USE OF VARIABLE-RATE TECHNOLOGY FOR AGRONOMIC AND ENVIRONMENTAL PHOSPHORUS-BASED LIQUID SWINE MANURE MANAGEMENT

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ABSTRACT

Land application is the most common method for utilizing manure produced by the livestock industry. Manure applications at rates that exceed crop P removal are increasing soil-test P (STP) in many regions. Precision agriculture methods and variable-rate (VR) application can improve nutrient management and provide an environmentally responsible method to distribute manure. This study used a strip-trial methodology and precision agriculture methods to compare fixed-rate (FR) and VR manure application based on STP for soybean [*Glycine max* (L.) Merr.] - corn (*Zea mays* L.) rotations in two fields and two rotation cycles. Liquid swine manure was applied before planting soybean to supply the P requirement of the 2-year rotation, and uniform fertilizer N was applied to corn. Manure increased whole-field crop yield ($P \leq 0.05$) in five site-years but the application methods did not differ. Analyses for field areas with contrasting STP showed frequent yield response to manure in low-testing areas and seldom in optimum or high-testing areas. Larger yield response to VR than to FR in low-testing field areas in one site-year did not influence the whole-field yield response significantly. On average, the VR method applied 11% more manure compared with FR. Use of VR reduced STP variability by increasing STP more than FR in low-testing areas and reducing or not affecting STP in high-testing areas. Use of VR may not result in increased economic benefits for producers, but allows for better management of liquid manure and reduces the risk of P loss to water resources from manured fields.

Keywords: variable rate technology, manure management, phosphorus management.

INTRODUCTION

Livestock production is a vital component of the economy in the United States. Livestock and their products provided over $95 million in cash receipts to farmers in 1999 (Agricultural Statistics Board, 2001). In Iowa there were 3.7 million cattle and 15.4 million hogs in 2000 (Agricultural Statistics Board, 2001). Manure generated by this industry provides nutrients that can be effectively utilized by crops when it is handled appropriately (Adeli and Varco, 2001; Eghball and Power, 1999; Jokela, 1992; McIntosh and Varney, 1972; Schlegel, 1992; Sutton et al., 1982). Eghball and Power (1994) calculated that the N, P, and K contained in cattle feedlot manure would have an annual value of $461 million if purchased as fertilizer. Cropland application is the most common and currently viable method for utilizing manure (Eghball and Power, 1994; Lorimor and Lawrence, 2001). Concentration of large livestock feeding operations along with the high cost of transporting a diluted material and N based manure applications that exceed crop P needs often lead to a build-up of STP (Sutton et al., 1982; Kingery et al., 1993; Muir, 2001). Studies have shown that P concentration in runoff increases with increasing STP (Sharpley, 1995; Pote et al., 1996; Pote et al., 1999; Klatt et al., 2001). Surface runoff containing excess P that is delivered to water bodies can cause eutrophication (Sharpley et al., 1996). Klatt et al. (2001) concluded that a reduction of unneeded P application to high-testing field areas would reduce P loss from agricultural areas of an Iowa watershed.

Variable-rate application of manure would help reduce environmental consequences by applying manure only where nutrients are needed. Several authors have emphasized the potential of VR fertilization to improve water quality by reducing fertilization where nutrients are above levels required for optimum crop production (Sawyer, 1994; Franzen and Peck, 1995; Mohamed et al., 1996; Scknitkey et al., 1996; Gupta et al., 1997). Furthermore, Morris et al. (1999) demonstrated that manure application equipment can be easily modified to apply VR manure. Our objectives were to evaluate corn and soybean response to FR and VR liquid swine manure applied before planting soybean and to study the effect of the two application methods on STP.

MATERIALS AND METHODS

Field strip-trials were conducted during 4 years on two Iowa farmer's fields managed with a corn-soybean rotation. An area of approximately 15 ha of each field was selected for the experiments. Both fields had previous histories of uniform P fertilization and corn-soybean rotations. Tillage consisted of chisel-plowing the corn residue in the fall and light disking in the spring. A complex map unit of Clyde (Typic Endoaquoll) and Floyd (Aquic Hapludoll) soils predominated in both sites (45 to 46% of the areas). Second dominant soils were Kenyon (Typic Hapludoll) in Site 1 (13% of the area) and Readlyn (Aquic Hapudoll) in Site 2 (29% of the area). Initial composite soil-samples (12 cores from a 15-cm depth) were collected using a grid-point sampling method (Wollenhaupt et al., 1994). Grid lines were spaced 55 m in both directions and cores were collected from approximately 100 m^2 near the center of each cell. Soil samples were analyzed for P, pH, K, and organic matter by procedures recommended for the North-Central region (Brown, 1998). Iowa State University (ISU) STP interpretation classes for the Bray-P_1 and Mehlich-3 P tests are used throughout this paper. The classes ≤ 8 mg kg^{-1} for Very Low, 9 to 15 mg kg^{-1} for Low, 16 to 20 mg kg^{-1} for Optimum, 21 to 30 mg kg^{-1} for High, and ≥ 31 mg kg^{-1} for

Very High (Voss et al., 1999).

The treatments were a control with no manure application, a FR of manure, and a VR of manure, which were applied before planting soybean to strips 18.3-m wide and 605-660 m long. Randomized complete-block designs (RCBD) were used in both fields. There were five replications in Field 1 and four in Field 2. Liquid swine manure from the same underground storage pit was used, and its average nutrient content was 6.0 g L^{-1} N, 1.8 g L^{-1} P, and 2.0 g L^{-1} K. Uniform rates of at least 150 kg N ha^{-1} were applied across all treatments for the corn crops. The manure was broadcast with a slurry tank spreader equipped with a differential global positioning receiver (DGPS), a flow meter, and a controller, and was incorporated by chisel-plowing and/or disking. The corn crops were evaluated without additional P fertilizer nor manure. The experiment at Site 1 was established in 1997 and treatments were applied in the spring of 1997 and 1999. The experiment at Site 2 was established in 1998 and treatments were applied in the spring of 1998 and 2000. The suffixes "a", "b", "c", or "d" sometimes were added to the site numeric code to denote the first through fourth year of the experiments.

The manure rates used are shown in Table 1. The FR of manure was calculated to supply 50 kg ha^{-1} of total P after reaching a consensus with the cooperating farmers for using their normal manure rate for the 2-yr rotation. This rate is within the high range of P maintenance rates recommended by ISU (based on expected P removal in grain) for this 2-year rotation (Voss et al., 1999). The VR of manure were based on STP values from the initial soil sampling and were calculated to supply the P requirements of the 2-year rotation. The target VR rates were 85 kg P ha^{-1} for areas testing Very Low, 68 kg P ha^{-1} for areas testing Low, and 42 kg P ha^{-1} for areas testing Optimum. A mistake in the computer programming determined that a rate of 34 kg P ha^{-1} were applied the first year to high-testing areas of Site 1.

Table 1. Macronutrients applied with fixed and variable manure treatments to field areas that tested within various soil-test P interpretation classes.

Manure treatment	Soil test class †	Area		Nutrients applied		
		Site 1	Site 2	N	P	K
		------ % -----		------- kg ha^{-1} -------		
Fixed	All	--	--	168	51	56
Variable	VL	32	27	280	85	94
	L	38	41	224	68	75
	Opt	27	16	140	42	47
	H ‡	3	7	(112)	(34)	(37)
	VH	0	9	0	0	0

† VL = very low, L = low, Opt = optimum, H = high, and VH = very high.

‡ Manure was applied to areas testing High only the first year at both sites.

Grain yield was harvested and recorded with farm combines equipped with impact flow-rate yield monitors and DGPS receivers. The yield monitors recorded data at 1-s intervals, and differential correction was obtained through the U.S.A. Coast Guard AM signal. Grain moisture was determined by a sensor located in the combine auger, and yield was corrected to 155 g kg^{-1} H_2O for corn and 130 g kg^{-1} H_2O for soybean. The yield data for the second year in Site 1 (corn) was lost due to a yield monitor problem. Thus, seven site-years of data were available.

Field-average grain yields were analyzed using an analysis of variance (ANOVA) for a RCBD for which data input were means for each treatment strip. The treatment sums of squares was partitioned into comparisons of a mean P effect and a comparison of the two application methods. A second procedure analyzed treatment effects on yield separately for field areas with different STP interpretation classes. This procedure was developed by Oyarzabal et al. (1996) and later used by Mallarino et al. (2001b). Yield data for this procedure were means for areas defined by the soil sampling grid lines along crop rows and the width of each treatment strip across crop rows. The STP input were the initial values for each sampling cell. Three yield treatment means corresponded to each STP value. To assess the consistency of treatment effects for field areas with different STP classes we used a one-way ANOVA for each STP class and site-year.

Simple correlation analysis was used to study relationships between STP and yield response to manure. The STP data input were values from the soil sampling grid-cells at each site. The yield data input were data triplets (for control, FR, and VR treatments) from the cells used for the previously described analyses. Relative responses were used to minimize effects caused by variation in yield potential across and within sites. Relative responses were calculated by subtracting the yield of the control treatment from the mean of the manured treatments (FR and VR), dividing the result by the control, and multiplying by 100.

Composite soil-samples (12 cores from a 15-cm depth) were collected after harvesting each crop for STP analyses from 100-m^2 areas near the center of cells defined by the initial soil sampling grid lines along crop rows and the width of each treatment strip across crop rows. Changes in STP due to manure and cropping were calculated by subtracting the initial STP from the mean STP value of samples collected after harvesting the soybean and corn crops of each rotation cycle. The initial STP data from samples taken from the center of the larger initial cells was assumed to represent STP of the whole cell. Potential treatment effects on STP change were assessed by using an ANOVA similar to that used for assessing crop responses to the P treatments for field areas with different STP interpretation classes. The standard deviation for each treatment was used to assess the effect of the manure application methods on STP variability.

RESULTS AND DISCUSSION

Analyses of soil samples collected before treatment application showed that STP in both sites spanned four to five STP interpretation classes. Areas testing Very Low or Low were 70% in Site 1 and 68% in Site 2 (Table 1). Mean and median STP values were 12 and 13 mg kg^{-1} for Site 1 and 15 and 11 mg kg^{-1} for Site 2. Large and frequent yield response to P should be expected in low-testing field areas according to ISU fertilizer recommendations for corn and soybean (Voss et al., 1999). Both sites contained significant high-testing areas that require no P according to current recommendations.

Whole-field analyses of yield (Table 2) showed that manure application increased ($P \leq 0.05$) soybean yield in Sites 1c and 2c and corn yield in all sites (Sites 1d, 2b, and 2d). Although the methods used cannot dismiss possible effects of nutrients in the manure other than P, the responses likely were due to the manure P because almost 70% of the field areas tested below the Optimum STP class. Also, a uniform rate of at least 150 kg N ha^{-1} was applied across all treatments for the corn crops, and both mean and median soil-test K values were in the Optimum K class. Results of late-season cornstalk NO_3^- tests (not shown) indicated no difference in N concentration due to the treatments, which suggests the uniform N fertilization eliminated any possible residual N effect from manure applied to the previous soybean crop. There were no yield differences between the VR and FR methods of manure application for any crop.

Table 2. Effect of fixed and variable manure treatments on whole-field grain yields.

			Treatment and grain yield			
Field	Year	Crop	Check	Fixed	Variable	Statistics †
			------------- kg ha^{-1} -------------			$P > F$
1a	1997	Soybean	4123	4242	4215	0.20
1c	1999	Soybean	3559	3731	3775	0.01
2a	1998	Soybean	4097	4219	4221	0.21
2c	2000	Soybean	2880	3427	3358	0.01
1d	2000	Corn	8123	9121	9248	0.01
2b	1999	Corn	10057	10683	10589	0.02
2d	2001	Corn	12210	12618	12605	0.01

† Probability of the manure main effect. Comparisons of the fixed-rate and variable-rate manure treatments never were significant ($P \leq 0.05$).

Analyses of soybean yield response for field areas having different initial STP levels (Table 3) showed statistically significant ($P \leq 0.05$) response to manure in the Low and Very Low classes in every site-year with only one exception. The exception was for the Very Low class in Site 1a, and this result cannot be explained satisfactorily. The manure application methods never differed. There was no response to manure in areas with STP Optimum, High, or Very High. Similar analyses for corn (Table 4) showed significant responses to manure in the low-testing classes of all site-years, in the Optimum class of one site-year (Site 2d), and no response in the high-testing classes. The manure application methods differed only in one site-year (Site 1d), where the VR method produced higher corn yield than the FR method in field areas testing Very Low.

Regression analyses of yield response on initial STP also showed a higher response to manure in soils with low STP. Except for Site 1a, relationships showed decreasing response with increasing STP (linear correlation coefficients ranged from -0.42 to -0.59) and were highly significant ($P \leq 0.01$). Results of ANOVA and regression analyses demonstrate that manure can supply P needed by both corn and soybean, and add support to the assumption that corn responses in low-testing areas were due to the manure P and not the manure N.

Table 3. Soybean grain yield response to manure for field areas testing within different soil-test P interpretation classes.

			Treatment and grain yield			
Field	Year	STP †	Check	Fixed	Variable	Statistics ‡
			---------- kg ha^{-1} ----------			$P > F$
1a	1997	VL	4104	4092	4270	0.25
		L	4159	4353	4248	0.03
		Opt	4062	4257	4112	0.19
		H	4374	4276	4139	0.37
1c	1999	VL	3430	3715	3759	0.01
		L	3638	3743	3777	0.01
		Opt	3697	3737	3853	0.15
2a	1998	VL	4001	4203	4142	0.02
		L	4080	4258	4214	0.01
		Opt	4090	4220	4166	0.11
		H	4148	4069	4370	0.48
		VH	4430	4203	4480	0.21
2c	2000	VL	2621	3303	3268	0.01
		L	2872	3450	3384	0.01
		Opt	3067	3323	3370	0.16
		H	3173	3568	3297	0.11
		VH	3497	3690	3628	0.27

† STP = soil-test P classes. VL = very low, L = low, Opt = optimum, H = high, and VH = very high.

‡ Probability of the manure main effect. Comparisons of the manure application methods never were significant ($P \leq 0.05$).

Table 4. Corn grain yield response to manure for field areas testing within different soil-test P interpretation classes.

			Treatment and grain yield			
Field	Year	STP †	Check	Fixed	Variable	Statistics ‡
			---------- kg ha^{-1} ----------			*P* > *F*
1d	2000	VL	7180	8568	9128	0.01 §
		L	8669	9450	9314	0.01
		Opt	9420	9809	9441	0.63
2b	1999	VL	9447	10644	10089	0.01
		L	10204	10831	10865	0.01
		Opt	10012	10594	10396	0.18
		H	10913	10930	10825	0.82
		VH	10664	10099	11007	0.80
2d	2001	VL	11913	12644	12432	0.01
		L	12185	12580	12607	0.01
		Opt	12564	12693	12774	0.03
		H	12612	12590	12690	0.84
		VH	12859	12685	13072	0.94

† STP = soil-test P classes. VL = very low, L = low, Opt = optimum, H = high, and VH = very high.

‡ Probability of the manure main effect.

§ Significant difference between the manure application methods ($P \leq 0.05$).

The results demonstrate that manure P can be withheld from high-testing field areas without causing a yield reduction. However, results also suggest that use of VR liquid manure applications will seldom increase yield above those from a FR. The possibility of yield increases has been proposed as a potential benefit for VR systems but it has not been well documented. Research with P fertilizers (Mallarino and Wittry, 1999; Mallarino et al., 1998; Lowenberg-DeBoer and Aghib, 1999; Yang et al., 2001) has shown little or no additional yield response with VR P fertilization compared with FR fertilization.

Study of STP changes due to manure application (Table 5) showed that manure always increased STP ($P \leq 0.05$) in the low-testing classes and seldom increased STP in the Optimum, High, or Very High classes. The VR method tended to produce a larger STP increase than FR in areas testing Very Low, although this trend was significant only for Site 2 after the second manure application. Although STP changes in the high-testing areas seldom were statistically significant, there were decreasing STP trends for VR and increasing trends for FR in most sampling dates.

Table 5. Effect of manure on changing soil-test P for various interpretation classes.

			Treatment and soil-test P change			
Field	Years	STP †	Check	Fixed	Variable	Statistics ‡
			-------------- mg kg^{-1} ------------			$P > F$
1	1997-98	VL	0.3	2.4	3.7	0.01
		L	-0.7	4.3	5.4	0.01
		Opt	-2.7	1.3	0.6	0.01
		H	-4.5	-1.3	-2.5	0.61
1	1999-00	VL	1.2	7.8	9.4	0.01
		L	1.3	6.5	4.8	0.01
		Opt	0.8	4.0	3.4	0.39
2	1998-99	VL	-0.3	4.0	4.3	0.01
		L	-0.2	5.9	5.9	0.01
		Opt	-1.7	3.0	0.1	0.26
		H	-2.2	7.8	1.8	0.02 §
		VH	-3.6	4.0	-2.9	0.57
2	2000-01	VL	2.7	5.4	9.8	0.01 §
		L	1.5	4.1	6.6	0.01 §
		Opt	-2.5	2.5	-6.0	0.94
		H	4.4	2.5	-3.3	0.29
		VH	2.1	5.8	-5.4	0.75

† STP = soil-test P classes. VL = very low, L = low, Opt = optimum, H = high, and VH = very high.

‡ Probability of the manure main effect.

§ Significant difference between the manure application methods ($P \leq 0.05$).

Average results of STP change across all fields in Fig. 1 show very clearly that VR increased STP more than FR in low-testing areas and reduced STP in high-testing areas. Analyses of variability for VR and FR methods confirmed that final STP values were less variable for VR than for FR in both sites (the yield standard deviation was 4 and 6 mg kg^{-1} for VR and FR in Site 1, and 11 and 17 mg kg^{-1} for VR and FR in Site 2). This was confirmed by a test for equality of variance that showed a significant ($P \leq 0.05$) difference of the variances of the VR and the FR final STP values. This result confirms that VR applied more P to low-testing areas and less P in high-testing areas compared with the FR method. Another important advantage of VR is that it utilized more manure than the FR (5.4 kg P ha^{-1} or 11% on average), and never decreased yield while decreasing STP variability. These results support the possibility of using VR application of liquid swine manure in conjunction with a P index (Mallarino et al., 2001a) to help determine agronomic and environmentally sound manure application to fields.

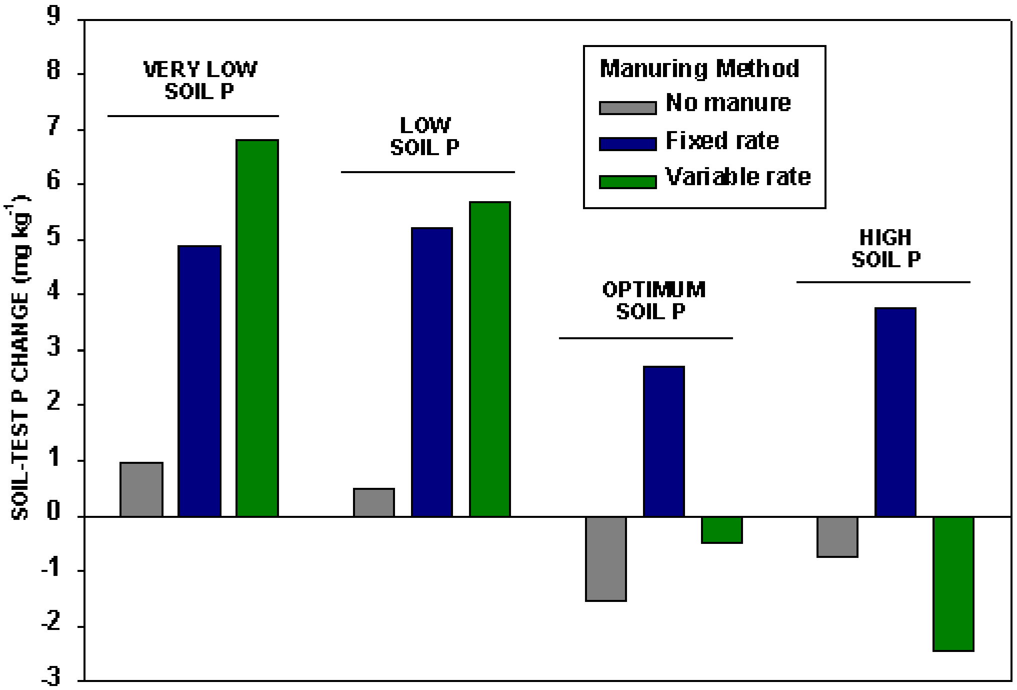

Fig. 1. Effect of the fixed-rate and variable-rate applications of liquid swine manure on soil-test P change after crop harvest for various initial soil-test P interpretation classes (means of 2 years and two fields).

CONCLUSIONS

The results showed that applying liquid manure with FR or VR methods produced similar soybean and corn yield over two rotation cycles in two fields. Only in one site-year the VR method increased yield further than the FR method in low-testing field areas, but this increase was overshadowed by lack of differences in larger field areas. Over both fields, the VR method applied 11% more manure than the FR method, and reduced STP variability by increasing STP in low-testing areas and decreasing or not affecting STP of high-testing areas. Thus, although use of VR technology may not increase crop yield and economic benefits for producers compared with a FR method, VR allows for better manure management and can reduce the risk of P delivery from manured fields to water resources.

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