Effect of Phosphorus Fertilization on Legume Green Fallow and Subsequent Wheat

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Abstract

A greenhouse study was conducted to determine effects of P fertilization on green manure and N production by chickling vetch, cv. AC Greenfix, in a degraded Brown sandy loam and to assess if P applied to the legume and N fixed during vegetative growth will be remineralized during partial fallow to adequately supply a subsequent crop of spring wheat. The soil from a stubble field near Cadillac, SK was placed in large plastic tubs which were randomized for the seven green fallow treatments consisting of Rhizobium inoculated and uninoculated AC Greenfix, each at three P levels (0,36 and 72 kg P ha-t), plus an uninoculated high N control fertilized with 72 kg P ha-t and 100 kg N ha-t. At full bloom, the legume top growth was coarsely chopped and soil incorporated. Then the green-manured soil was managed for 12 weeks as 'partial fallow' with occasional watering and periodic soil sampling to monitor available nutrients. Thereafter, all green-manured tubs plus tubs with the 'conventional fallow' control were seeded to spring wheat, cv. AC Barrie, which was harvested 14 weeks later when all treatments had reached maturity. Despite suboptimal legume growth due to midwinter light deficiencies in the greenhouse there was still a positive response to P fertilization. On a DM per plant basis, high P fertilized inoculated and uninoculated treatments produced 35% and 30% more green manure biomass than the respective unfertilized controls. Fertilization with P tended to enhance symbiotic N2 fixation while N fertilization at 100 kg ha-t resulted in complete inhibition of root nodule formation. Upon soil incorporation, legume decomposition in the greenhouse proceeded so rapidly that much of the green manure P and N was remineralized within the first three weeks of fallowing. Green fallow P fertilization accelerated the maturity of subsequent spring wheat by 12 to 18 days but it had no effect on grain yield. Grain protein and P contents were generally also unaffected by preceding P fertilization. This lack of green fallow P fertilization response in the greenhouse, in terms of wheat yield and quality, points to the need for a similar study under natural field conditions and greater crop nutrient demands. Nevertheless, all green fallow treatments in the greenhouse effected significant wheat yield increases over the yield on conventional fallow. Thus, benefits of green manuring per se on wheat were confirmed by an average 54% increase in grain and 20% increase in straw production. Green fallowing also increased the efficiency of grain production (e.g. harvest index) and it improved grain quality with an average 29% increase in kernel size and 14% increase in protein content. These results imply that legume green fallowing per se was more important to wheat production in the greenhouse than the rate of legume fertilization.

Introduction

The replacement of conventional fallow with forage or green manure legumes helps to protect the surface, improves soil quality and increases N fertility due to symbiotic N2 fixation (Green and Biederbeck, 1995; Biederbeck et al. 1998). Since deep-rooted perennial legumes use too much soil water, annual legumes, when grown for only six to eight weeks, i.e. until bloom, are better suited as 'Green Fallow' in dry regions. Among several annual legumes tested in southwest Saskatchewan, the chickling vetch (Lathyrus sativus) was identified as particularly well adapted (Biederbeck et al. 1993) and the cultivar AC Greenfix was developed as the green manure crop of choice for Brown and Dark Brown soils (Leyshon and Biederbeck, 1993).

Nodulated legumes require increased amounts of phosphorus to ensure optimum nodule formation and functioning (Vincent 1965). The increased requirement for phosphate is linked to the symbiotic process by way of the high ATP demand for N2 fixation (Bergersen 1971). As little is known about the P requirements of chickling vetch, when this new, high N2 fixing legume is grown as green fallow, this greenhouse study was conducted to (i) determine effects of P fertilization on green manure and N production by AC Greenfix in sandy soil, and (ii) assess if the P applied to the legume green manure will be remineralized during partial fallow to supply enough available P for a subsequent wheat crop.

Materials and Methods

In late fall 1996, the top 15 cm of Brown sandy loam in an eroded patch of an organic producer's stubble field near Cadillac, SK was stripped with a front end loader and trucked to S.P.A.R.C. for use in the greenhouse study of green manuring. Average physical and chemical properties of this soil were: FC (0.3 bar) = 10.20% and PWP (15.0 bar) = 5.47% moisture, pH = 7.21, EC = 0.28 dSm^{-1}, Total C = 1.31%, Organic C = 0.55%, Total N = 0.06%, NO_3-N = 0.39 ppm and PO^{1}-P = 2.12 ppm.

The field moist soil was mixed and sieved to remove plant material and then placed into large plastic tubs (56cm x 56cm x 35cm). Each tub was filled with 79kg field moist (i.e. 75kg OD) soil. All tubs were watered to induce germination of weed seeds and then kept moist for three weeks to allow for the growth and removal of weeds prior to the experiment. The tubs were arranged in a randomized complete - block design with seven treatments and four replications. The treatments consisted of <u>Rhizobium leguminosarum</u> - inoculated and uninoculated AC Greenfix, each at three P levels (viz. 0, 36 and 72 kg P ha-l), plus an uninoculated high N control fertilized at the highest P level and with 100 kg N ha^{-1}. The P fertilizer was banded 5cm below the soil surface along the planting rows by injecting with a syringe a saturated solution of super-phosphate (0-45-O). AC Greenfix was seeded at a depth of 2.5 cm and for a target density of 60 plants per m^2. For the high N control NH_4NO_3 solution was surface applied at five different times during the green manure phase with 20 kg N ha-t being added each time. Soil moisture was maintained between PWP and 3/4 of maximum available water by monitoring frequently with a Time Domain Reflectometry (TDR) portable system.

At full bloom (55 days after planting) i.e., February 5, 1997, all legume top growth was cut, weighed and subsampled for dry matter and nutrient analysis. The root systems of five randomly selected plants in each tub were excavated to examine the number, color and size of their nodules and to rate the nodulation by the scoring procedure commonly used with field pea in western Canada (W.A. Rice, personal communication). The legume top growth was coarsely chopped and incorporated into the top 10 cm with 25-30% of plant material still visible to provide soil protection during the partial fallow period, as would be required under field conditions.

For the next 12 weeks the green-manured soil in all tubs was managed as ‘partial fallow’ with occasional watering, to simulate rainfall events, and periodic soil sampling to monitor available nutrients.

On April 28, 1997, all green-manured tubs plus tubs containing the ‘conventional fallow’ control, i.e., without green manure or fertilization, were seeded to spring wheat, cv. AC Barrie, at a depth of 1 cm and for a target density of **100** plants per m^2. During the wheat phase moisture levels in the sandy soil were again closely monitored and were maintained in the range between 5.5% and 9% by frequent watering. The crop was grown until maturity was attained in all treatments. On August 6, 1997 (100 days after planting), the wheat was harvested by cutting all aboveground plant material and drying it at 40°C for a week prior to threshing. Grain and straw samples were weighed for yield and sub-sampled for nutrient analyses. Following the wheat harvest there was also a final sampling of soil from all tubs for nutrient analyses.

Result and Discussion

This greenhouse study comprised three very distinct sequential periods: first the 8 weeks of vegetative legume growth for green manure production, then 12 weeks of fallow following legume incorporation (plowdown) and finally the 14 weeks of spring wheat growth for grain production. However, we have deemed it to be more appropriate to discuss the results from the legume growth and the decomposition periods together under the heading ‘Green Fallow Phase’ and separately from results of the Wheat Phase.

Green Fallow Phase

Green manure production under the prevailing mid-winter greenhouse conditions ranged only from 16.3 to 22.2 g per tub (Table 1) which is equivalent to only 560 to 762 kg DM per ha. This is about one quarter to one third of the level of biomass production (i.e., 2,000 to 2,500 kg/ha) normally expected from AC Greenfix under favorable field conditions (Leyshon and Biederbeck, 1993). Obviously, legume growth in all treatments was suboptimal in the greenhouse during December and January due to insufficient supplementation of the very short daylight periods. The light deficiency also appeared to change the growth habit of the chickling vetch from it’s normal compact to a more spindly growth but it did not change the time required to reach full bloom. Under the unnatural greenhouse conditions, the uninoculated legumes produced similar amounts of green manure biomass and N as did inoculated legumes because all plant growth was suboptimal and because most uninoculated plants had some pink, i.e., effective, nodules and were apparently still able to symbiotically fix sufficient N_2 as indicated by the dark green color of their foliage and it’s 3.3 to 3.9% N content (Table 1).

Table 1. Effect of P Fertilization on Green Manure Production, Nutrient Content and Nodulation of AC Greenfix at Time of Soil Incorporation.

Fertility Treatment		Aboveground Dry Matter					Root Nodulation
Nitrogen	P fertilization. kg P/ha	Plants/tub	gDM/tub	gDM/plant	%N	%P	Score†
100 kg N/ha	72	20.50	22.12	1.08	4.30	0.24	0.50
Inoculated	72	19.50	20.97	1.08	3.91	0.27	7.00
Inoculated	36	21.00	19.47	0.93	3.83	0.26	7.00
Inoculated	0	20.50	16.33	0.80	3.61	0.24	7.50
Uninoculated	72	20.75	22.22	1.07	3.29	0.26	2.75
Uninoculated	36	20.00	19.48	0.97	3.28	0.24	2.75
Uninoculated	0	21.25	17.50	0.82	3.81	0.25	1.25
LSD (0.05)			2.89	0.14	0.90	0.09	1.99

† Rated on a scale from 0 to 8 according to nodule number, color and size.

Despite a general depression of legume growth due to lighting problems there was still a significant positive response to P fertilization. When compared on a DM per plant basis the inoculated and high P fertilized plants produced as much biomass as the high N & P fertilized reference treatment and 35% more than plants in the inoculated and P fertilized control treatment (Table 1). Uninoculated, high P fertilized plants also produced 30% more green manure than the corresponding unfertilized control plants. Furthermore, P fertilization tended to enhance symbiotic N_2 fixation but treatment differences in legume N production were generally not significant as nutrient demands and deficiencies were partly masked by the inadequate lighting. Similarly, the failure of green manure P contents to differ significantly must be attributed to the greatly reduced demand for this essential nutrient.

The chickling vetch is known to nodulate very readily and abundantly (Biederbeck et al. 1993), thus it was not surprising to find an excellent level of root nodulation, despite suboptimal growth conditions, in all inoculated treatments and a significantly weaker noduiation on the uninoculated plants. The five step application of a total 100 kg N/ha effected complete inhibition of root nodule formation on the fertilized plants (Table 1).

During the 12 weeks of fallow between green manure incorporation and wheat seeding soils from all treatments were sampled five times to assess the rate of legume decomposition and nutrient release. At the time of soil incorporation the levels of plant available N, P and S were naturally very low. Thus, on average (across all treatments), the soil contained only 2 ppm nitrate-N but, within three weeks of fallow this increased to 11 ppm and then more gradually to a maximum of 16 ppm just before wheat seeding. Practically all of the increase in N supply must be attributed to mineralization from green manure because nitrate-N levels in the non-green-manured control soil did not increase significantly during the same 12 week period. It seems that legume decomposition was greatly accelerated in the greenhouse which was likely due to more favorable soil temperature and moisture conditions. Thus, the rate and extent of N mineralization that occurred in the tubs within three weeks of green manuring was considerably greater than has been measured in the field when several annual legumes were decomposing under typical late summer dryland conditions (Biederbeck et al. 1996). The remineralization of fertilizer P, taken up during legume growth, also proceeded rapidly in the greenhouse after green manure incorporation because average phosphate levels in previously P-amended soils increased from 8 ppm P at incorporation to 21 ppm P three weeks later and then to a maximum of 25 ppm just before wheat seeding. During the same 12 week period, average phosphate levels in soils with P-unfertilized green manure barely increased from an initial 5 ppm to a final 7 ppm level, thus confirming the very low P supplying power of this infertile, sandy soil.

Wheat Phase

Neither P fertilization nor N treatment of the preceding green fallow affected the grain yield of spring wheat (Table 2) in this greenhouse study. However, P fertilization of the legume greatly influenced the maturity date and head size of subsequent spring wheat. At 83 days after seeding wheat heads were still green and rather short after P-unfertilized green manure while wheat following high P-fertilized green manure had tall heads with almost mature grain. In general, green fallow P fertilization accelerated grain maturity of the wheat by 12 to 18 days. Green fallow P fertilization did not influence wheat straw production or the harvest index but it affected grain quality, primarily by increasing kernel size (i.e., TKW) by as much as 28% over respective controls (Table 2). Wheat protein and, surprisingly, the grain P content also were generally unaffected by preceding P fertilizations.

All green fallow treatments effected significant increases in grain yield of subsequent wheat over the yield on conventional fallow. The benefits of legume green manuring per se on wheat were confirmed by the average 54% increase in grain and 20% increase in straw production (Table 2). Thus the harvest index of the wheat was significantly increased by all non-N fertilized green manures. After N fertilized green fallow the harvest index was as low as on conventional fallow because. the residual N fertilizer increased wheat straw production by an average 22% over that after unfertilized green fallow. Furthermore, plant N analyses and N balances indicated that the straw contained one third of total aboveground wheat-N after N-fertilized fallow but only one quarter on conventional fallow and less than a quarter after unfertilized green fallow (data not shown). Green fallowing increased not only the yield and efficiency of grain production but it also improved grain quality with an average 29% increase in kernel size and a 14% increase in protein content (Table 2).

Table 2. Effect of Green Fallow Fertility Treatment on Subsequent Spring Wheat Production and Quality.

Green fallow fert. trtmt.		Wheat production			Grain quality		
Nitrogen	P fertilization. kg P/ha	Grain. g/tub	Straw, g/tub	Harvest index	TKW†. g	Protein. %	Total P. %
100 kg N/ha	72	29.51	40.58	0.42	31.53	18.6	0.50
Inoculated	72	32.30	35.15	0.48	36.15	17.0	0.50
Inoculated	36	30.09	34.00	0.47	32.68	16.8	0.54
Inoculated	0	30.26	32.38	0.48	28.28	16.8	0.47
Uninoculated	72	28.57	31.03	0.48	34.28	17.0	0.48
Uninoculated	36	30.82	35.35	0.47	32.93	16.1	0.51
Uninoculated	0	33.60	34.61	0.49	30.15	15.9	0.45
Conventional (no GM)fallow control		20.01	28.93	0.41	25.13	14.8	0.49
LSD (0.05)		6.81	3.94	0.06	3.46	1.8	0.07

† Thousand kernel weight.

The lack of significant green fallow P fertilization response in terms of wheat yield and grain P content under the greenhouse conditions was unexpected and makes it essential that this study be conducted under natural field conditions with increased crop nutrient demand.

Conclusions

In this greenhouse study of green fallow fertilization we found that biomass and N_2 fixation during vegetative growth of inoculated and uninoculated AC Greenfix on a degraded sandy loam were increased by P fertilization. Upon soil incorporation much of the legume P & N was very readily remineralized and made available to subsequent spring wheat. Yet P fertilization of the preceding green fallow had no effect on grain yield or P content of the wheat crop. However, all green fallow treatments greatly increased the yield of grain over yields on conventional fallow and most treatments also improved the efficiency of wheat production and grain quality. Thus we concluded that the practice of legume green fallowing per se was more important to wheat production in the greenhouse than the rate of legume fertilization.

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