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Mustard Green Manures Replace Fumigant and Improve Infiltration in Potato Cropping System

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Abstract

In potato (*Solanum tuberosum*) production, farmers often use expensive fumigants to control soilborne pests. Mustard green manures may offer farmers an equally effective, but less expensive, alternative to fumigants for control of these pests. In a spring wheat (*Triticum aestivum*)-potato rotation, potato (Russet Norkotah) yields following white mustard (*Sinapis alba* Martigena) or oriental mustard (*Brassica juncea* Cutlass) green manures averaged 32.5 tons/acre with or without the soil fumigant metam sodium. An average of 86% of the tubers met the US #1 grade (>4 oz). Infiltration rates for soils receiving mustard green manures were from 2 to 10 times greater than those not receiving green manures. In similar potato cropping systems, farmers replacing metam sodium with mustard green manures could potentially improve their soil's infiltration rate while saving an estimated $66/acre.

Introduction

Washington potato farmers produce record yields but low market prices are forcing them to cut production costs to remain competitive. Given this incentive, a central Washington farmer developed a wheat/mustard-potato cropping system that allowed him to successfully grow potatoes every other year in a region where a majority of the potatoes are grown in four year or longer rotations. In this system, a mustard green manure is planted in August after wheat harvest (Figs. 1 and 2), and incorporated in late October (Fig. 3). In 1999, this farmer asked us to investigate and verify the benefits which he attributed to green manuring with mustard.

Fig. 1. Direct seeding of mustard into wheat stubble.

Fig. 2. Mustard in September growing through wheat stubble.

Fig. 3. Flail-chopping and disking mustard in late October.

Mustard and other *Brassica* crops have been shown to suppress nematodes (8), weeds (1), and soilborne fungal pathogens (10,13). The potato pest *Verticillium dahliae*, a major cause of the potato early dying complex, has been suppressed by green manures of sudangrass (*Sorghum sudanense*), wheat, and sweet corn (*Zea mays*) (2,3). One study (7) found that other *Brassica* green manures increased the total fungal populations but reduced those of *Pythium*, while a non-*Brassica* green manure resulted in increases in both total fungal and *Pythium* populations. The differing results may be due to specific chemicals produced by *Brassica* crops. The effects of these chemicals on soilborne pests, when incorporated as a green manure has been termed biofumigation (6) because of the similarities between some of the degradation products and synthetic fumigants.

While green manures are known for improving soil properties, knowledge of their ability to suppress pests is relatively new. We set out to quantify the effects of the mustard green manures on both soil quality and on soilborne pests in this cropping system. To evaluate soil quality, we chose to measure infiltration because it is meaningful to farmers and it integrates several other soil quality attributes such as bulk density, aggregation, and pore space. To evaluate pest suppression, we chose to compare potato yields in this cropping system with and without the fumigant metam sodium. This fumigant is used routinely in potato production and is viewed by most farmers to be necessary for control of potato early dying disease, especially in short rotations (less than three years between potato crops) and with susceptible varieties.

Effects on Infiltration Rates

Washington potato farmers frequently have problems with irrigation water runoff because their center-pivot irrigation systems often operate above the infiltration capacity of their soils. The resulting problems of non-uniform water and chemical application and with increased disease potential in low areas can be minimized by obtaining and maintaining high infiltration rates.

We measured infiltration rates using a single 6-inch ring (15) on adjacent fields near Moses Lake, WA. One field was under a rotation of crops commonly grown in the area, but without green manures. The other field was under the wheat/mustard-potato cropping systems previously mentioned. The soils were Timmerman coarse sandy loams (sandy, mixed, mesic Xerollic Camborthids). Measurements were taken at various dates and points in each rotation with 4 to 10 replications per sampling date. Random sites were chosen in areas that had not been compacted by field machinery and, when possible, in the crop row. We measured the time required for one inch of applied water to soak into the soil, halting the measurement at 20 min (average infiltration rate of 0.05 inch/min) or after the third application of water at a ring location, whichever came first. The measurements were analyzed as a complete randomized design. We also compared the stability of aggregates from the two fields, as estimated by a slake test (15).

The infiltration rates in the field receiving mustard green manures exceeded those of the other field in all but two of the comparisons (Table 1). The field receiving mustard green manures also had more water-stable aggregates (average stability class 5.0) than the other field (average stability class 3.2, difference significant at $P = 0.05$). Because the two fields had different rotations, the effects cannot be attributed directly to the mustard green manures.

However, these results show that the wheat/mustard-potato rotation maintained higher infiltration levels than a longer rotation of crops including corn, wheat, potatoes, and sugar beets. Some of this effect is likely the result of the green manure, as the wheat/mustard-potato rotation by itself with a low residue, intensively tilled (at harvest) crop like potatoes grown every other year would not be recommended to maintain soil quality. In addition, the increase in soil aggregation after a green manure has long been known (4).

Table 1. Average infiltration rates (inches/min), after consecutive 1-inch applications of ponded water.

Point in rotation[b]	Average Infiltration Rates (inches/minute)[a]		
	1st inch	2nd inch	3rd inch[c]
September 3, 1999			
After wheat harvest (MGM[d])	1.39a	0.48a	
After wheat harvest	0.13b	0.18b	
November 2, 2000			
After potato harvest (MGM)	0.20a	0.19a	0.16
After sugarbeet harvest	0.39a	0.05b	
March 7, 2001			
Potatoes/winter (MGM)	0.57a	0.10a	
Sugarbeets/winter	0.06b	0.05b	
March 5, 2002			
Potatoes/winter (MGM)	0.14a	0.09a	0.08
Fallow/winter	0.10a	0.05b	

[a] Mean separation, within date and inch applied, by PLSD at 0.01 level.

[b] Before sampling, the fields had no tillage operations after harvest of the crops in the first two comparisons, and no spring tillage operations in the latter two comparisons.

[c] Third inch not measured on the first and third dates due to time constraints, and on the other dates because measurements with the second inch were halted at 20 min for all replications in that field.

[d] Rotation with mustard green manures (MGM).

Potato Yields, With and Without Fumigant

Three trials were conducted to compare the existing, proven technology, metam sodium, with the new technology of mustard green manures to suppress *Verticillium dahliae*, under conditions where metam sodium would normally be used. One trial took place in 1999-2000, and two other trials, differing only in the type of mustard used, took place in 2000-2001. The fields had produced three (1999-2000 trial) or six (2000-2001 trials) previous potato crops, grown in the wheat/mustard-potato rotation described above. Russet Norkotah, a relatively short season, fresh market potato cultivar, was grown in these fields. It is considered susceptible to *Verticillium dahliae*/potato early dying (11).

Since the trials were carried out under center-pivot irrigation systems, leaving plots without mustard would have required either giving up randomization of the treatments or adding confounding factors associated with leaching and nitrogen levels. Therefore, the two treatments, with (+) and without (-) fumigant, both followed mustard.

The trials were conducted following spring wheat in two fields, 25 acres (1999) and 20 acres (2000), under center-pivot sprinkler irrigation. The fields were planted to white mustard Martigena (1999 and 2000), or oriental mustard Cutlass (2000). The mustards were planted in mid-August at approximately 10 lb/acre. The sum of residual soil-N and applied fertilizer-N was 120 lb/acre and adequate soil moisture was maintained through irrigation. Volunteer wheat was killed using a selective herbicide. In late October, the mustard was flail-chopped and immediately disk-incorporated with two passes into moist soil.

Aboveground biomass yields for the mustard were 5564 and 4773 lb dry matter/acre for Martigena (1999 and 2000, respectively) and 5023 lb dry matter/acre for Cutlass (2000).

The following March (2000 and 2001), metam sodium was applied to the fields with a ground applicator at 37.5 gal/acre. The entire field was fumigated except for plots 200+ ft long by 28 ft wide (two passes of the applicator), where the flow of the fumigant was turned off. These plots were paired with similarly sized fumigated plots and were set up perpendicular to the direction of the potato rows and replicated six (2000) or five (2001) times. The order of the paired treatments, with (+) and without (-) fumigant, was randomized yielding a complete randomized block design. Management was equal in all plots after the application of the fumigant and was similar to other potato operations in the region.

Potatoes (Russet Norkotah) were planted the third week of April with 10.5-inch in-row spacing and 34 inches between rows. In early to mid September, the potatoes from ten feet of row were dug by hand from each plot, graded, and weighed. The same row was harvested from all plots to avoid any planting differences between rows. Statistical analysis of the data showed that there were no significant differences between the potato yields of the two treatments in any of the three trials. Nor were there any statistically significant differences in the harvested tuber size classes. The total yields, averaged across the treatments, were 31.6, 34.2, and 31.6 tons/acre, respectively, for the three trials, with 82%, 88%, and 88%, respectively, of the tubers meeting the US #1 grade (>4 oz). These yields are above the average yields for Grant County in those years (16), which were 30.5 (2000) and 30 tons/acre (2001).

Without metam sodium treatment, serious losses due to potato early dying would be expected from the combination of multiple potato crops with a susceptible potato clone in a two-year rotation. Furthermore, analysis of soil from the 2001 trials confirmed the presence of damaging levels of *V. dahliae.* Soil samples taken from these trials were sent to a lab that assayed the levels of *V. dahliae* using methods reported in Johnson et al. (5). The results were reported in colony forming units (CFU) per gram of dry soil. Average pre-plant levels (4 April 2001) after mustard were 10 and 22 CFU/g, for the (+) fumigant and (-) fumigant plots respectively (no significant difference). Samples from an unreplicated fallow area (without mustard) showed 18 CFU/g. According to the scientist doing this analysis, fields planted to the potato Russet Burbank in this region, with 13 CFU/g, would be considered at high risk of yield losses from potato early dying (P.B. Hamm, personal communication, 2003). Russet Burbank is considered moderately resistant to *V. dahliae*, therefore the threshold for Russet Norkotah may be even lower.

These results suggest that, in this cropping system, the mustard green manure by itself can suppress *Verticillium dahliae* sufficiently to maintain potato yields, and that metam sodium after a mustard green manure does not further increase crop yield. This conclusion is supported by the fact that despite conditions favoring significant yield loss to potato early dying, the measured yields exceeded the county averages, which include the yields of many potato crops grown under more favorable conditions. Furthermore, metam sodium is used on over 50% of the potato acreage in Washington (9), usually in situations less risky than this one because the yield decreases due to Verticillium wilt have been well documented (12). Therefore, it is reasonable to assume that yields would have been below the county average if the *Verticillium* had not been suppressed by either the mustard green manure or the metam sodium.

Two further assumptions are required to support this conclusion. First, that the mustard green manure did not reduce yields. This assumption is supported by the fact that the potato yields were above average for the county and they were produced in a short two-year rotation that would not normally be recommended. Second, that the mustard green manure did not reduce the effectiveness of the fumigant. This is not likely in this system where the green manure is incorporated in October and the fumigant is applied five months later in the following March. We believe these assumptions and the conclusion are reasonable.

Cost of the Mustard Green Manure and Expected Savings

The total estimated production cost for the mustard green manure is $93/acre (Table 2). Although this includes the cost of the fertilizer applied to the mustard, a portion of the nutrients incorporated in a green manure crop will become available to the following crop. Thus, a portion of the $38/acre spent on nitrogen fertilizer may be recovered by reduced nitrogen requirements in the following crop. Although we have not yet quantified this nutrient cycling, the 2001 potato crop required (based on petiole nutrient sampling) only 160 lb N/acre, applied as fertilizer. This is much less than the 250+ lb N/acre that is normally applied to potato crops in this region and suggests that a significant amount of nitrogen from the green manure is being utilized by the potato crop.

Table 2. Estimated variable costs for a mustard green manure (per acre, 2002).

Item	Unit	Cost/unit	Quantity	Mustard	Normal[a]
Seed	lb	$2.35	10	$23	$0
Planting	acre	$6.10	1	$6	$0
Fertilizer	lb	$0.38	100	$38	$0
Herbicide	acre	$15.00	1	$15	$0
Irrigation power	acre-inch	$1.78	9	$16	$5
Chopping	acre	$6.00	1	$6	$6
Disking/packing	acre	$5.00	2	$10	$10
			Total:	$114	$21
				Mustard cost over normal practice:	$93

[a] Costs normally incurred following wheat harvest.

This nutrient cycling reduces the cost of the green manure, but the amount of nitrogen cycled is difficult to estimate because it will vary with crop growth and the climatic conditions preceding potato planting. A common recommendation is that farmers can expect 50% of the nitrogen incorporated in a green manure to become available for the following crop (14). Using this estimate and an average of 100 lb N/acre in the mustard green manure crops, the expected reduction in the potato N requirement would be about 50 lb/acre. An additional savings of $140+/acre will occur if the mustard replaces the metam sodium. A partial budget analysis for the replacement of metam sodium by mustard green manures (Table 3) shows an overall savings of $66/acre.

Table 3. Partial budget for the replacement of metam sodium by a mustard green manure.

Partial Budget, per acre			
Additional costs		**Additional revenues**	
Mustard green manure	$93		None
Reduced revenue		**Reduced costs**	
	None	Metam sodium application	$140
		50 lb N/acre fertilizer, at $0.38/lb	$19
A. Total additional costs and reduced revenue	$93	**B.** Total additional revenue and reduced costs	$159
		Net change in income (B-A):	$66

Conclusions

The findings suggest potential for mustard green manures to replace the fumigant metam sodium for the production of potatoes in some cropping systems. The practice can also improve water infiltration rates and provide substantial savings to farmers. While these results should not be extrapolated to longer rotations, longer-season potatoes, or to different soil types without further verification, they are promising and warrant further study into the use of mustard green manures for control of soilborne pests in potato and other cropping systems. Related work on the management of mustard green manures may be found online at the Grant-Adams website of WSU Extension (17).

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Literature Cited

1. Boydston, R. A., and Hang, A. 1995. Rapeseed (*Brassica napus*) green manure crop suppresses weeds in potato (*Solanum tuberosum*). Weed Technol. 9:669-675.
2. Davis, J. R., Huisman, O. C., Westermann, D. T., Sorensen, L. H., Schneider, A. T., and Stark, J. C. 1994. The influence of cover crops on the suppression of Verticillium wilt in potato. Pages 332-341 in: Advances in Potato Pest Biology and Management. G. W. Zehnder, M. L. Powelson, R. K. Jansson, and K. V. Raman, ed. American Phytopathological Society, St. Paul, MN.
3. Davis, J. R., Huisman, O. C., Westermann, D. T., Hafez, S. L., Everson, D. O., Sorensen, L. H., and Schneider, A. T. 1996. Effects of green manures on Verticillium wilt of potato. Phytopathology 86:444-453.
4. Harris, R. F., Chesters, G., and Allen, O. N. 1966. Dynamics of soil aggregation. Adv. Agon. 18:107-169.
5. Johnson, K. B., Apple, J. D., and Powelson, M. L. 1988. Spatial patterns of Verticillium dahliae propagules in potato field soil of Oregon's Columbia Basin. Plant Dis. 72:484-488.
6. Kirkegaard, J. A., and Sarwar, M. 1998. Biofumigation potential of brassicas. I. Variation in glucosinolate profiles of diverse field-grown brassicas.. Plant and Soil 201:91-101.
7. Lazzeri, L., and Manici, L. M. 2001. Allelopathic effect of glucosinolate containing plant green manure on *Pythium* sp. and total fungal population in soil. HortSci. 36:1283-1289.
8. Mojtahedi, H., Santo, G. S., and Wilson, J. H. 1993. Managing *Meloidogyne chitwoodi* on potato with rapeseed as green manure. Plant Dis. 77:42-46.
9. National Agricultural Statistics Service. 2002. Agricultural chemical usage: 2001 field crops summary. USDA, Washington, DC.
10. Olivier, C., Vaughn, S. F., Mizubuti, E. G., and Loria, R. 1999. Variation in allyl isothiocyanate production within *Brassica* species and correlation with fungicidal activity. J. Chem. Ecol. 25:2687-2701.
11. Powelson, M. L., Johnson, K. B., and Rowe, R. C. 1993. Management of diseases caused by soilborne pathogens. Pages 149-158 in: R. C. Rowe, ed. Potato health management. American Phytopathological Society, St. Paul MN.
12. Powelson, M. L., and Rowe, R. C. 1993. Biology and management of early dying of potatoes. Ann. Rev. Phytopathol. 31:111-126.
13. Smolinska, U., and Horbowicz, M. 1999. Fungicidal activity of volatiles from selected cruciferous plants against resting propagules of soil-borne fungal pathogens. Phytopathology 147:119-124.
14. Sustainable Agricultural Network. 1998. Managing cover crops profitably. 2nd ed. SAN, Washington, DC.
15. USDA-ARS/NRCS Soil Quality Institute. 1999. Soil quality test kit guide. USDA, Washington, DC.
16. Washington Agricultural Statistics Service. 2003. 2002 Washington Agricultural Statistics. Washington State Department of Agriculture, Olympia.
17. Washington State University Cooperative Extension. 2003. Grant-Adams Area Cooperative Extension. Online. USDA, WSU, and Grant and Adams Counties, Ephrata, WA.