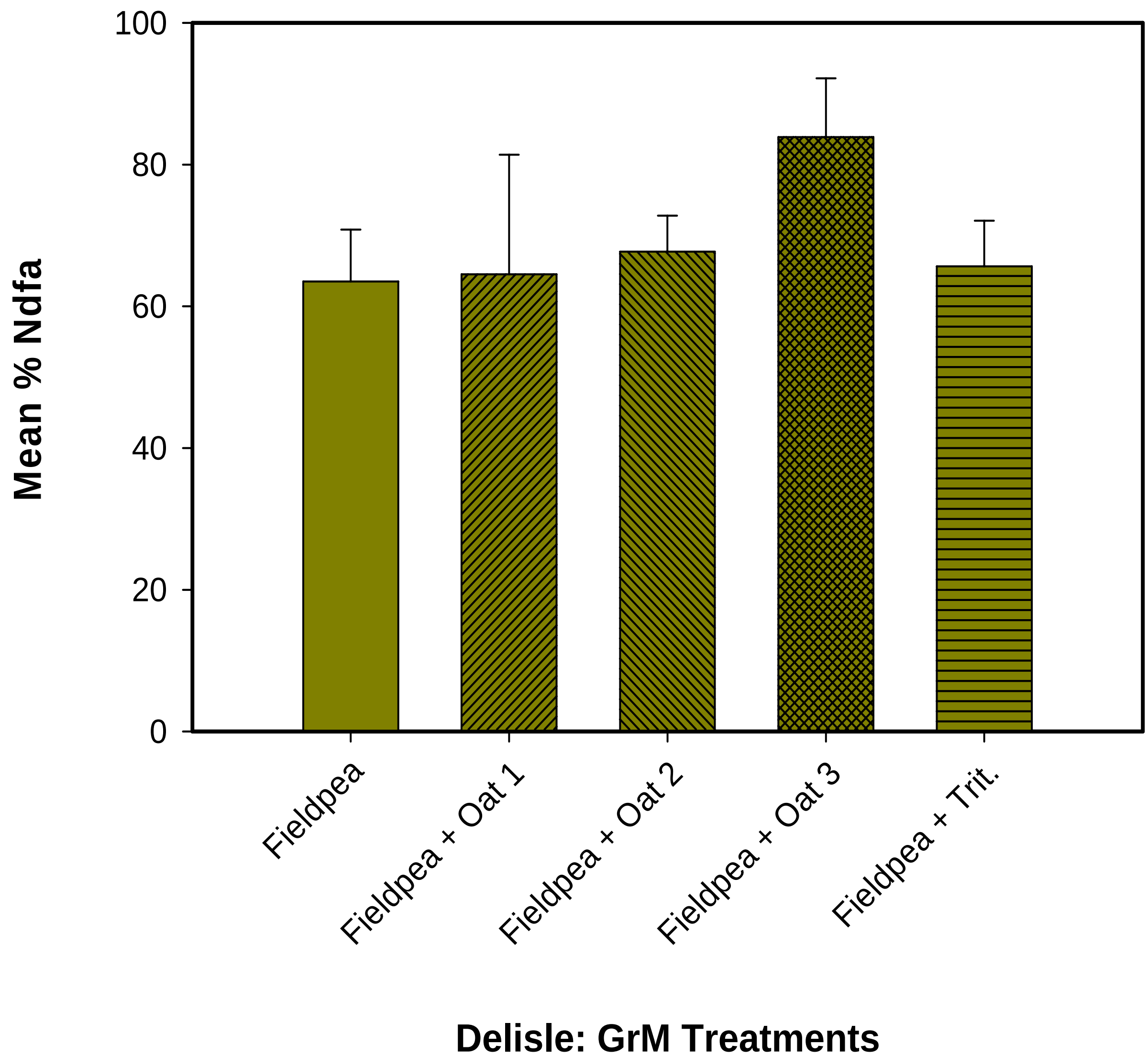


**Figure 3.** Comparison of N-fixation with increasing cereal density in intercrops and monoculture legume at the Delisle site in 2005. Error bars are standard errors.

Wheat grain yield was consistently higher following the GrM treatments (Figure 4). However, there were no significant differences in yield after GrM treatments, neither were significant differences in yield after GF treatments. These findings support other studies that have demonstrated that inclusion of green manure crops is an effective way to reduce N loss due to leaching over winter and improving supply of N in organic cropping systems (Fowler et al. 2004). The GF treatments resulted in wheat yields intermediate between GrM and continuous wheat whereas the fallow treatment was second highest probably due to enhanced nutrient and moisture availability.

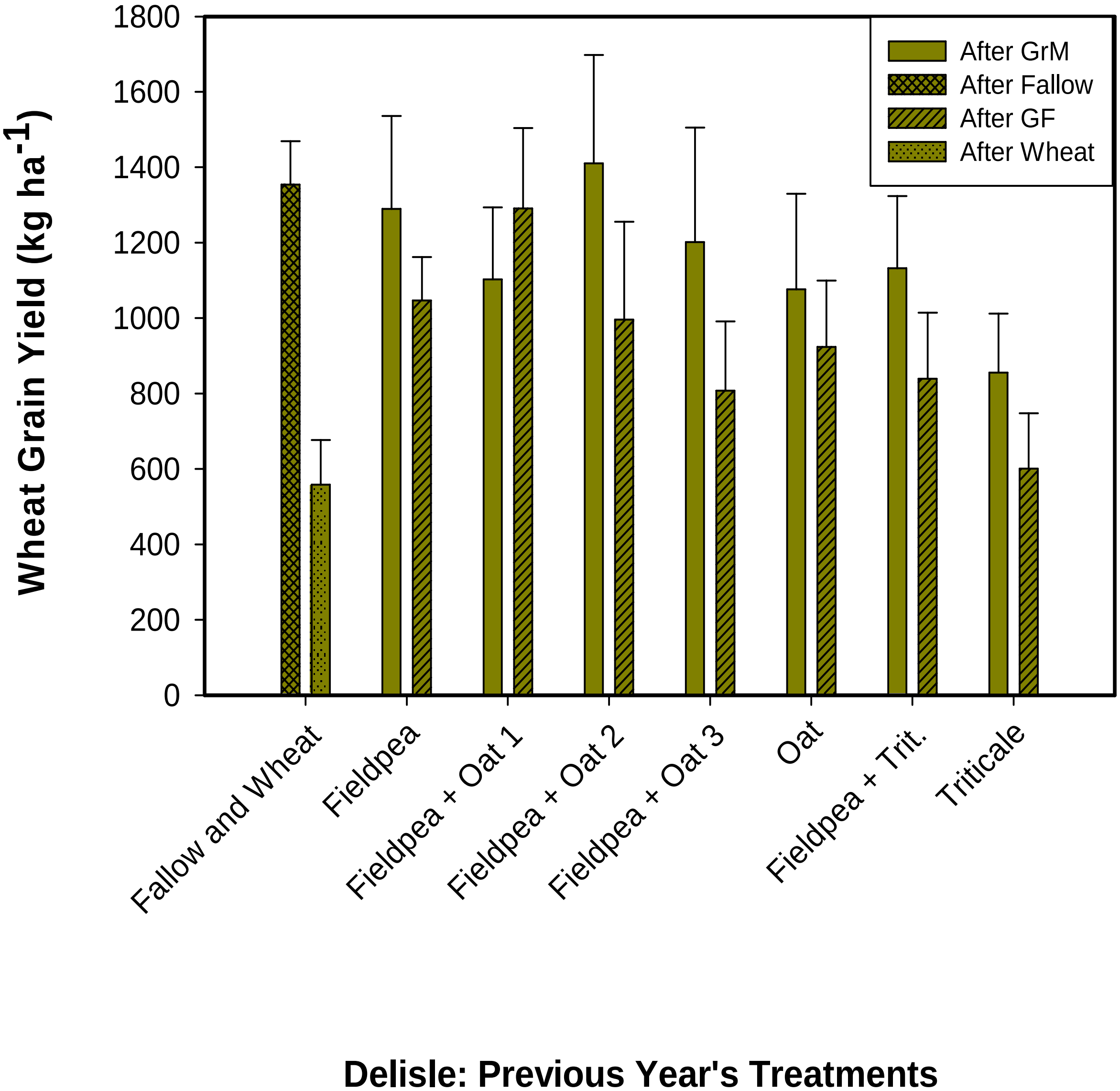


**Figure 4.** Impact of GrM and GF options on wheat grain yield at Delisle in 2006. Error bars are standard errors.

**Conclusion**

Intercrops did not yield more than their monocultures probably due to higher moisture and nutrient availability. Increasing cereal density triggered more N-fixation. Wheat after GrM had highest biomass, grain, and N enhanced availability of N from plow-down organic material. Enhanced nutrient and moisture availability in the soil resulted in wheat yield after fallow being high. Biomass removal compromised subsequent wheat yield in the GF treatment.

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