MANURE SLURRY-ENRICHED MICRO-SITE SEEDING OF BIOSUPPRESSIVE COVERS

T. M. Harrigan, D. R. Mutch, S. S. Snapp

ABSTRACT. *There is increasing interest among growers in novel establishment systems for cover crops that can rehabilitate and protect soil. Cropping intensification has led to yield declines, compacted and poor quality soil, and increased pest problems. Cover crops in the Brassica (mustard) family offer benefits in soil conservation, improvement in soil quality, reduction in nitrate leaching, and suppression of certain pests and soil borne fungal diseases. Establishment of cover crops by conventional methods following harvest presents a significant challenge as soil is generally dry, compacted, uneven, and far from an ideal environment for seed germination. An alternative method, manure slurry-enriched micro-site seeding, incorporates aeration tillage, manure application, and seeding in a single operation. The objective of this work was to evaluate manure slurry-enriched micro-site seeding of cover crops by assessing stand establishment and biomass yield of oilseed radish and oriental mustard. The species were chosen for contrasting seed size, thus allowing evaluation of how small versus medium seeded brassica respond to aeration tillage, manure application, and seeding done in a single efficient 'manure slurry-enriched micro-site seeding' operation. Results of field trials in 2004 and 2005 were consistent with the new manure slurry seeding process as an efficient and effective cover crop establishment method. Compared to direct-drilling, manure slurry seeded plant stands (plants m^{-2}) were significantly less ($\alpha = 0.10$) in five of seven comparisons but biomass yields (kg ha^{-1}) were similar because individual plant biomass was up to six times greater with manure slurry seeding. Biomass (aboveground and total) of manure slurry seeded plants was significantly greater in two of seven comparisons and there were no instances when the conventionally seeded crops yielded significantly more than the manure slurry seeded crops. Seed size did not affect the success of the manure slurry seeding method.*

Keywords. *Manure management, Manure slurry-enriched micro-site seeding, Manure slurry seeding, Cover crops, Biosuppression, Aeration tillage.*

The development of cropping systems that reduce tillage intensity, enhance the use of cover crops, and make efficient use of manure can protect the environment and improve soil quality. Low-disturbance tillage and conservation practices that stabilize soil will keep land-applied manure in the root zone and protect water quality. Manure slurry-enriched micro-site seeding of cover crops holds promise as a novel and cost effective means to establish a vegetative cover with little soil disturbance. Such a process could expand the land base and window of opportunity for land application, reduce cover crop establishment costs, improve soil quality and nutrient management, and improve farm profitability.

Cover crops prevent erosion and filter contaminants in runoff (Coyne et al., 1995; Burket et al., 1997; Lowrance et al., 1997; Lim et al., 1998; Feyereisen et al., 2003). They have also improved water-stable aggregation of soil and increased water infiltration compared to soil without cover crops (Mathers et al., 1977; McVay et al., 1989). As soil aggregation improves, soil structure and tilth also improve (Allison, 1968).

Small grains can provide winter cover, reducing soil erosion and nitrate leaching (Brinsfield and Staver, 1991; Ferguson et al., 2005). Because the length of time during the year in which growing plants are present in the field is a critical factor in preventing nutrient loss and conserving nitrogen, a winter cover crop is a valuable tool for preventing nutrient loss to the environment. Research has documented organic matter accumulation, improvements in soil quality and reduced pest problems by integrating small grains, brassica, and legume cover crops into field crop rotations (Harwood et al., 1996; Mutch, 1996; Kinyangi et al., 2001).

BIOSUPPRESSIVE ORGANIC MATTER INPUTS

In the Upper Midwest, vegetable growers use winter cereals as cover crops to protect soil from wind erosion, but establishment costs and the additional management requirements of cover crops have limited their widespread use (Snapp et al., 2005). There is growing evidence that cover crops in the *Brassica* (mustard) family offer benefits in some rotations beyond soil conservation. Forage radish crops have been used to alleviate compaction in coastal plain soils in Maryland (Williams and Weil, 2004). When grown as a green

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manure trap crop, oilseed radish (*Raphanus sativus*) has suppressed sugar beet cyst nematode (*Heterodera schachtii;* Hafez, 1998). The incorporation of oriental mustard (*Brassica juncea* L., variety Pacific Gold) in the spring before planting potatoes suppressed *Rhizoctonia solani* by 73%, and the cover was highly suppressive of fungal activity by *Pythium ultimum* and *Fusarium solani* (Snapp et al., 2006). During tissue decomposition of *Brassica* spp., glucosinolate compounds are produced that have antifungal, nematicidal, and bactericidal properties (Lewis and Papvizas, 1974; Stapleton and Duncan, 1998; Morra and Kirkegaard, 2002).

Manure with relatively high levels of nitrogen and available carbon has suppressed soil borne pathogens under some but not all field environments studied (Conn and Lazarovits, 1999; Tenuta, 1999). These studies reported that poultry and swine manure were the most consistently beneficial manure sources for reducing *Verticillium dahliae* and common scab in potato. Findings from several long-term research trials were also consistent with manure enhancing root health and yield response of potatoes, vegetables, and field crops, particularly when manure was applied in combination with a winter cover crop (Sanchez et al., 2001; Snapp et al., 2004). Manure and cover crop integration in long-term Maine potato system trials had more variable results (Griffin and Porter, 2004). Timing and management of organic inputs appear to be critical to promoting health and yield in cropping systems.

Seeding Micro-Sites and Seed Contact with Manure

In the natural environment, variations in topography create micro-sites for seedling establishment. Seeds that fall to the ground are carried by wind or water to protected micro-sites within soil cracks, beneath soil aggregates or crop residues where they compete for germination sites with other seeds in the soil-seed bank. Specific properties of a favorable seeding site vary among species (Naylor et. al, 1983). The site must provide a suitable environment for seed germination (temperature, water, light exposure), leaf expansion (temperature, light, exposure), and root penetration (soil particle size, pore size distribution, aeration, pH, nutrient, and moisture availability; Pearson and Ison, 1997). Surface sowing is generally less reliable than a tilled seed bed because soil temperature and moisture fluctuations are more extreme than that below the soil surface.

A common method of seed dispersal is through ingestion and subsequent deposition of the seed in feces of grazing animals. The survival of seed in the feces varies with the type of livestock and forage species. Neto and Jones (1983) recovered 51%, 20%, and 11% of ingested seed from cattle, goats, and sheep, respectively. The viability of many seed species is not greatly affected by immersion in stored manure. In New York, Mt. Pleasant and Schlather (1994) recovered viable seeds from 13 grasses and 35 broadleaf plants in dairy manure samples collected from 20 farms. Cudney et al. (1992) recovered more than 21,000 viable weed seeds per ton of sediment from dairy manure handling facilities and reported that anaerobic storage did not have a significant impact on seed viability.

Manure in the Seedbed

Several researchers have reported germination inhibition and problems in the subsequent crop when seeding soon after a manure application in a conventional seedbed (Adriano et al., 1973; Sawyer et al., 1991; Schmitt et al., 1992). Apparent causes of seed inhibition were locally high concentrations of NH_4 followed by accumulation of NO_2 and an elevated pH; lowered redox potential, and an elevated osmotic potential creating temporary, locally toxic conditions. Matsi et al. (2003) reported no effect on wheat seed germination from 40 Mg ha^{-1} yr^{1} (4300 gal. $acre^{-1}$; 120 N, 26 P, and 90 K kg ha^{-1} yr^{-1}) of liquid cattle manure applied two days before seeding. In contrast, a greenhouse study by Adriano et al. (1973) showed that dry and fresh manure applications equivalent to 5%, 10%, 15%, and 20% by weight in a loam soil suppressed seed germination of all species except barley.

Crop Inhibition in Injection Zones

Researchers have reported problems in subsequent crops when manure was injected at high rates, but the equipment used was considerably different from that used for manure slurry seeding. Manure injected with a chisel-type tool tends to deposit the slurry in a non-uniform, narrow band. Corn injury has been observed following such an application (Schmitt et al., 1983; Schmitt and Hoeft, 1986). Corn roots did not grow into these injection zones and the plants had a chlorotic appearance. Soil chemistry was greatly altered by the high concentration of manure in the injection zone. Schmitt et al. (1992) reported that the soil redox potential was decreased, pH increased for a two week period following manure injection, and nitrite-N (NO_2-N) accumulated at high levels for up to 4 weeks. Winged injectors were found to distribute the manure over a wider area and decreased the potential for root inhibition and nitrogen losses (Schmitt and Hoeft, 1986; Sawyer et al., 1991).

Aeration Tillage and Shallow Manure Deposition

Land management alternatives that reduce tillage intensity and make efficient use of manure in the cropping system could improve nutrient cycling and farm profitability. Aeration tillage provides a low-disturbance option for alleviation of shallow compaction and improved infiltration of liquid manure. This could be an important new tool for enhancing establishment within livestock-based, no-till cropping systems. Harrigan et al. (1996) described a modified no-till system that used aeration tillage which reduced machinery costs 25%; fuel costs 45%; and labor costs 50% compared to conventional tillage and planting. Chen et al. (2001) reported that a rolling-tine aerator provided an earlier yield response than three other shallow slurry injectors and a dribble-bar applicator when applying swine manure to grassland at N rates of 112 kg ha^{-1}. Bittman et al. (2005) reported that surface banding over aeration slots improved the yield of perennial grass by about 11% over surface broadcasting and 4% over surface banding. In Michigan, when a rolling-tine aerator was used with a slurry distribution system and drop tube applicator, the slurry was placed in soil voids and loosened soil directly behind each group of aerator tines (Harrigan et al., 2006). The greatest manure nutrient concentration was in the surface-to-eight centimeter soil layer at the points of tillage tine entry, but the slurry infiltrated quickly and crop inhibition following such an application was considered unlikely. This system shows promise as a means to establish cover crops with minimal disturbance while disbursing manure using environmentally sensitive technology.

OBJECTIVES

The overall goal of this work was to evaluate manure slurry-enriched micro-site seeding of a range of plant species in various soil types, and develop practical, efficient, and cost-effective guidelines for on-farm adoption. The specific objectives were to:

- Evaluate plant stand (plants m^{-2}) and biomass yield (kg ha^{-1}) of two cover crop species: 1) oil seed radish, and 2) oriental mustard.
- Quantify the effect of seeding method on fall cover crop establishment in wheat stubble comparing a new process -- manure slurry-enriched micro-site seeding -- with conventional seeding methods.

MATERIALS AND METHODS

Oil seed radish (*Raphanus sativus* L.) and oriental mustard (*Brassica juncea* L.) were sown in wheat stubble at the University Farms at Michigan State University in East Lansing, Michigan, in 2004 and 2005 and at the Kellogg Biological Station (KBS) in Hickory Corners, Michigan, in 2005. Each crop was sown with a grain drill and with a new manure slurry-enriched seeding method developed at Michigan State University. The manure slurry seeding was done with a commercially available slurry tanker (11,340 L) equipped with a rear-mounted rolling-tine aerator (3.66 m; Aer-Way, Holland Equipment Ltd. Norwich, Ontario, Canada) and a SSD (sub-surface deposition) slurry distribution system (fig. 1). The rolling-tine aerator was ground-driven with sets of four 20-cm tines mounted helically on a rotating shaft with 19-cm spacing between each set of tines. The tines were angled slightly on the shaft to provide lateral movement and loosening of the soil. The angle of the rotating shaft was adjustable in 2.5° increments from 0° to 10° degrees from perpendicular relative to the direction of travel. The 0° gang angle provided little soil disturbance while the 10° gang angle provided the most soil loosening. No additional seedbed tillage or soil firming was used. The aeration tool and slurry tank were drawn behind a 112-kW tractor at 4.8 km h^{-1}.

Figure 1. The rolling tine aerator created cracks and fissures in the untilled ground and the drop tube applicator placed the seed-laden slurry in the fractured soil.

The manure slurry seeding process involved mixing cover crop seed in the slurry tank (fig. 2) and passing the seed-laden slurry through a hydraulically driven, rotating chopper/distributor (300 rpm) with radially configured outlets and then through drop tubes to the fractured and loosened soil behind each set of rolling tines. The oriental mustard (OM; *Brassica juncea* L., variety Pacific Gold) seed was small (393,700 seeds kg^{-1}) with a uniform, oval, smooth seed coat. The oil seed radish (OSR; *Raphanus sativus*, variety Colonel) was larger (90,600 seeds kg^{-1}) with an irregular, rough seed coat. Based on the slurry tank volume and seed added the OM and OSR seed concentration was about 79 and 27 seeds L^{-1}, respectively.

The throughput of the slurry tank PTO-driven centrifugal pump was about 6000 L min^{-1}, but only about 1600 L min^{-1} was needed to apply agronomic rates of 46,750 to 56,100 L ha^{-1}. The excess pump capacity provided bypass flow for seed mixing and distribution. Slurry rate calibration was based on tractor engine rpm, travel speed, machine width, and slurry flow rate. The flow rate was monitored with an electromagnetic flow meter (12.7 cm diameter; Danfoss, Danfoss Inc., Milwaukee, Wis.) mounted on the SSD. The manure analysis and nutrient application rate for each year and location are listed in table 1. Because commercial fertilizer is not often used in cover crop establishment, no manure or commercial nutrients were applied to the drilled treatments. Each site was sprayed with glyphosate (0.38 kg ha^{-1} A.I.) 7 to 10 days prior to seeding to suppress weeds and volunteer wheat.

PLANT MEASUREMENTS

All plants contained in two quadrats per plot (0.5 × 0.5m) at East Lansing, and three quadrats per plot at KBS were harvested. Plant biomass and population were measured by pulling all plants in each quadrate out of the soil to recover the taproot, cutting as close as possible at the root/shoot interface, and washing taproots of excess soil. All plant material was dried at 60°C for 72 h (*ASAE Standards*, 2003) for dry matter and yield determination.

East Lansing, 2004

Replicated plots (3.7 × 18.3 m) were established in a randomized complete block with four replications in a Capac fine sandy loam (fine-loamy, mixed, active, mesic Aquic

Figure 2. The seed was added to the manure slurry in the tank. Bypass flow provided tank agitation for seed mixing and distribution.

Glossudalfs). Two oilseed radish varieties: 1) Common (Com-OSR) and 2) Colonel (Col-OSR), 16.8 kg ha^{-1} pure live seed (PLS), and one oriental mustard variety (Pacific Gold (OM), 11.2 kg ha^{-1} PLS) were sown in untilled wheat stubble on 13 August. Each crop was sown with a Great Plains no-till drill (3.05-m width, 19-cm opener spacing) and with the manure slurry seeding process. The aerator gang angle was set at 10° for maximum soil fracturing and seed-laden swine slurry (table 1) was applied at 56,100 L ha^{-1}. The plots were harvested on 13 October 2004.

East Lansing, 2005

One oil seed radish variety (Colonel, 16.8 kg ha^{-1} PLS) and one oriental mustard variety (Pacific Gold, 11.2 kg ha^{-1} PLS) were sown in wheat stubble in a Capac fine sandy loam (fine-loamy, mixed, active, mesic Aquic Glossudalfs) on 8 August. The plots were arranged in a randomized complete block with four replications. Three seeding methods were used with each of the two crops: 1) conservation tillage with two passes of a combination tillage tool (3.66-m width Kongskilde Triple-K, 7.5-cm tillage depth) with a front disk gang, field cultivator teeth, and a rolling basket for soil firming, 2) direct-drilling into the undisturbed wheat stubble, and 3) slurry seeding with aeration tillage and seed-laden manure slurry. The aerator gang angle was set at 10° for maximum soil fracturing and seed-laden swine manure was applied at 56,100 L ha^{-1} (table 1). The conservation tillage and direct-drilled crops were seeded with a Great Plains no-till drill (3.05-m width, 19-cm opener spacing). The plots were harvested on 28 October 2005.

Kellogg Biological Station, 2005

Oil seed radish (Colonel , 16.8 kg ha^{-1} PLS) and oriental mustard (Pacific Gold, 11.2 kg ha^{-1} PLS) were sown in untilled wheat stubble on an Oshtemo sandy loam (coarse-loamy, mixed, mesic Typic Hapludalfs) on 2 August. Two seeding methods were used with each crop: 1) direct-drilling with a Deere 750 no-till drill (3.7-m width, 19-cm opener spacing), and 2) slurry seeding with aeration tillage and seed-laden dairy manure (table 1). The plots were arranged in a randomized complete block with four replications. The aerator gang angle was set at 7.5° for soil fracturing and seed-laden dairy manure was applied at 46,750 L ha^{-1}. The plots were harvested on 30 October 2005.

STATISTICAL ANALYSIS

The field experiments were designed as randomized complete blocks with four replications. Biomass of the surface plant, the root, and surface plus root (total) as well as plant stand (plants m^{-2}) were analyzed as a two-factor factorial with seeding method and crop sown as factors (table 2). An analysis of variance (ANOVA) was conducted using the General Linear Model in Minitab (Minitab Inc., 2003). The null hypothesis of no difference between treatments was tested at $\alpha = 0.10$. Because manure slurry-enriched micro-site seeding is a new process, the α-value was set at 0.10 to identify potentially important differences. Comparisons between the levels of factors to obtain confidence intervals for all pair-wise differences were conducted using Tukey's multiple comparison tests with a family error rate of 0.10.

RESULTS

STAND ESTABLISHMENT AND BIOMASS PRODUCTION — EAST LANSING, 2004

In 2004 at East Lansing, the aeration tines created a rough surface with well-defined cracks and fissures in moist and consolidated soil (fig. 3). The germination and emergence were facilitated by 48 mm of rain two weeks after the seeding on 18-19 August, but rainfall was below normal in September and October. There were significant effects on plant stand (plants m^{-2}) from both the seeding method and crop sown (table 2). Direct-drilling (56 plants m^{-2}) led to a greater stand

Table 1. Manure characteristics.

	2004, East Lansing			2005, East Lansing			2005, KBS		
Parameter	Content (%)	(g L^{-1})	(kg ha^{-1})	Content (%)	(g L^{-1})	(Kg ha^{-1})	Content (%)	(g L^{-1})	(kg ha^{-1})
Source	Swine			Swine			Dairy		
Moisture	99.25	993	55,558	98.32	983	55,037	95.86	958	44,733
Solids	0.75	7.5	420	1.68	16.8	940	4.14	41.4	1,932
Nitrogen, Total (N)	0.154	1.54	86.0	0.364	3.64	203.6	0.274	2.74	127.7
N as NH_4-N	0.123	1.23	68.5	0.309	3.09	172.3	0.198	1.98	92.4
N Organic	0.031	0.31	17.5	0.056	0.56	31.3	0.076	0.76	35.3
Phosphorus (P)	0.029	0.29	37.6	0.059	0.59	33.0	0.042	0.42	19.6
Potassium (K)	0.111	1.11	74.6	0.184	1.84	102.8	0.199	1.99	93.0
Sulfur (S)	--	--	--	0.02	0.2	11.4	0.03	0.3	14
Magnesium (Mg)	--	--	--	0.02	0.2	11.4	0.07	0.7	32.5
Calcium (Ca)	--	--	--	0.05	0.5	28.0	0.18	1.8	84.0
Sodium (Na)	--	--	--	0.04	0.4	22.4	0.11	1.1	51.5
Aluminum (Al)[a]	--	--	--	14	--	0.8	104	--	4.8
Boron (B)	--	--	--	3	--	0.2	2	--	<0.1
Copper (Cu)	--	--	--	5	--	0.3	74	--	3.4
Iron (Fe)	--	--	--	47	--	2.6	541	--	25.1
Manganese (Mg)	--	--	--	4.5	--	0.3	27	--	1.3
Zinc (Zn)	--	--	--	26	--	1.5	20	--	0.9

[a] Al, B, Cu, Fe, Mg, and Zn content reported in parts per million (ppm).

Table 2. Two-way analysis of variance for plant characteristics of cover crop, as influenced by crop species and by seeding method (seeder).[a]

	East Lansing, 2004			East Lansing, 2005			KBS, 2005		
Source	D.F.	F	p	D.F.	F	p	D.F.	F	p
Plants (m^{-2})									
Seeder	1	5.03	0.040	2	33.23	0.000	1	72.56	0.000
Crop	2	2.59	0.108	1	5.71	0.030	1	39.52	0.000
Seeder × Crop	2	3.48	0.057	2	6.42	0.010	1	12.84	0.006
Surface biomass (kg ha^{-1})									
Seeder	1	5.14	0.039	2	0.09	0.916	1	18.76	0.002
Crop	2	7.45	0.006	1	0.01	0.916	1	24.29	0.001
Seeder × Crop	2	0.34	0.715	2	1.47	0.216	1	2.87	0.124
Root biomass (kg ha^{-1})									
Seeder	1	0.66	0.430	2	0.71	0.63	1	23.75	0.001
Crop	2	12.36	0.001	--	--	--	1	31.04	0.000
Seeder × Crop	2	2.88	0.087	--	--	--	1	1.27	0.289
Total biomass (kg ha^{-1})									
Seeder	1	4.63	0.048	2	0.18	0.836	1	26.09	0.001
Crop	2	1.57	0.240	--	--	--	1	33.89	0.000
Seeder × Crop	2	3.67	0.050	--	--	--	1	3.13	0.111

[a] D.F. -- Statistical degrees of freedom; F -- F statistic; and p -- probability values are reported.

than manure slurry seeding (35 plants m^{-2}; $p = 0.04$). Oriental mustard (71 plant m^{-2}) produced a greater stand than either Com-OSR (32 plants m^{-2}; $p = 0.01$) or Col-OSR (34 plants m^{-2}; $p = 0.01$).

There was a significant *seeder* × *crop* interaction ($p = 0.06$) with surface biomass (kg ha^{-1}). There was significantly greater OM surface biomass with manure slurry seeding ($p = 0.04$; 5326 vs. 2760 kg ha^{-1} with direct drilling), but there was no significant difference between OSR varieties due to the seeding method (table 3). The manure slurry seeded OM plant stand was only 73% of the direct-drilled stand but biomass per hectare was greater because dry matter per plant was nearly three times greater with manure slurry seeding (89 vs. 34 g plant^{-1}). There were no significant differences in root biomass within crops due to the seeding method, but the OSR root biomass was significantly greater than the OM root biomass ($p < 0.01$).

There was a significant *seeder* × *crop* interaction ($p = 0.05$) in total biomass production. The manure slurry seeded OM biomass was significantly greater ($p = 0.03$; 5953 kg ha^{-1}) than the direct drilled OM biomass (3089 kg ha^{-1}) but there was no significant difference between the OSR varieties. Individual plant biomass with the manure slurry seeded Com-OSR was 1.5 times greater (117 vs. 72 g plant^{-1}) and the manure slurry seeded Col-OSR stand was 2.7 times greater than with direct drilling (fig. 4).

Figure 3. The seed-laden manure slurry carried the cover crop to micro-sites in the loose and fractured soil. No additional seedbed tillage or soil firming was done.

Stand Establishment and Biomass Production — East Lansing, 2005

In East Lansing in 2005, the soil was dry at seeding and it remained warm and dry until mid-September. Rainfall was normal (66.3 mm) from mid-September until crop harvest on October 20. There were significant effects on plant stand from crop sown and seeding method. The direct-drilled OSR stand (153 plants m^{-2}) was significantly greater than the manure slurry seeded stand (27 plant m^{-2}; $p < 0.01$), and the direct-drilled OM stand (148 plant m^{-2}) was significantly greater than the manure slurry seeded stand (28 plant m^{-2}; $p < 0.01$; table 3). There was a significant ($p = 0.01$) *seeder* × *crop* interaction in the magnitude of crop response with the till-drilled seeding method. The till-drilled (134 plant m^{-2}) and the manure slurry seeded OM stands (28 plants m^{-2}; $p < 0.01$) were significantly different, but the till-drilled and direct-drilled OM stands (148 plants m^{-2}) were not different ($p = 0.98$). In contrast, the till-drilled (42 plants m^{-2}) and the manure slurry seeded (27 plants m^{-2}) OSR stands were not significantly different ($p = 0.98$) but the till-drilled and direct-drilled (153 plant m^{-2}) stands were different ($p < 0.01$).

There were no significant differences in OM surface biomass ($p = 0.92$), OSR root biomass ($p = 0.15$) or OSR total biomass ($p = 0.84$) due to the seeding method (table 3). Surface OM biomass was 34, 31, and 189 g plant^{-1} with the till-drilled, direct drilled and manure slurry seeded seeding methods, respectively. Individual OSR plant biomass was 161 g plant^{-1} with manure slurry seeding, 117 g plant^{-1} with till-drilled, and 35 g plant^{-1} with direct drilling.

Table 3. Shoot (or aboveground), root, and total biomass, and plant stand density for oil seed radish (OSR) and oriental mustard (OM) in three site-years.

Crop	Seeding Method	Aboveground Biomass (kg DM ha^{-1})[a]	Root Biomass (kg DM ha^{-1})	Total Biomass (kg DM ha^{-1})	Plants (m^{-2})
2004 East Lansing					
OM	Slurry	5326 b	627 ab	5953 a	60 ab
OM	Direct-drill	2760 a	328 b	3089 b	82 b
Common OSR	Slurry	3033 a	694 ab	3727 b	26 a
Common OSR	Direct-drill No-Till	2658 a	842 a	3500 b	37 ab
Colonel OSR	Slurry	3812 a	955 a	4513 ab	19 a
Colonel OSR	Direct-drill No-Till	3558 a	920 a	4510 ab	49 ab
2005 East Lansing					
Colonel OSR	Till-Drill	4898 a	828 a	5726 a	42 a
Colonel OSR	Slurry	4340 a	1062 a	5402 a	27 a
Colonel OSR	Direct-drill No-Till	5293 a	670 a	5962 a	153 b
OM[b]	Till-Drill	4540 a	--	--	134 b
OM	Slurry	5283 a	--	--	28 a
OM	Direct-drill No-Till	4573 a	--	--	148 b
2005 KBS					
Colonel OSR	Slurry	5155 a	1904 a	7060 a	26 a
Colonel OSR	Direct-drill No-Till	3134 b	1207 b	4341 b	65 b
OM	Slurry	2934 b	1125 b	4059 bc	47 ab
OM	Direct-drill No-Till	2049 b	690 c	2739 c	144 c

[a] abc letters within columns and locations indicate values not significantly different by Tukey's HSD procedure ($\alpha = 0.10$).

[b] Oriental mustard root biomass was not measured at East Lansing in 2005.

Figure 4. On the left -- five direct-drilled OM plants; on the right -- five slurry seeded OM plants. The slurry seeded crop had fewer plants per hectare but equal or greater biomass because individual plant biomass was as much as six times greater.

Stand Establishment and Biomass Production — Kellogg Biological Station, 2005

In 2005 at KBS, soil moisture was favorable at seeding but then became warm and dry until the middle of September. The direct-drilled OM stand (144 plants m^{-2}) was significantly greater than the manure slurry seeded OM stand (47 plant m^{-2}; $p < 0.01$), and the direct-drilled OSR stand (65 plants m^{-2}) was significantly greater than the manure slurry seeded OSR stand (26 plants m^{-2}; $p = 0.03$; table 3). There was a significant *seeder X crop* interaction ($p < 0.01$) whereby the direct-drilled OM stand was significantly greater than the direct-drilled OSR stand ($p < 0.01$), but the manure slurry seeded OM and OSR stands were not different ($p = 0.29$; table 2).

There were significant effects on surface biomass due to both seeding method ($p < 0.01$; manure slurry seeding was greater than direct drilling) and crop sown ($p < 0.01$; OSR was greater than OM; table 3). The manure slurry seeded OSR surface biomass (5155 kg ha^{-1}) was significantly greater than the direct drilled OSR ($p = 0.01$; 3134 kg ha^{-1}), but the difference between the manure slurry seeded and direct drilled OM was not significant ($p = 0.31$; table 3).

There were significant effects on root biomass due to seeding method ($p < 0.01$; manure slurry seeded root biomass was greater than direct drilled root biomass) and crop sown ($p < 0.01$; OSR was greater than OM; table 3). The manure slurry seeded OM root biomass (1125 kg ha^{-1}; 62 g plant^{-1}) was significantly greater than the direct drilled biomass (690 kg ha^{-1}; 14 g plant^{-1}; $p = 0.10$; table 3). The manure slurry seeded OSR root biomass (1904 kg ha^{-1}; 198 g plant^{-1}) was significantly greater than that of the direct drilled OSR (1207 kg ha^{-1}; 48 g plant^{-1}; $p = 0.01$).

There were significant effects on total biomass due to seeding method ($p < 0.01$; manure slurry seeding was greater than direct drilling) and crop sown ($p < 0.01$; OSR was greater than OM; table 3). Individual plant biomass was more than four times greater with manure slurry seeding. The manure slurry seeded OSR biomass (7060 kg ha^{-1}; 198 g plant^{-1}) was significantly greater than the direct drilled biomass (4341 kg ha^{-1}; 48 g plant^{-1}; $p < 0.01$), but the manure slurry seeded OM (4059 kg ha^{-1}; 62 g plant^{-1}) was not significantly different from direct drilled OM (2739 kg ha^{-1}; 14 g plant^{-1}; $p = 0.16$; table 3).

DISCUSSION

Manure slurry-enriched micro-site seeding is an environmentally sensitive option for manure management in diverse cropping systems. Aeration tillage creates an absorptive surface that prevents overland flow and soil erosion by fracturing the soil, increasing surface roughness, improving infiltration, and conserving crop residues. In the same pass, nutrient-rich, seed-laden slurry quickly infiltrates the soil matrix, thereby reducing volatile N losses compared to surface spreading. The cover crop that emerges traps nutrients and forms a vegetative barrier to overland flow. Soil quality is enhanced by reducing tillage intensity and adding organic inputs -- manure and cover crops -- that stimulate soil building biological processes. Reducing tillage intensity and adding organic inputs increases carbon sequestration and reduces greenhouse gas emissions. Because manure slurry seeding combines low-disturbance tillage, manure application and seeding in one efficient operation, the process provides fuel (more than 18 L ha^{-1}) and labor savings (more than 0.85 h ha^{-1}) compared to conventional tillage and seeding.

Manure slurry seeding requires seed placement in suitable micro-sites. From these trials, visual inspection revealed seed germination and emergence through cracks and fissures from depths ranging from near the surface to 5 to 8 cm below the surface. Seed placement was largely influenced by slurry infiltration into fractured soil: untilled, consolidated soil that formed large clods and aggregates in response to aeration tillage triggered deeper placement in cracks and fissures; loose and flowable soils that backfilled the aeration tine opening before the seed-laden slurry was applied caused near-surface seed placement. In earlier work we noted poor germination and emergence in tilled or loose and flowable soils that did not create well defined cracks and fissures for seeding micro-sites (unpublished data).

The manure slurries applied in the reported work were greater than 95% moisture which provided a precipitation equivalent of about 4 to 6 mm ha^{-1} at seeding. Antecedent soil moisture ranged from moist, but suitable for tillage and planting in East Lansing in 2004, to dry at KBS in 2005. Moist soil was more likely than dry soil to form protected micro-sites in well defined cracks and fissures, but antecedent soil moisture did not have a clear impact on seed germination and emergence. At each location, seedling emergence was not observed until additional rainfall occurred. Manure slurry seeding is not recommended as a means to alleviate droughty soil conditions. Work is ongoing in evaluating the physical and chemical characteristics of the micro-environment of manure slurry seeded seed beds.

Because seed can imbibe water only through the portion of the seed that is in contact with the soil, small-seeded species may have an advantage over larger seeds with a large surface area. The OM seed concentration was about three times greater than the OSR, but the OM plant stand was only two times greater averaged across trials (45 plants m^{-2}) compared to the OSR (25 plants m^{-2}). The smaller OM seed did not appear to have an advantage in seedling establishment.

The manure slurry-enriched micro-site seeding process demonstrates the ability of crops to respond to varying levels of moisture, nutrient availability, area for light exposure and leaf expansion, and a soil environment suitable for root penetration. In East Lansing in 2004, the manure slurry seeded Com-OSR plant stand was 73% of the direct drilled stand, but the individual plant biomass was 150% greater with manure slurry seeding. In 2005, the manure slurry seeded OM stand was only about one-fifth of the direct drilled stand, whereas individual plant biomass was six times greater than that of the direct drilled crop. No significant difference in crop biomass was observed. This indicates that no-till manure slurry seeding can be as effective as conventional seeding methods. Biomass levels were comparable to previously reported biomass levels for brassica cover crops in Michigan (Snapp et al., 2005; 2006). Additional work in evaluating methods to improve stand establishment with manure slurry seeding is in progress.

CONCLUSIONS

A new and innovative cover crop stand establishment method -- manure slurry-enriched micro-site seeding -- that combined low-disturbance aeration tillage, manure application, and cover crop seeding in one efficient operation was evaluated. Experimental evaluation of this process in Michigan indicated that:

- Establishing OSR and OM as late summer seedings in wheat stubble with a new manure slurry-enriched micro-site seeding process is an efficient and effective cover crop establishment method for use in no-till cropping systems.
- The manure slurry seeded plant stands (plants m^{-2}) were significantly less ($\alpha = 0.10$) than that of the conventional seeding in 5 of 7 comparisons. Manure slurry seeded OM stands ranged from 28 to 60 plants m^{-2}, and direct drilled stands ranged from 82 to 148 plants m^{-2}. OSR stands ranged from 19 to 49 plants m^{-2} with manure slurry seeding and 37 to 153 plants m^{-2} with direct drilling.
- Individual plant biomass was greater with manure slurry seeding than with conventional seeding. In East Lansing, individual OSR plant biomass ranged from 1.6 to 4.6 times greater with manure slurry seeding. OM plant biomass ranged from 2.6 to 6 times greater with manure slurry seeding. At KBS, individual plant biomass with manure slurry seeding of OSR and OM was more than 4 times greater than with direct-drilling.
- Surface, root, and total biomass (kg ha^{-1}) were significantly greater ($\alpha = 0.10$) with manure slurry seeding than with the conventional seeding in two of seven comparisons. There were no instances when the biomass production of the conventionally seeded crop was significantly greater than the manure slurry seeded crop.

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