

A Mechanical Sidedresser for Solid Wastes

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An applicator for topdressing (or sidedressing) row crops with solid waste materials was evaluated. The apparatus can meter and deliver animal manures and other raw solid waste materials between rows of a growing crop without the material contacting the crop. Results from a three-year field study clearly indicate that new poultry litter management strategies, using this litter topdressing equipment and improved soil and plant nitrogen tests, should improve the agronomic and environmental efficiency of corn production in the mid-Atlantic region. Economically optimum yields were obtained with starter fertilisers and moderate topdress N rates, and poultry litter as a topdress material was found to be as effective as topdressing with commercial fertiliser. Comparison of total application costs revealed that topdressing with poultry litter is about US\$ 10 ha⁻¹ more expensive than conventional methods, which can be attributed to the lower concentrations of N in poultry litter, requiring significantly more applications and greater operator time per hectare.

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1. Introduction

Delaware is the site of one of the most concentrated poultry production areas in the world, with about 250 million broiler chickens produced each year, primarily in the southernmost county (Sussex County) in the state. Years of intensive ground water sampling in southern Delaware have shown that widespread nitrate-N (NO₃-N) contamination of the shallow aquifer in southern Delaware has occurred (Denver et al., 2004; Shedlock, et al., 1999). Highest ground water NO₃-N concentrations have always been found in areas where broiler production was concentrated and agronomic crop production and fertiliser N use were the most intensive (Andres, 1995). Ritter and Chrinside (1987) reported in the 1980s that at least 21% of the wells in Sussex County had NO₃-N concentrations exceeding the USEPA maximum contaminant level (10 mg [NO₃-N] l⁻¹) for drinking water and emphasized the need for improved N management strategies for the agricultural use of poultry litter (PL, a mixture of poultry faeces, urine, and wood chips or shavings) and fertiliser N. More recent studies (Denver et al., 2004) continue to show elevated concentrations of NO₃-N in Delaware ground waters.

Many efforts have been made by Delaware agriculture to reduce the extent of ground water contamination by NO₃-N. These efforts have intensified since 1999 when a state nutrient management law was passed that mandated improved N management practices to protect water quality (Sims, 1999). However, producing economically optimum crop yields without

contaminating ground waters with $\text{NO}_3\text{-N}$ still remains one of the greatest challenges faced by Delaware's intensive, animal-based agriculture. Fortunately, previous research conducted in Delaware has identified some innovations in nutrient management that have the potential to greatly improve the efficient use of PL as a N source for corn, and perhaps for other crops as well. Two key advances have been the development and use by farmers and their advisors of the pre-sidedress soil nitrate test (PSNT) and two diagnostic plant N tests, the leaf chlorophyll meter (LCM) and the stalk nitrate test (Hansen et al., 1999; Sims et al., 1995). Sims et al. (1995) conducted a three-year, 56 site study evaluating soil and plant N tests for corn in fields frequently treated with PL. Results showed that the PSNT was an accurate predictor of the need for topdress N. This study also found that the LCM was of comparable predictive accuracy as the more time-consuming PSNT, consistent with other multi-site, multi-year research in the Mid-Atlantic region (Piekielek and Fox, 1992). Because the LCM provides indications of plant N status in a matter of minutes, it has the potential to be more widely used than the PSNT. Finally, the corn stalk nitrate test (CSNT), developed in Iowa (Binford et al., 1990) was also shown by Sims et al. (1995) to be an effective means of evaluating the success of N management decisions made based on PSNT and/or LCM results. Today, these tests allow farmers to better predict crop N needs (PSNT, LCM) and assess the effectiveness of N fertilization at the end of the growing season (CSNT).

In addition to these soil and plant N testing and assessment tools, there have been advances in manure application technology that offer great promise as a means to improve the efficiency of manure management as a nutrient source for crops. Lague, et al. (2006) has developed a precision manure applicator for uniformly applying solid and semi-solid manures. Lague et al. (1994) prototyped liquid manure applicator capable of uniformly applying manure to a growing crop. Lodhe and Rammer (2002) and Lodhe and Etana (2005) examined the benefits of banding and injecting slurry manures, looking at both ammonia loss and crop response. Specific rate recommendations for in-row topdressing of liquid pig manure, based field tests that included PSNT testing, have been developed by Ball-Coelho et al. (2005). For solid manures and waste materials, Glancey and Adams (1996) developed a solid waste topdresser (Fig.1) that allows farmers to avoid broadcasting manures like PL in advance of planting, a particularly inefficient N management practice on the sandy soils common to southern Delaware. This applicator, configured to meter and deliver solid manures between rows of a growing crop like corn, allows growers to apply PL during the growing season based on recommendations from the PSNT or LCM tests as is commonly now done with fertiliser N sources.

Our objective in this study was to determine the agronomic value and potential environmental benefits of combining the use of these soil and plant N testing methods with this newly developed application technology for PL shown in Fig. 1. In addition, the costs associated with current topdress practices and PL topdressing were computed and used to assess economic feasibility.

2. Methodology

2.1. Preliminary screening study in year 1

An initial field study was conducted during the 1994 growing season at the University of Delaware Research and Education Center (UDREC) in Georgetown, DE to screen four methods of applying poultry litter (PL) for irrigated corn production at a single, optimum application rate (224 kg [available N] ha⁻¹) by comparison with fertiliser N (32% urea-ammonium nitrate solution, UAN). Treatments included broadcasting PL and incorporating through tillage (BC), broadcasting PL followed by sidedressing (i.e. topdressing) PL with incorporation (BC+SPLI) and without incorporation (BC+SPL), only sidedressing PL (SPL),

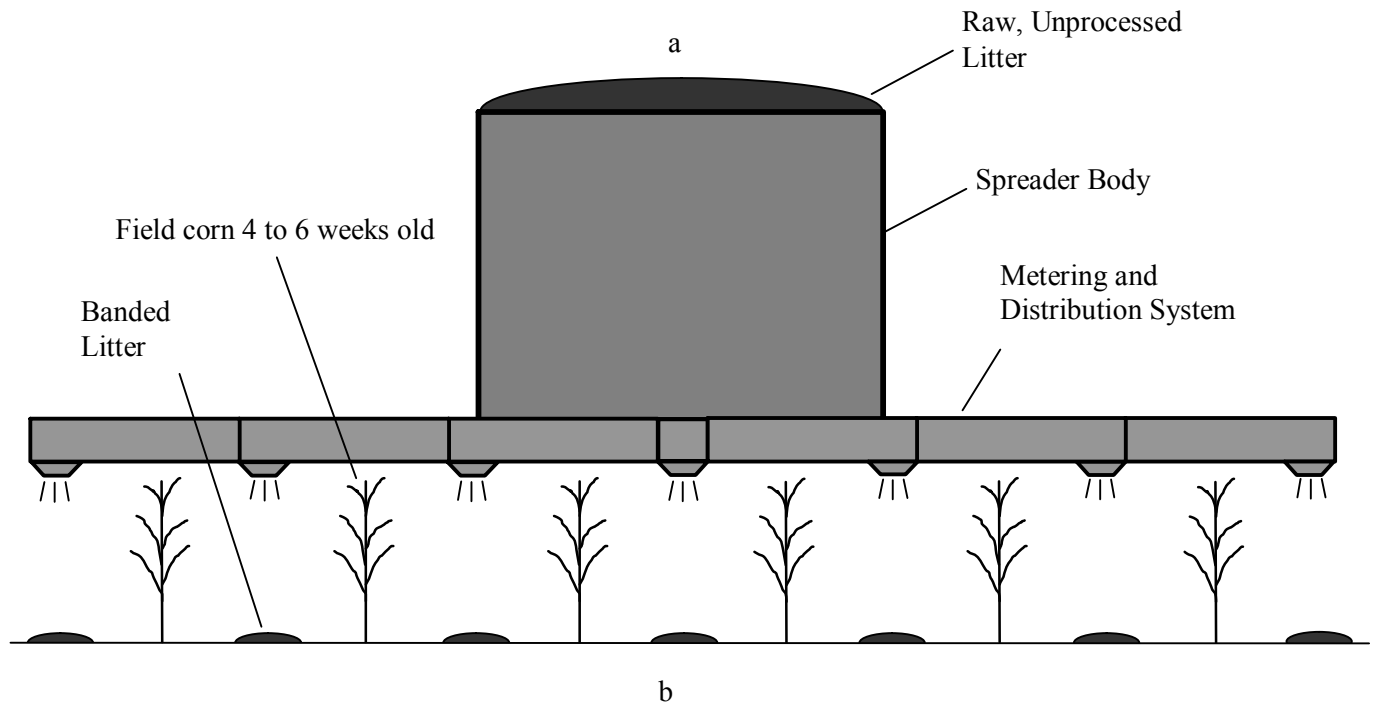


Figure 1. (a) schematic diagram of a solid waste topdresser, and (b) a photograph of the left side of the topdresser used in this study.

and sidedressing UAN (SUAN). The experimental design was a randomized complete block design with four replications. A summary of the plot characteristics is provided in Table 1. The soil type at the site was a Rumford loamy sand (coarse-loamy, siliceous thermic Typic Umbraquults). Corn (cv. Pioneer 3394) was planted at an average population of 65,009 plants ha⁻¹ using conventional tillage and standard cultural practices recommended by the University of Delaware. Overhead sprinkler irrigation was used as required to ensure that moisture stress was minimised. The corn was harvested in September and grain yields (15.5% moisture basis) and total N concentrations were determined.

2.2. Expanded field studies in years 2 and 3

Based on our evaluation in the year 1 preliminary study, an expanded two year field study was initiated in 1995 to evaluate three approaches to N management for corn grown in an

Table 1. Summary of plot characteristics and locations.

Year	Site No.	Location	Soil Type	Corn Variety	Plant Population plants ha ⁻¹	Irrigation Method
1	1	Georgetown	Rumford Loamy Sand	Pioneer 3394	65,009	Overhead Sprinkler
2	1	Newark	Matapeake Silt Loam	SS 682	66,268	None
	2	Lincoln	Rumford Loamy Sand	SS 683	61,213	Travelling Gun
	3	Georgetown	Rumford Loamy Sand	SS 684	65,763	Overhead Sprinkler
3	1	Middletown	Matapeake Silt Loam	Pioneer 3394	64,563	None
	2	Georgetown	Rumford Loamy Sand	Pioneer 3394	65,112	Overhead Sprinkler

area dominated by poultry-grain agriculture. In year 2, as summarised in Table 1, experimental locations included the University of Delaware farm in Newark, DE (site 1; Matapeake silt loam; fine-silty, mixed, mesic, Typic Hapludults), a co-operator's farm in Lincoln, DE, and the University of Delaware Research and Education Center (UDREC) near Georgetown, DE (sites 2 and 3: Rumford loamy sand; coarse-loamy, siliceous thermic Typic Umbraquults). In year 3, the study was repeated at two locations. site 1 (Matapeake silt loam; fine-silty, mixed, mesic, Typic Hapludults) was located on a co-operator's farm near Middletown, DE and site 2 (Rumford loamy sand; coarse-loamy, siliceous thermic Typic Umbraquults) was again located at the UDREC. In year 2, all locations were planted with the same variety of field corn and two locations, Lincoln (travelling gun) and the UDREC (overhead sprinkler) were irrigated. Cultural practices followed standard recommendations of the University of Delaware for field corn. In year 3, the corn hybrid was Pioneer 3394; no irrigation was used at site 1 and overhead irrigation was again used as needed at site 2.

A split plot experimental design with three replications was used at all locations in both years of this study. The main plot treatments were the N management approaches including:

- BC+SPL: a broadcast application of PL at 4.5 tonne ha⁻¹ (wet weight basis) prior to planting (incorporated), followed by sidedressing (top dressing) with PL during the growing season
- SPL: only sidedressing (topdressing) with PL
- SUAN: sidedressing (topdressing) with a 32% solution of urea-ammonium nitrate (UAN)

Note that starter fertilizer, providing from 12 to 21 kg [N] ha⁻¹ depending upon location, was used with all treatments. The split plot treatments were five rates of topdressed N which varied slightly between N management approach and location, and ranged from 100 to 280 kg [total N] ha⁻¹ for BC+SPL, from 100 to 235 kg [total N] ha⁻¹ for SPL, and from 0 to 225 kg [total N] ha⁻¹ for SUAN.

The broadcast PL treatments were applied with a *Spread Master Model DT-16*¹. Topdressed PL treatments were applied with the *New Holland Prototype Manure Sidedresser* (Fig.1) and the topdressed UAN treatments were applied with a *John Blue Fertilizer Sidedresser*. All

¹ The commercial names used in this report are provided to adequately describe the experimental procedures in this study and should not be interpreted as an endorsement.

application equipment was calibrated at each of the required rates following ASAE Standard S341.2. Typical results after calibration of the PL topdresser are illustrated in Fig. 2.

2.3. Soil, plant, and poultry litter sampling and analysis

Prior to planting, soil samples were taken at each site at three depths (0-200, 200-400 and 400-600 mm) and were characterized for pH, buffer pH, organic matter, texture and soil test (Mehlich 1: 0.05N HCl + 0.025N H₂SO₄) extractable nutrients (P, K, Ca, Mg, Mn and Zn) by standard methods of the University of Delaware Soil Testing Laboratory (Sims and Heckendorn, 1991). Poultry litter samples were collected at the time of application from the BC+SPL and SPL treatments, dried, ground to pass a 0.80 mm sieve and analysed for total N using a LECO CNS analyser.

Pre-sidedress soil nitrate-N (PSNT) was measured in each main plot prior to N topdressing. Leaf chlorophyll meter (LCM) readings were made in each plot at the same time as PSNT sampling and at two week intervals until corn maturity using a Minolta SPAD meter. Relative LCM values were calculated by dividing LCM values in each plot with values from an adjacent well-fertilized plot that had received 252 kg [N] ha⁻¹, as NH₄NO₃,

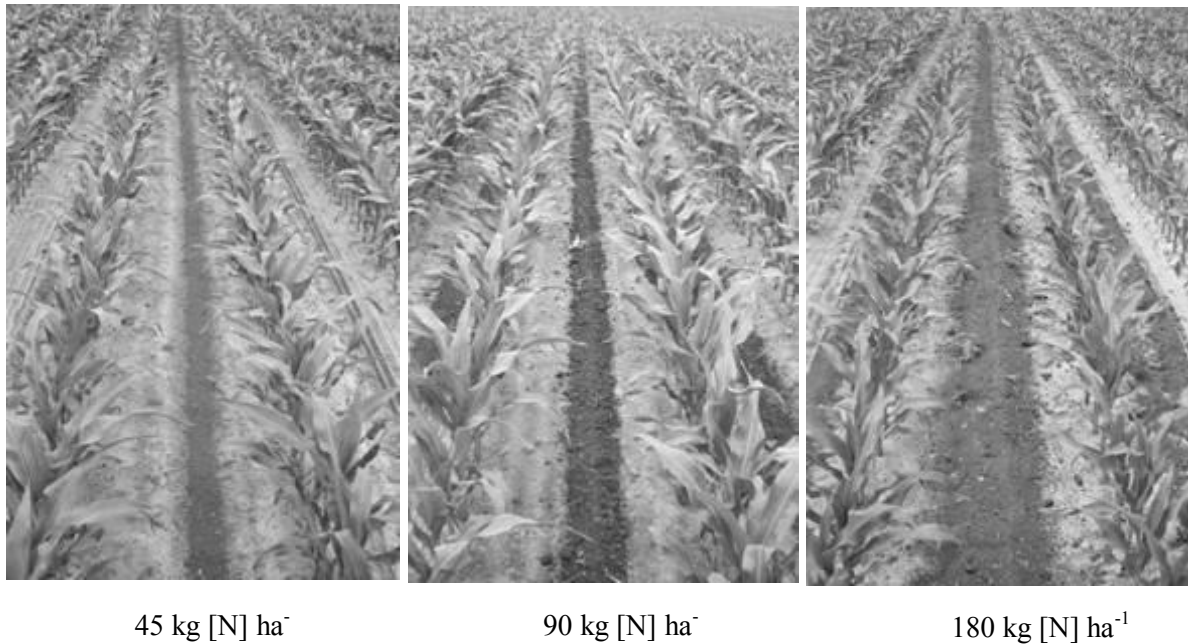


Figure 2. Typical field treatments of topdressed poultry litter using the prototype field applicator illustrated in Figure 1. Calibrations reveal an average error of +/- 6 kg [N] ha⁻¹.

shortly after planting. Whole plant samples, collected from all main plots at the time of PSNT sampling, and ear leaf samples obtained at silking were analysed for total N. Late season CSNT samples were taken from every plot and analysed colourimetrically for NO₃-N after extraction of the dried, ground, stalk samples with 2M KCl.

Grain yields were measured by harvesting the centre two rows from each plot using a conventional grain combine and are reported on a 15.5% moisture basis. All grain samples were analysed for total N by use of a LECO CNS analyser.

2.4. Statistical Analysis

The influence of N management approach and topdress N rate on all parameters measured was determined by statistical analysis of the data using the PROC GLM procedure in the *SAS System* statistical package. An ANOVA was used to identify statistically significant differences among the experimental treatments, and regressions were performed to quantify the relationship between N topdress rate and corn grain yield. Confidence levels of 95% were used to identify statistically significant differences ($p < 0.05$).

Two different regression models were used to quantify yield responses to topdress N rates: a segmented model, and an exponential model. The segmented model consisted of a quadratic portion and a plateau of the form:

$$y = a_0 + a_1x + a_2x^2 \quad \text{for } x < x_0$$

and

$$y = p \quad \text{for } x > x_0 \quad (1)$$

where

y = predicted yield (tonne ha^{-1})
 x = topdress N rate (kg ha^{-1})
 a_0 = regression coefficients for the quadratic segment (ton ha^{-1})
 a_1 = regression coefficient for the quadratic segment (ton ha^{-1})
 a_2 = regression coefficient for the quadratic segment (ton $\text{ha} \text{ kg}^{-2}$)
 p = regression coefficient for the plateau (ton ha^{-1})

As a result, yield response will be modelled as a quadratic for topdress rates less than x_0 , and will be equal to p for rates greater than x_0 . A continuous, smooth curve at x_0 implies that:

$$x_0 = -a_1/2a_2$$

and

$$p = a_0 - a_1^2/4a_2$$

For the exponential model, the following form was used:

$$y = A(1 - e^{-bx}) \quad (2)$$

where

A = exponential model regression coefficient (ton ha^{-1})
 b = exponential model regression coefficient ($\text{ha} \text{ kg}^{-1}$)

The regression coefficients in Eqns. 1 and 2 were determined using *SAS*, and regressions were performed on data sets for each treatment (BC+SPL, SPL, SUAN) at each site for each year.

To determine the optimal rate of N, the economically optimal N rate (EON) was computed as the N rate at which profit is maximum. Yield at this N rate is slightly below maximum yield, but the cost of the additional fertiliser (or manure) to achieve maximum yield exceeds the value of

the additional yield produced. For quadratic-plateau yield response functions (Eqn.1), the optimal N rate can be shown to be:

$$EON = (P_N/P_m - a_1)/2a_2 \quad (3)$$

where

$$P_N = \text{price of N (\$ kg}^{-1}\text{)}$$

$$P_m = \text{price of corn (\$ kg}^{-1}\text{)}$$

3. Results and discussion

3.1. Influence of nitrogen management approach on corn yields and grain N

3.1.1. Screening study: year 1

All topdressing treatments significantly increased corn grain yields and grain protein concentrations in year 1 relative to broadcasting PL (Figure 3). Topdressing with PL was

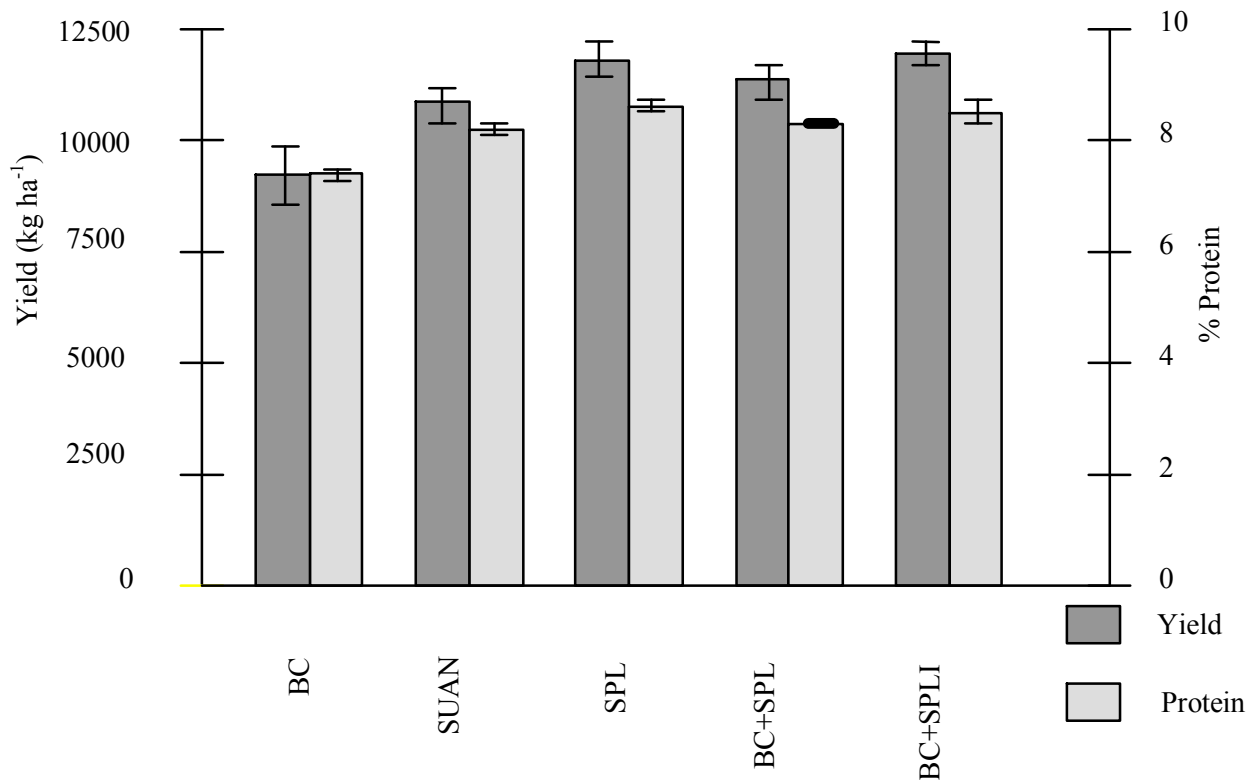


Figure 3. Effects of N management treatment on grain yield and grain protein content for the year 1 screening trials. The bars indicate means of the 5 replicates and error bars indicate the minimum and maximum values measured.

equally effective as topdressing with commercial fertilizer (SUAN) in terms of grain yield and grain protein. There was no yield or grain quality difference ($p < 0.05$) to incorporating PL after sidedressing (topdressing) (SPLI) compared to leaving the topdressed PL in a narrow band on the soil surface.

Previous studies (e.g. Hansen (2004); Misselbrook (2002)) have shown that ammonia loss with land applied manures can be significant, and Rodhe and Karlsson (2002) has shown that incorporating poultry litter immediate after broadcast application significantly reduces these

losses, thus increasing N available for crop uptake. However, results from our study show no benefit to incorporating topdressed PL in terms of crop yield, suggesting that ammonia loss from the narrow manure bands applied in this study was low. Examination of the 200 mm wide bands of topdressed manure reveal that the exposed surface area is reduced by more than 70% compared to broadcast manure when corn is planted in 75 cm rows. As a result, the finding that topdressed PL that was incorporated had no effect on yield is not surprising since significantly less surface area is available for ammonia volatilization when the manure is applied in a 25 cm band. Based on these data, and the additional labour and energy costs associated with incorporating topdressed PL, we selected the BC+SPL and SPL methods for further evaluation in field studies conducted in years 2 and 3.

3.1.2. Effect of N management approach on corn yields in years 2 and 3

In year 2, there were no significant differences in corn grain yield due to the N management approach at sites 1 and 2 and topdressing with N did not increase grain yields, hence these data are not shown. However, at site 3 in year 2 and both sites in year 3, corn yields increased as topdress total N rate increased for all three N management approaches (Fig. 4). Yield responses were successfully modelled ($R^2= 0.91$ to 0.98) using quadratic and exponential models, and the regression coefficients are provided in Table 2. These coefficients were used to compute yield response for various N rates thus allowing for direct, quantitative comparison of the N use efficiency of the three approaches (Table 3) and for the calculation of economically optimum N rates (Table 4) using Eqn 3. For fertiliser N (SUAN), the EON rates ranged from 158 to 238 kg [total N] ha⁻¹, compared to 197-267 kg [total N] ha⁻¹ for SPL and 222-274 kg [total N] ha⁻¹ for BC+SPL. However, since not all N

Table 2. Regression coefficients for the quadratic (Eqn. 1) and exponential (Eqn. 2) models.

The quadratic model

N Management Approach	a ₀	a ₁	a ₂
<u>site 3: year 1</u>			
BC+SPL	-16.5	0.204	-39.3(10 ⁻⁵)
SPL	2.82	0.039	-8.01(10 ⁻⁵)
SUAN	1.13	0.071	-18.0(10 ⁻⁵)
<u>site 1: year 2</u>			
BC+SPL	1.00	0.088	-19.0(10 ⁻⁵)
SPL	7.50	0.051	-11.90(10 ⁻⁵)
SUAN	11.4	0.015	-1.80(10 ⁻⁵)
<u>site 2: year 2</u>			
BC+SPL	-5.5	0.104	-18.2(10 ⁻⁵)
SPL	3.04	0.057	-9.76(10 ⁻⁵)
SUAN	9.5	0.018	-3.90(10 ⁻⁵)

The exponential model

N Management Approach	A	b
<u>site 3: year 1</u>		
BC+SPL	19.1	3.90(10 ⁻³)
SPL	8.79	13.9(10 ⁻³)
SUAN	7.96	22.3(10 ⁻³)
<u>site 1: year 2</u>		
BC+SPL	15.50	7.57(10 ⁻³)
SPL	12.89	22.2(10 ⁻³)
SUAN	14.2	17.4(10 ⁻³)
<u>site 2: year 2</u>		
BC+SPL	15.3	4.50(10 ⁻³)
SPL	13.1	9.63(10 ⁻³)
SUAN	12.2	15.1(10 ⁻³)

Table 3. Estimated corn grain yields at selected total nitrogen rates based on the quadratic and exponential models of the relationship between yield and fertiliser or manure total N applied.

Estimated yield at selected total nitrogen rates based on quadratic models.

TN rate (kg ha ⁻¹)	BC+SPL (tonne ha ⁻¹)	SPL (tonne ha ⁻¹)	SUAN (tonne ha ⁻¹)
<u>site 3: year 2</u>			
100	na [†]	6.5	7.2
150	na	7.6	7.8
175	6.6	8.0	7.8
200	7.9	8.2	7.8
225	8.7	8.4	7.8
<u>site 1: year 3</u>			
100	na	11.3	11.5
150	na	12.3	12.7
175	11.5	12.6	13.1
200	12.2	12.7	13.4
225	12.7	12.7	13.7
<u>site 2: year 3</u>			
100	na	8.0	9.5
150	na	9.8	11.0
175	na	10.5	11.4
200	8.9	11.1	11.7
225	9.8	11.6	11.7

Estimated yield at selected TN rates based on exponential models.

TN rate (kg ha ⁻¹)	BC+SPL (tonne ha ⁻¹)	SPL (tonne ha ⁻¹)	SUAN (tonne ha ⁻¹)
<u>site 3: year 2</u>			
100	na	6.6	7.1
125	na	7.1	7.4
175	7.4	7.9	7.8
200	8.6	8.2	7.8
225	9.2	8.4	7.9
<u>site 1: year 3</u>			
100	na	11.5	11.7
125	na	11.9	12.3
175	11.4	12.5	13.2
200	12.2	12.7	13.6
225	12.7	12.8	13.9
<u>site 2: year 3</u>			
100	na	8.1	9.5
125	na	9.0	10.2
175	7.9	10.5	11.2
200	9.1	11.1	11.5
225	9.9	11.6	11.8

† na = not applicable (the derived equation is not applicable at these applied N rates)

Table 4. Economically optimum sidedress rates (in kg [N] ha⁻¹) for corn using three N management approaches†.

N Management Approach	site 3: year 2	site 1: year 3	site 2: year 3
BC+SPL	254	222	274
SPL	217	197	267
SUAN	207	238	158

†Based on a fertiliser N cost of US\$0.66 kg⁻¹ and a corn grain value of US\$98 tonne⁻¹

in PL is available to plants during the first year after application, a more meaningful comparison is between fertiliser total N, which is all plant available, and manure plant available N (PAN), estimated in Delaware as ~60% of total N (Bitzer and Sims, 1988). Based on this, the average (and ± standard deviation) over all responsive sites, EON rates for SUAN, SPL, and BC+SPL were 201±40, 136±22, and 150±16 kg [PAN] ha⁻¹. Therefore, topdressing PL was shown in this study to be the most efficient approach to N management.

3.2 Evaluation of Soil and Plant N Tests in years 2 and 3

Profitable and environmentally efficient N management for poultry-grain agriculture not only requires identification of the proper N source and method of application, but also the ability to predict the need for supplemental N based on the N supplying capacity of the soil, particularly in situations where most of the N can be topdressed, as is the case with corn. In our study, we found the PSNT to be an effective predictor of the need for topdress N, either as UAN or PL (Table 5). The PSNT has been well-documented as an effective means to identify N responsive sites in the eastern U.S. (Fox et al., 1992; Meisinger et al., 1992; Sims et al., 1995), with critical values reported to range from 20-25 mg [NO₃-N] kg⁻¹. In year 2, based on PSNT values at Site 1 (24-33 mg [NO₃-N] kg⁻¹), no yield response to topdress N would have been expected (Table 5). Lower PSNT values at Sites 2 (12-14 mg [NO₃-N] kg⁻¹) and 3 (9-11 mg [NO₃-N] kg⁻¹) suggested that grain yields should have increased in response to topdressing with N, although the high plant available NH₄-N values at site 2 (14-23 mg [NH₄-N] kg⁻¹) indicated that this site may also be non-responsive. In year 3, the PSNT values at both locations (6.8 to 17.1 and 2.3 to 10.7 mg [NO₃-N] kg⁻¹ at sites 1 and 2, respectively) indicated that yield increases from topdressing with N would occur. As noted above and shown in Fig.4, based on the yield results obtained, the PSNT was an accurate predictor of N sufficiency at four of the five sites in this study. The only exception was site 2 in year 2, incorrectly identified, based on soil NO₃-N alone, as being responsive to topdressed N; however as noted above had the high soil NH₄-N concentrations at site 2 been taken into consideration this site would likely have also been considered to be non-responsive to topdressed N.

The predictive accuracy of the PSNT can be supplemented with plant analysis or use of the LCM. Sufficiency levels for N in early whole corn plants range from 3.5-5.0 % (Mills and Jones, 1996) while critical LCM values at this growth stage have been reported to range from 43 to 48 SPAD units (Piekielek, et al., 1992; Sims et al., 1995). Based on these studies and the early whole plant N concentrations and LCM readings at each site (Table 5), significant yield responses to topdress N would only have been anticipated in year 2 at site 3,

Table 5. Influence of nitrogen management approach on pre-topdress soil NH₄-N and NO₃-N, early whole plant N and actual and relative leaf chlorophyll metre (LCM) readings at each site in Year 2 and 3.

Year 2

Treatment	Pre-topdress Soil			Early Whole Plant		
	NH ₄ -N	NO ₃ -N	N	N	LCM	REL LCM [‡]
	(mg kg ⁻¹)			(%)	(SPAD)	(decimal)
<u>Site 1: Newark</u>						
BC-PM + SD-PM	6.3	27.8	34.1	4.5	54	0.99
SD-PM	6.0	32.9	38.9	4.6	53	0.97
SD-CF	6.3	24.1	30.4	4.4	53	0.98
<u>Site 2: Lincoln</u>						
BC-PM + SD-PM	22.5	13.5	36.0	4.6	52	0.99
SD-PM	14.4	13.7	28.1	4.3	51	0.97
SD-CF	19.1	11.5	30.6	4.6	51	0.98
<u>Site 3: Georgetown</u>						
BC-PM + SD-PM	15.4	10.6	26.0	4.1	52	0.94
SD-PM	10.8	11.2	22.0	3.6	49	0.88
SD-CF	11.2	8.5	19.7	3.4	48	0.87

Year 3

Treatment	Pre-topdress Soil			Early Whole Plant		
	NH ₄ -N	NO ₃ -N	N	N	LCM	REL LCM [‡]
	(mg/kg)			(%)	(SPAD)	(decimal)
<u>Site 1: Middletown</u>						
BC+SPL	4.0	17.1	21.1	5.3	49	1.00
SPL	3.5	6.8	10.3	5.0	47	0.95
SUAN	5.3	8.2	13.4	4.9	47	0.96
CHECK	5.2	36.7	41.9	5.4	49	1.00
<u>Site 2: Georgetown</u>						
BC+SPL	8.3	10.7	19.1	4.5	48	1.04
SPL	6.1	2.3	8.4	3.6	43	0.94
SUAN	6.6	3.0	9.6	3.9	44	0.96
CHECK	15.2	25.0	40.2	4.7	46	1.00

[‡]REL LCM = (LCM value for the 5th leaf in SPAD units)/(LCM value of a well fertilised plot in SPAD units)

in agreement with the PSNT data. In year 3, early whole plant N concentrations were clearly in the sufficiency range at both sites while LCM values were at or slightly below the critical value of 48 SPAD units reported by Sims et al., (1995) for Delaware conditions. The three N

responsive sites had the lowest LCM readings, averaging, across treatment, 50, 48, and 45 SPAD units at Site 3 (year 2) and Sites 1 and 2, respectively, in year 3 (Table 5). When data from both years were combined, a significant correlation was found between LCM readings

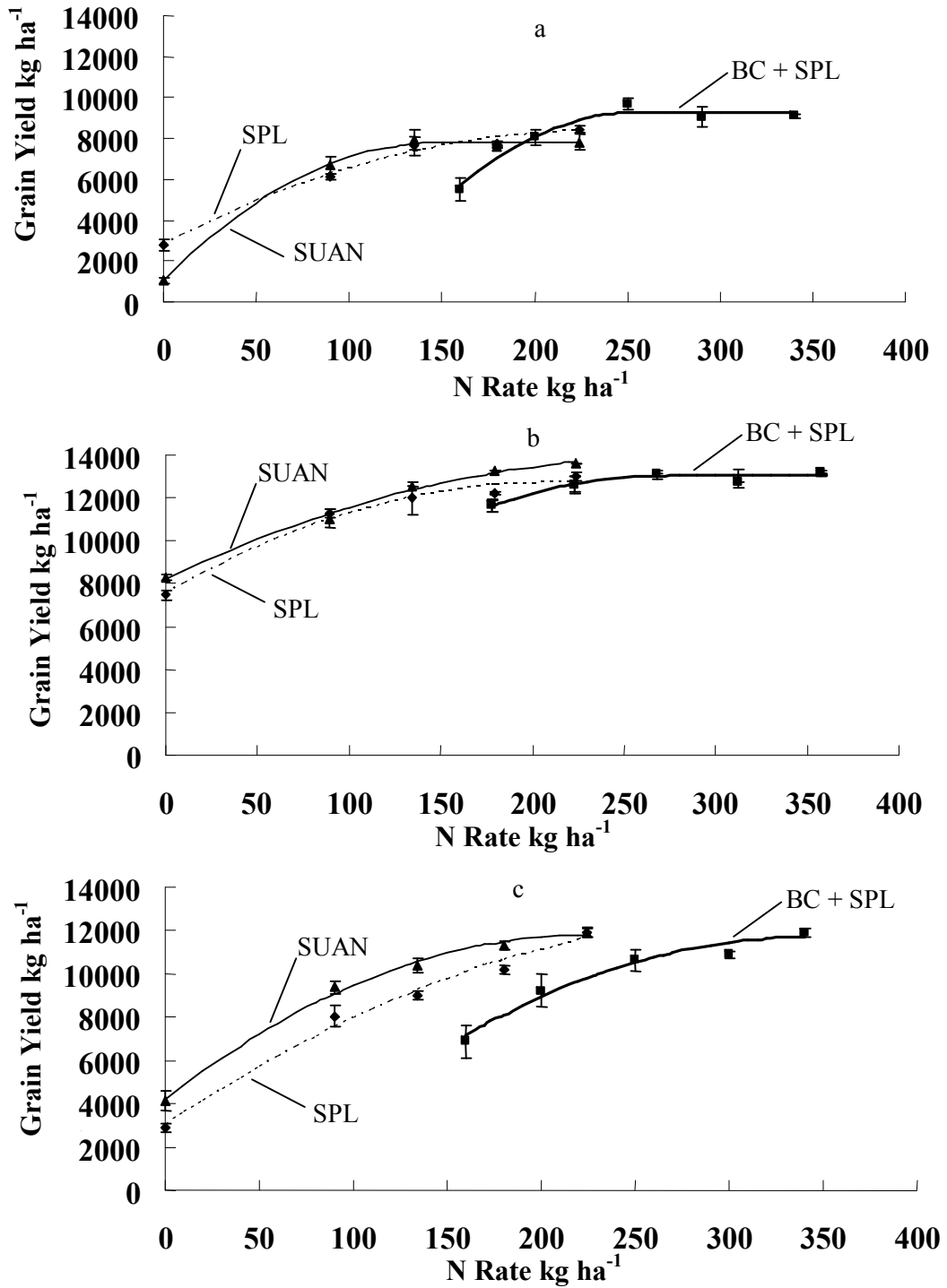


Figure 4. Corn response to different topdress rates and sources for three of the sites evaluated in years 2 and 3 of this study. Plots correspond to the following time and location: a) year 2, site 3; b) year 3, site 1; c) year 3, site 2.

from early whole plants and the pre-topdress soil $\text{NO}_3\text{-N}$ ($R^2=0.67$). However, LCM and soil inorganic N ($\text{NH}_4\text{-N} + \text{NO}_3\text{-N}$) were better correlated ($R^2=0.88$). The LCM values corresponding to either $20 \text{ mg } [\text{NO}_3\text{-N}] \text{ kg}^{-1}$ or $20 \text{ mg } [\text{NH}_4\text{-N} + \text{NO}_3\text{-N}] \text{ kg}^{-1}$ (estimated from linear regression equations between these variables) were 51 and 48 SPAD units, respectively.

We also measured LCM values at two week intervals throughout the growing season to determine if critical values changed as corn matured. Highly significant linear relationships were obtained, for the three responsive sites, between relative yield and LCM readings on four sample dates. The LCM values associated with a relative yield of 0.93 (a value often used to most effectively separate sites that are responsive and non-responsive to topdress N; Fox et al., 1992) were 55, 58, 60, and 58 SPAD units at 14, 28, 42, and 56 days after topdressing, respectively. This suggests that LCM critical values may increase slightly during the growing season.

Finally, we measured $\text{NO}_3\text{-N}$ concentrations in the lower portion of the corn stalk at maturity, which have been shown to be a reliable predictor of N sufficiency during the growing season. The optimum range for corn stalk $\text{NO}_3\text{-N}$ concentrations reported by both Blackmer et al. (1992) and Sims et al. (1995) was from 700-2000 $\text{mg } [\text{NO}_3\text{-N}] \text{ kg}^{-1}$. Values above 2000 $\text{mg } [\text{NO}_3\text{-N}] \text{ kg}^{-1}$ indicate that excess N had been applied relative to that needed for optimum crop yields. Our data, shown in Fig. 5, were very consistent with data from previous research and provide further evidence that the late season stalk $\text{NO}_3\text{-N}$ test can be a valuable management tool for corn production in the mid-Atlantic region.

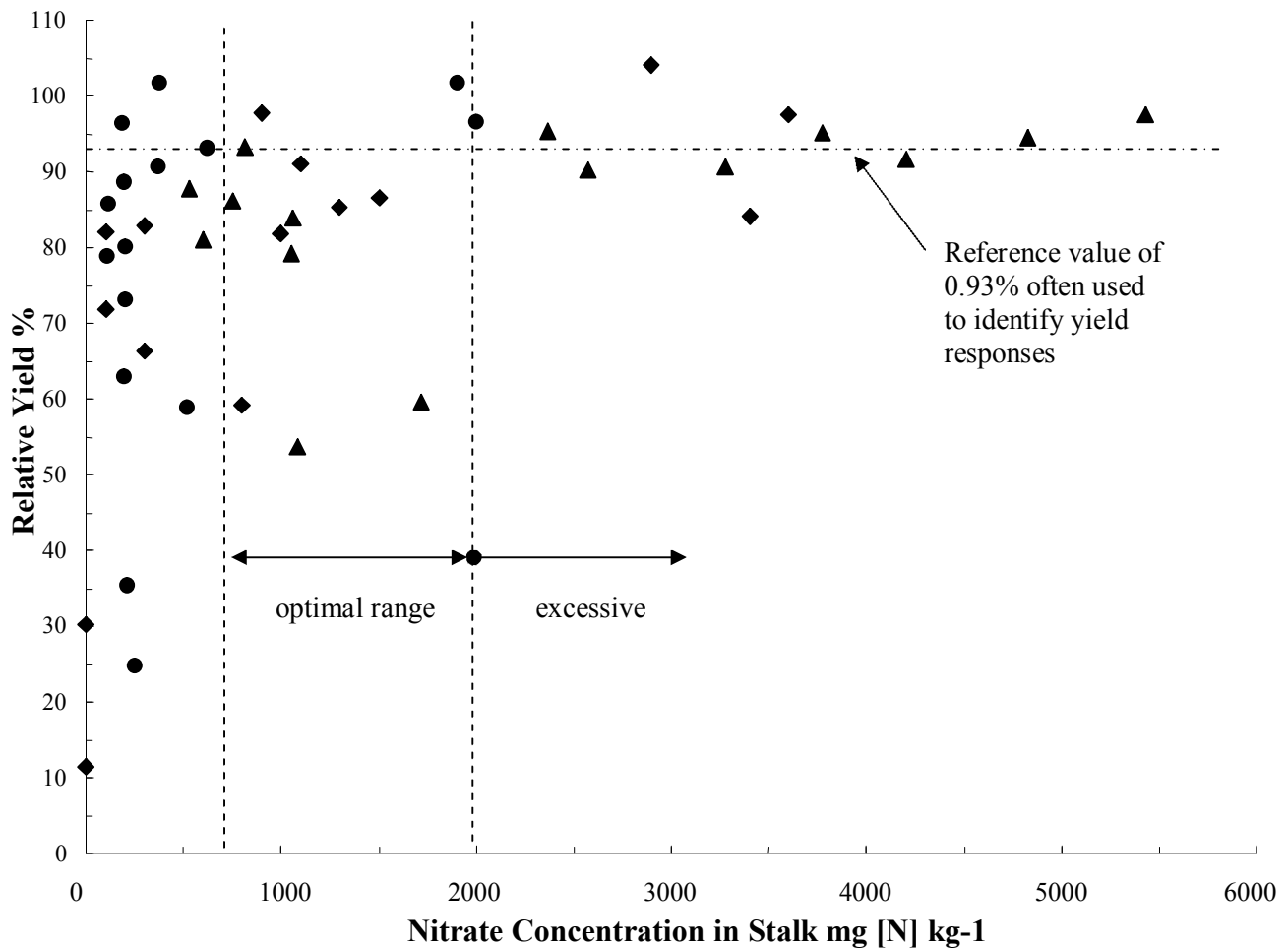


Figure 5. Relationship between the stalk nitrate content and relative yield. Data points correspond to the following locations: \blacktriangle Site 1; \bullet Site 2; \blacklozenge Site 3.

3.3. Cost Analysis of the N Management Practices

To evaluate the costs associated with the different N application methods evaluated in this study, expenses were estimated for each practice. Table 6 summarises the various costs associated with applying $140 \text{ kg [PAN] ha}^{-1}$, and corresponds to 2007 prices and costs in the U.S. Fixed costs are the sum of expenses associated with purchasing and owning the equipment (i.e., tractor & applicator) required to implement each practice. These costs were more than three times higher for BC+SPL compared to SUAN because of the additional costs resulting from two tractors and applicators. Labour and fuel costs per hectare for the SPL practices were approximately eight times higher than SUAN; this additional expense can be attributed to the lower concentrations of N in poultry litter, thus requiring significantly more applicator trips and operator time per hectare.

Total application cost for each practice was computed assuming a price of $\text{US\$}0.44 \text{ kg [N]}^{-1}$ ($\text{US\$}13.2 \text{ tonne}^{-1}$ of PL) wet basis for poultry litter and $\text{US\$}0.66 \text{ kg [N]}^{-1}$ for UAN. The BC+SPL practice was $\text{US\$}18 \text{ ha}^{-1}$ higher than SUAN. When all the PL is topdressed, total cost is

about US\$10 ha⁻¹ higher compared to SUAN. Again, these higher costs are the result of the additional applications required for the SPL practice. However, it should be noted that the largest single expense for each practice is the cost to purchase PL (or UAN). As a result, the estimates for total cost presented in Table 6 are very sensitive to UAN and PL prices.

3.4. Implications for a Comprehensive Poultry Litter Management Plan

The goal of this study was to determine optimal PL and UAN topdress rates as a means to improve overall N management for corn. For PL, the results from this study should be used as part of an overall nutrient management plan in which both N and phosphorous (P) requirements are considered. In many instances in the Mid-Atlantic region, PL rates are now based on soil test P and crop P removal in harvested grain in order to protect water quality (Sims and Kleinmann, 2005). Topdressing PL should help farmers apply manure P at rates that do not exceed, or are less than crop P removal and thus improve field and farm-scale P management. For example, our study showed that the EON rate for SPL was 140 kg [PAN] ha⁻¹. Based on typical PL analyses at the time of this research (TN=4.0%, PAN=2.5%, total P=2.0%), it would require 5600 kg [PL] ha⁻¹ to provide this amount of topdress N which, in turn, would add 112 kg [total P] ha⁻¹. Most farmers grow corn in rotation with soybeans and only need to apply manure N to the corn. Crop P removal for a typical corn-soybean rotation in Delaware is 115 kg [total P] ha⁻¹. Thus, topdressing PL would appear to meet, but not exceed, the amount of P removed in harvested grain. Even more encouraging, recent advances in dietary P management for poultry have been shown to reduce litter total P concentrations in Delaware by 25-40% and today, based on state manure testing, litter P concentrations average ~1.4% (Hansen et al., 2005, McGrath et al., 2005). Hence, topdressing PL at 5600 kg ha⁻¹ using litters generated with today's diets would only add ~78 kg [total P] ha⁻¹, less than is removed in harvested corn and soybeans. Since most of the soils in Delaware's poultry producing region are now considered "excessive" in soil P (Sims et al., 2002), topdressing PL produced using current diets could meet crop N requirements for economically optimum yields and help to decrease soil test P values in over-fertilised soils back into the agronomically optimum range.

Table 6. Projected costs for each of the application methods evaluated in this study. Costs are based on an application rate 140 kg [N] ha⁻¹ corresponding to the EON for SPL. Annual fixed costs were assumed to be 1% of the purchase price, and the price of diesel fuel was \$0.53 l⁻¹. The analysis is based on a purchase price of \$0.44 kg[N]⁻¹ wet basis for poultry litter and \$0.66 kg[N]⁻¹ for UAN.

N Management Practice	Tractor Power (kW)	Applicator Purchase Price (US\$)	Equipment Fixed Costs (US\$ ha ⁻¹)	Field Capacity (ha h ⁻¹)	Labour and Fuel Costs (US\$ ha ⁻¹)	PL or UAN Cost (US\$ ha ⁻¹)	Total Cost (US\$ ha ⁻¹)
BC+SPL	90* & 60**	10,000* & 15,000**	5.5* & 3.5**	9.6* & 2.0**	28.5	77	115.0
SPL	60	15,000	3.8	1.5	26	77	106.8
SUAN	45	5,000	2.3	4.0	3.2	91	96.5

* cost estimates for the BC portion of this practice. ** cost estimates for the SPL portion of this practice.

4. Conclusions

The results of this study clearly show that alternate PL management strategies, using improved N tests and solid waste topdressing technology, should improve the agronomic and environmental efficiency of corn production in Delaware and similar states. Economically optimum yields were obtained by the use of starter fertilisers and moderate topdress N rates, and PL was as effective as UAN for topdressing corn. Comparison of total application costs revealed that topdressing with PL is about US\$10 ha⁻¹ higher compared to SUAN and can be attributed to the lower concentrations of N in poultry litter, thus requiring significantly more applicator trips and operator time per hectare.

The N testing methods used in this study (PSNT, LCM, stalk NO₃-N) were found to be important components of an overall N management program for corn. Based on corn yields, the PSNT and LCM data successfully predicted the likelihood that corn would respond to topdress N and stalk NO₃-N data accurately identified sites that were deficient or excessive in N. Note, however, that the LCM values associated with economically optimum corn yields in our study, were higher than those reported in previous research (43 to 48 SPAD units), ranging from 48 SPAD units for early whole plants to ~60 SPAD units for ear leaves during the growing season.

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