Crop Performance and Plant Microbe-Interactions are Affected by the Sequence and Frequency of Pulse Crops in the Canadian Prairie

Navarro-Borrell A[1,2]; Dai M[2]; Hamel C[1,2]; Fernandez MR[2]; Gan Y[2]; Germida J[1].

[1] University of Saskatchewan, Saskatoon, SK, Canada;

[2] Semiarid Prairie Agricultural Research Centre, AAFC, Swift Current, SK, Canada.

Short summary:

Different crop sequences best benefited different pulses and wheat in the field.

Monocultures were inefficient in wheat, where it reduced yield and nitrogen level. In chickpea, monoculture resulted in devastating diseases. Wheat yield was greatest following pulses suggesting that the microbial legacy of pulses is well suited to wheat.

Beneficial arbuscular mycorrhizal fungi and dark septate endophytes were found to associate in different ways with different crops.

Keywords: Crop rotation, fungi, pulses, wheat

Introduction:

We are seeking the optimum frequency and sequence of pulse crops in rotation systems with wheat by analysing the performance of 14 different 4-year crop rotation systems, at SPARC in Swift Current. Preliminary results obtained until phase-III of the rotation will be presented.

Different crop sequences best benefited different pulses. A chickpea-wheat sequence benefited chickpea productivity more than pea-mustard; pea yielded more after lentil-chickpea than pea-wheat, whereas lentil was not affected by crop sequence. Monocultures were inefficient in wheat, where it reduced yield and nitrogen level. In chickpea, monoculture resulted in devastating diseases, showing how the microbial legacies of crops can feedback on the performance of the following crop. Wheat yield was greatest following pulses suggesting that the microbial legacy of pulses is well suited to wheat.

Nowadays cropping systems must be nutrient and water efficient and sequester carbon in soil. Pea was the most N and P use efficient pulse crop. Wheat had the lowest N efficiency, but has high potential for C sequestration, with a higher straw C/N ratio than pulses. Water use efficiency in wheat was not influenced by previous crops.

Our objective is to determine the optimum frequency and sequence of pulse crops (pea, lentil, chickpea) in rotation systems by analysing the performance of 14 different 4-year crop rotation systems in terms of yield production and quality, disease incidence, beneficial microbial associations and nutrient use efficiency.

Materials and Methods:

Experimental design

The field experiment was conducted at the Agriculture and Agri-Food Canada Semiarid Prairie Agricultural Research Centre (SPARC), Swift Current, Saskatchewan. Samples of crops, roots, rhizosphere soil and microbes were taken from the plots of the field experiments, and a series of laboratory analysis were conducted at SPARC Microbiology laboratory, where measurements were made using traditional and molecular tools. We chose this experimental site with the consideration that chickpea can only be grown well in the Southern areas of the Prairie. The sampling was at mid bloom stage. The plant varieties in the field were Lillian Hard Red Spring Wheat, CDC Frontier Kabuli Chickpea, CDC Meadow Yellow Pea and CDC Maxim CL Red Lentils. The treatments were tested in a RCB design with 4 replicates (16 plots; plot size: 4 x 8 m, borders: 2 x 12 m) as shown in Table 1. The experiment was first conducted in 2010-11 and was replicated in 2011-12.

Table 1. Treatments in field experiment for biodiversity study corresponding to different sequences of pulses and wheat crops grown from 2009 to 2013.

Pre-test (2009)	Treat.	Year 1 (2010)	Year 2 (2011)	Year 3 (2012)	Year 4 (2013)	Note
Wheat	1	Wheat	Wheat	Wheat	Wheat	Continuous wheat crop as a control system
Wheat	2	Pea	Wheat	Wheat	Wheat	1 pulse every 4 yrs (can a pea crop function as green fallow?)
Wheat	3	Chickpea	Wheat	Wheat	Wheat	1 pulse every 4 yrs (can deep-rooted chickpea function as shallow-rooted pea?)
Wheat	4	Pea	Wheat	Pea	Wheat	2 shallow-rooted pea every 4 yrs, alternated with wheat break
Wheat	5	Pea	Wheat	Lentil	Wheat	2 shallow-rooted alternate pulses every 4 yrs, with a wheat break
Wheat	6	Lentil	Wheat	Chickpea	Wheat	2 pulses every 4 yrs, shallow- and deep-rooted pulses alternated with wheat break
Wheat	7	Lentil	Wheat	Lentil	Wheat	2 pulses every 4 yrs, shallow-rooted lentil alternated with wheat break
Wheat	8	Chickpea	Wheat	Chickpea	Wheat	2 pulses every 4 yrs, only deep-rooted chickpea alternated with wheat break
Wheat	9	Pea	Mustard	Chickpea	Wheat	2 pulse species every 4 yrs with oilseed/wheat alternate breaks
Wheat	10	Pea	Mustard	Lentil	Wheat	2 shallow-rooted pulses every 4 yrs, with oilseed/wheat breaks
Wheat	11	Pea	Pea	Pea	Wheat	3 consecutive shallow-rooted pea every 4 yrs
Wheat	12	Lentil	Lentil	Lentil	Wheat	3 consecutive shallow-rooted lentil every 4 yrs
Wheat	13	Chickpea	Chickpea	Chickpea	Wheat	3 deep-rooted chickpea every 4 yrs
Wheat	14	Lentil	Chickpea	Pea	Wheat	3 pulses in 4 yrs with deep- and shallow-rooted pulses diversified

Sampling

Roots (0-15 cm) were collected a week after flowering of pulses and also on re-cropped cereal, and soil was sampled after harvest. Roots were washed and divided into representative subsamples. One subsample was cut to 1 cm fragments, mixed and stained for root colonization analysis. The parameters listed in Table 2 were or will be determined as indicated. All samples were taken from the right hand side of the plots while agronomy work was done in left hand side of the plot.

Assessment of root colonization

Root colonization was determined using the gridline intercept method after clearing in 10% KOH and staining in 5% Schaeffer black ink in vinegar (Giovannetti and Mosse, 1980). A photographic collection has been developed from these samples targeting the most common features that allow us to recognize AMF and DSE when colonizing the roots.

Root density and root length colonized by the fungi

Two root subsamples were also taken for the determination of plant root length per plant in duplicates. Samples were weighed, freed from all organic debris, placed in a biopsy cassette and stained in 0.8% Toluidine Blue solution for 5 min just before scanning, as described in Costa *et al*. (2001). Roots were spread apart on scanner tray and scan in an optical scanner Epson Protection V700 Photo with Dual Lens System. Image was saved and analyzed using the program WinRhizo PRO V 2003 for Windows (Régent Instrument Inc., Québec).

Root length was expressed as the total root length of an average plant in each plot, by multiplying sample length by total root weight, and dividing by the measured sample weight and by the number of plants sampled. Duplicates were averaged to obtain one value per plot. Root length colonized (RLC) was calculated as: colonization values X root length measurements.

Plant productivity and nutrient content analysis

Plant materials were sampled at harvest maturity. Plants on 0.5 m of four adjacent rows were hand harvested, dried at 45°C, and threshed. The dry mass of grain and straw was recorded and plant harvest index (HI) was calculated as the ratio of seed weight to the total weight of the harvested material. Straw and grain samples were submitted to the SPARC Chemistry Laboratory for determination of N and P concentrations in seed and straw. The 15.24 m^2 in the centre of each plot was harvested with a plot combine for yield determination.

Results:

Different crops and their sequence and frequency in the field influenced the biomass, yield, straw and seed nutrient content, soil water and nutrients and the function of the microbial community associated to the subsequent crops.

In 2011 wheat mature biomass and yield were greater when wheat was grown after pulses compared with the wheat monoculture (Fig.1). No differences were found among these parameters in the repetition of this trial in space/time in 2012 among treatments (data not shown).

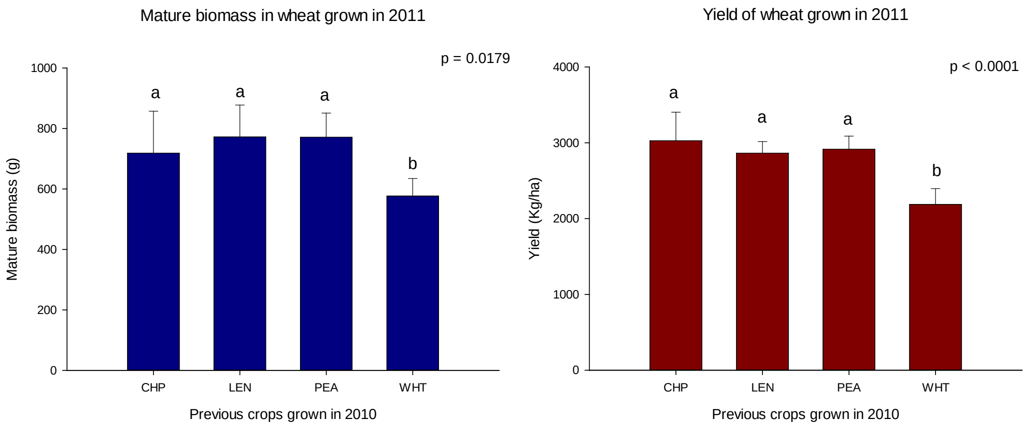

Figure 1. Plant mature biomass and yield of wheat grown in 2011 (trial 11-1040) after different crops. Data analyzed with ANOVA and LSMeans Differences Student's t using JMP10 software (SAS Institute Inc., Cary, NC, USA).

In 2011, P and N use efficiency varied among the crops sequences. P use efficiency was higher in wheat rotations. Among the pulse rotations pea monoculture had a greater P use efficiency than lentil or chickpea monoculture. N use efficiency was higher in pulses rotation and lower in wheat rotations (Fig.2).

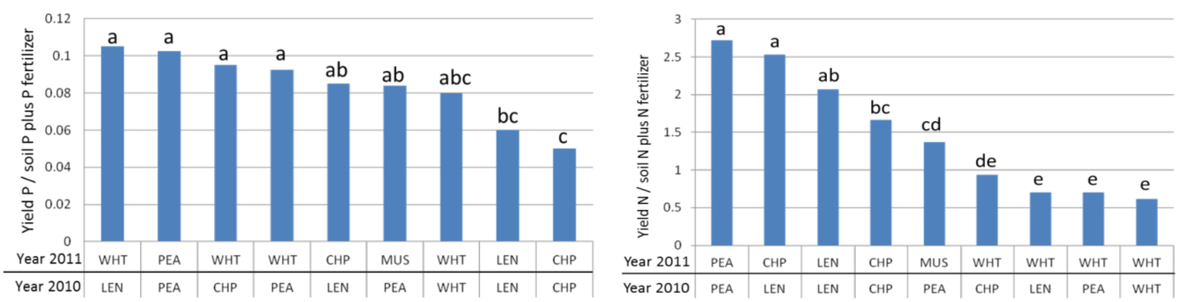

Figure 2. P and N use efficiency in the crops grown in 2011. Data analyzed with ANOVA and LSMeans Differences Student's t using JMP10 software (SAS Institute Inc., Cary, NC, USA).

Straw C:N ratio in the wheat rotations was higher than in pulses rotations. Pulses residues are easier to decompose by the microbial community due to their lower C:N ratio compared to wheat residues. However wheat has high potential for C sequestration, with a higher straw C/N ratio than pulses which increases the nutritional value of this crop (Fig.3).

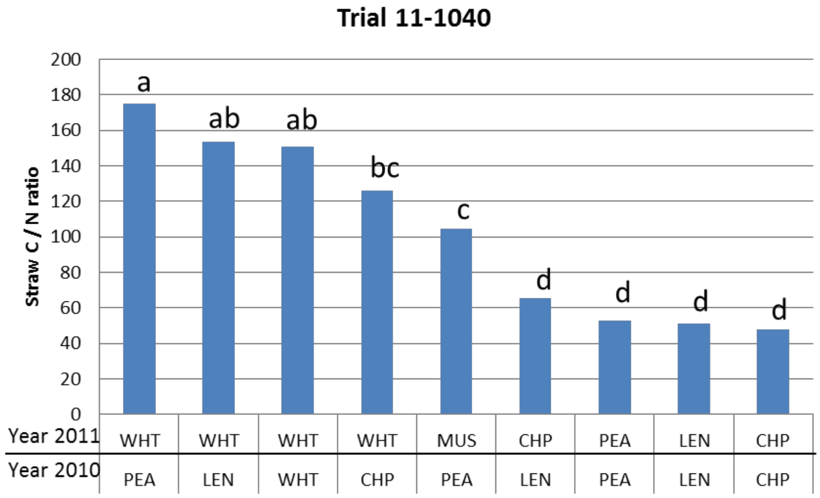

Figure 3. Straw C:N ratio in 2011. Data analyzed with ANOVA and LSMeans Differences Student's t using JMP10 software (SAS Institute Inc., Cary, NC, USA).

Crops differentially associated with pathogenic and beneficial fungi. *Fusarium avenaceum* was more frequent in pea than in other non-cereal crops, *F. oxysporum* was more abundant in lentil than in pea, whereas *Alternaria* spp. were most common in mustard. *Fusarium* spp. were less frequent in subcrown internodes of wheat than in the roots of non-cereals (Table 2).

Table 2. Root rot in noncereals (chickpea, peas, lentil, mustard) and percentage isolations of most common fungi in 2011.

Year 1	Year 2	Year 3	Year 4	% Severe-Very Severe root discolouration[1]		*% F. avenaceum*		*% F. oxysporum*		*% Alternaria spp.*	
CHP	**CHP**	CHP	WHT	51.4	a						
LEN	**CHP**	PEA	WHT	41.6	a						
PEA	**PEA**	PEA	WHT	20.8	b						
LEN	**LEN**	LEN	WHT	14.6	b						
PEA	**MUS**	CHP	WHT	3.2	b						
PEA	**MUS**	LEN	WHT	5.0	b						
	CHP			46.5	a	0.0	b	22.1	ab	2.5	b
	PEA			20.8	b	40.5	a	6.8	b	2.3	b
	LEN			14.6	bc	8.3	b	38.1	a	0.0	b
	MUS			4.1	c	8.1	b	20.9	ab	16.6	a

[1] Dark brown-black lesion covers 50-75% (severe) or >75% (very severe) of the root surface area.

Beneficial arbuscular mycorrhizal fungi and dark septate endophytes were also found to associate in different ways with different crops. This supports that plant have a selective influence on soil microorganisms and that plant-microbe interactions are regulated by plant factors (Fig.4).

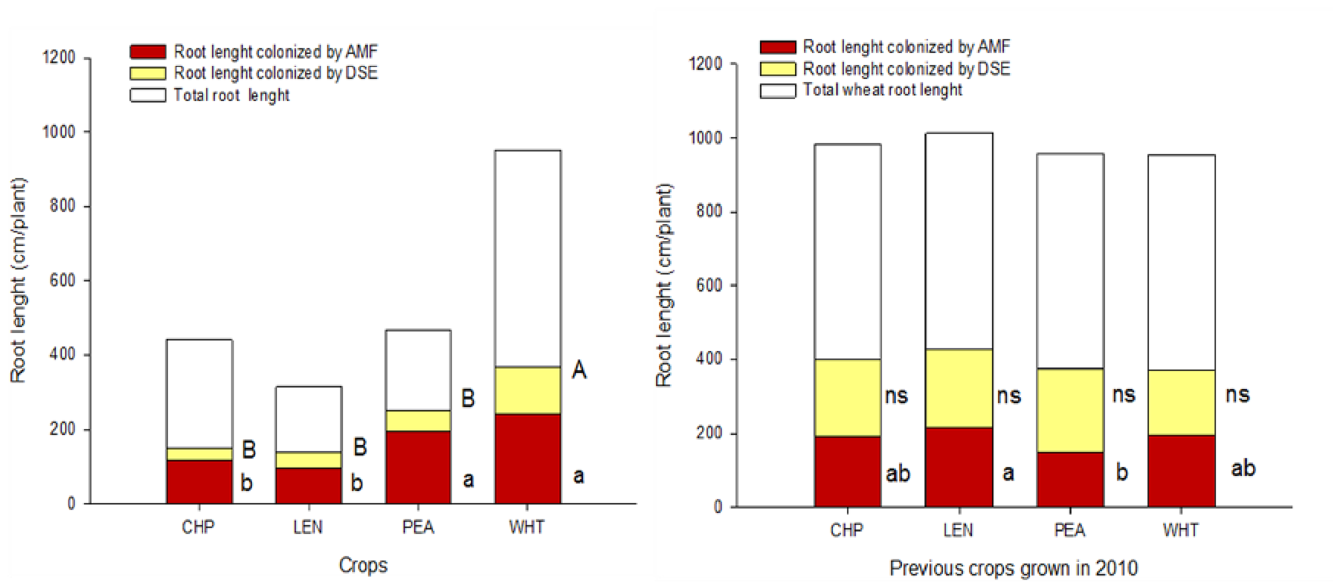

Figure 4. Root length colonized by AM fungi and dark septate endophytes in 2010 and 2011. Levels not connected by same letter are significantly different. Capital letters correspond to significant differences in RLC colonized by DSE among the crops. $p<0.0001$. Small case letters correspond to significant differences in RLC colonized by AMF among the crops. $p<0.0001$. ns: No significant difference was found.

Preliminary conclusions:

✓ Wheat plants grow and yield better when grown after pulses compared with wheat monoculture.

✓ Chickpea monoculture is highly susceptible to root rot disease.

✓ Pea is the most N and water use efficient pulse crop and wheat has the lowest N efficiency.

✓ Wheat has high potential for C sequestration, with a higher straw C/N ratio than pulses.

✓ Water use efficiency in wheat is not influenced by previous crops.

✓ Crop rotation can stimulate specific soil microbial communities that might directly influence the growth of successive crops.

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