Subsurface Application Enhances Benefits of Manure Redistribution

Jian Liu,* Peter J. A. Kleinman, Douglas B. Beegle, Curtis J. Dell, Tamie L. Veith, Lou S. Saporito, Kun Han, Dan H. Pote, and Ray B. Bryant

Abstract: Sustainable nutrient management requires redistribution of livestock manure from nutrient-excess areas to nutrient-deficit areas. Field experiments were conducted to assess agronomic (i.e., corn yield) and environmental (i.e., ammonia volatilization and surface nutrient loss) effects of different poultry litter application methods (surface vs. subsurface) and timings (fall vs. spring) in a potential manure-importing region in the Chesapeake Bay Watershed in the United States. All four litter treatments (205 kg nitrogen ha⁻¹) produced grain yields (10.9–12.8 Mg ha⁻¹) nearly equivalent to or higher than the 11.5 Mg ha⁻¹ yield expected from the same mineral nitrogen rate. Compared with surface application, subsurface application significantly reduced ammonia emission ($p < 0.0001$), runoff volume (fall: $p = 0.02$; spring: $p = 0.004$), and loads of nitrate nitrogen ($p < 0.0001$; $p = 0.003$) and dissolved phosphorus ($p < 0.0001$; $p = 0.004$) soon after application. Integrating subsurface manure application technologies into the manure redistribution programs would help ensure that the surplus nutrients being relocated provide a maximum agronomic impact and minimum environmental impact to the importing region.

Environmental sustainability requires improved manure management in animal agriculture, by both efficiently using valuable nutrient resources and minimizing nonpoint-source pollution impacts (Maguire et al., 2011). In the Chesapeake Bay Watershed, which occupies an area of 166,000 km² in the eastern United States, 36 million Mg of manure is produced per year, and brokering programs have been established to promote the redistribution of manure from areas of concentrated animal production to areas of nutrient deficit (Kleinman et al., 2012). Such programs most commonly result in redistribution of dry poultry litter because it is more economically and conveniently transported than liquid or semisolid manure (Aillery et al., 2005). Ideally, imported manure contributes to farm nutrient needs without adversely affecting local air and water quality (Kleinman et al., 2012), while simultaneously reducing excess nutrients from its source location.

Immediate incorporation of manure into soil can reduce the potential for manure phosphorus (P) losses in runoff (McLeod and Hegg, 1984; Johnson et al., 2011) and ammonia (NH₃) volatilization (Malgeryd, 1998; Dell et al., 2012), both by as high as 90%. Nonetheless, surface application of manure remains the dominant application method in the Chesapeake Bay Watershed, where more than 60% of the agricultural land is in reduced tillage or perennial grass cover. Thus, low soil disturbance technologies are crucial for successful adoption of manure incorporation (Maguire et al., 2011).

The USDA-ARS Subsurfer is a mechanical applicator that places dry poultry litter below the soil surface using no-till planter components with minimal disturbance (Pote et al., 2011, 2012). The Subsurfer has reduced nutrient losses to the environment in areas of concentrated poultry production, such as Maryland’s eastern shore (Feyereisen et al., 2010; Kibet et al., 2011), where farmland area is small relative to the manure nutrients produced. Recent Subsurfer trials on poultry litter application in Pennsylvania’s south-central poultry production region confirmed soil nitrogen (N) increase with incorporation but significant yield increase in only one of the six fields.

Core Ideas

- Manure redistribution adds fertility benefits to recipient fields.
- Subsurface application of poultry litter has environmental benefits.
- Redistribution plus subsurface application benefits both farmers and the environment.

Environmental, Agricultural &

Research Letter

Letters
We hypothesize that manure redistribution provides high nutrient values to the recipient fields comparable to those provided by the mineral fertilizer that manure replaces and that subsurface application reduces nutrient losses compared to surface application. Here we quantify the differences in surface and subsurface application of poultry litter on a combination of agronomic and environmental variables. Specifically, we evaluated the effects of the Subsurfer on crop yields, midseason soil nitrate N, NH$_3$ volatilization, and runoff water quality.

**Materials and Methods**

This study was conducted on a field located at The Pennsylvania State University’s Russell E. Larson Agricultural Research Center. The field, underlain by a moderately well drained Buchanan soil (fine-loamy, mixed, semiactive, mesic Aquic Fragiudult) with a 3 to 5% slope, was in a region normally managed with no-till rotation of corn (*Zea mays* L.), soybean (*Glycine max* (Merr.) L.), and winter wheat (*Triticum aestivum* L.).

**Treatments**

Poultry litter was imported from the extensive poultry production sector in south-central Pennsylvania, 140 km away. Aillery et al. (2005) reported that areas with extremely limited spreadable land within the Chesapeake Bay Watershed have been required to export litter as far as 150 km. Litter composition was typical for Pennsylvania: 25% moisture with 30.6 kg total N (including 4.1 kg ammonium N), 14.0 kg total P, and 21.5 kg total potassium, per Mg dry matter (Peters et al., 2003). The four poultry litter treatments included surface and subsurface applications at 6.7 Mg ha$^{-1}$ (dry weight), supplying 205 kg total N ha$^{-1}$ and 94 kg total P ha$^{-1}$. Subsurfer incorporation units were raised during surface applications, spreading litter in 5-cm-wide bands. Statistical significance ($\alpha = 0.05$) of mean comparisons were determined by generalized linear models (GLM) with Tukey’s pairwise comparison (SAS v. 9.2, SAS Institute, Carey, NC).

**Agronomic Efficiency**

Nitrogen use efficiencies were evaluated via a randomized block design (plot size: 3 m by 10 m) with 10 treatments and four replicates: the four litter treatments as described previously (205 kg N ha$^{-1}$), and surface-applied ammonium sulfate (0, 45, 90, 135, 180, and 225 kg N ha$^{-1}$) immediately after corn planting. Pre-sidedress soil nitrate tests (PSNT) were conducted in June at corn vegetation stage 6 via plot-composite soil samples at a depth of 30 cm (Sims et al., 1995). Grain yields were determined from the center two rows (each 0.76 m wide by 9 m long) of each plot in late November using an Almaco Plot Combine with Harvest Master System that recorded plot weight, test weight, and moisture.

**Results and Discussion**

**Agronomic Efficiency**

Immediately after the May application, sets of six steel chamber bases were inserted into each of the two spring litter treatments, adjacent to the yield plots to avoid disturbing N response measurements. A single vented, aluminum chamber (0.76 m by 0.76 m by 0.10 m high), with internal air recirculation, was connected to an Innova 1412 photo-acoustic gas monitor (LumaSense Technologies) to quantify NH$_3$ flux. The chamber was sequentially attached to each chamber base, and air samples were analyzed every 45 s over a 6-min period at approximately 1, 6, 26, and 56 h after installation. Emission rates were calculated from the linear regression of NH$_3$ concentration versus chamber deployment time.

**Nutrient and Sediment Losses**

Sixteen runoff plots (2 m by 2 m; 4 litter treatments $\times$ 4 replicates) were constructed adjacent to the yield and emissions plots (per Kleinman et al., 2009). In fall 2011, a 1.5-h, 2.5 cm h$^{-1}$ rainfall was simulated 2 d after litter application. Because of runoff generation concerns, rainfall intensity was increased (7.5 cm h$^{-1}$) for simulation 129 d after application. In spring 2012, 7.5 cm h$^{-1}$ events were conducted 12 and 200 d after application, with duration for each plot based on 20 min of runoff. All runoff was combined per plot, volume measured, mixed thoroughly, and sampled for laboratory analysis. Total solids (APHA, 2005) and total P (USEPA, 1979), from unfiltered samples, and dissolved P (USEPA, 1979), following 0.45-μm filtration, were determined by inductively coupled plasma atomic emission spectrometry. Particulate P was calculated as total P minus dissolved P.

**Ammonia Volatilization**

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**Agronomic Efficiency**

All four poultry litter treatments (surface/subsurface, spring/fall) demonstrated high nutrient values. Corn grain yields following litter application (205 kg N ha$^{-1}$) ranged from 10.9 to 12.8 Mg ha$^{-1}$, encompassing the 11.5 Mg ha$^{-1}$ yield estimated for 205 kg mineral fertilizer N ha$^{-1}$ (Fig. 1a). Poultry litter benefits that were acknowledged by the farming community include high yields (Rasnake et al., 2004) and macro- and micronutrients (Bolan et al., 2010). Grain yield did not differ significantly within the four litter treatments, consistent with Mitchell and Tu (2005). In this experiment, the lowest manure treatment yield (surface, fall) was at or very close to the plateau yield for N; thus, yield would not be a sensitive indicator of the impact of the manure application treatments on N availability. Elsewhere, subsurface litter application was reported to increase crop yields in nutrient deficient systems (Pote et al., 2012). Improved N conservation due to subsurface application was demonstrated by increased PSNT values, significantly so in the spring (Fig. 1b), echoing Pote et al. (2011). Significantly larger PSNT values after spring subsurface application than fall indicate N efficiencies increase with applications nearer...
planting. A PSNT value of 21, as met by the surface trials, indicates N sufficiency. Thus, PSNT values above 21 in the subsurface trials indicate that desirable corn yields may still be achieved using less manure N.

**Ammonia Volatilization**

Ammonia N emissions (mean ± SE) following surface application decreased from 42.9 ± 6.8 g ha⁻¹ h⁻¹ 1 h after application to 7.2 ± 1.7 g ha⁻¹ h⁻¹ by the sixth hour; it then dropped steadily to undetectable levels (<1 g ha⁻¹ h⁻¹) by the 56th hour. In contrast, emissions from subsurface applications peaked at 1.8 ± 0.2 g ha⁻¹ h⁻¹ 26 h after application, and 80% of all samples were below detection. Measurements between treatments 1 and 6 h after application were significant at \( p < 0.0001 \) and \( p = 0.001 \), respectively. Emissions with our system were lower than expected (Pote and Meisinger, 2014) but provided a reliable relative comparison between treatments. Our \( \text{NH}_3 \) reduction with subsurface application (84%) was consistent with that (88%) observed by Pote and Meisinger (2014).
Nutrient and Sediment Losses

The subsurface plots produced consistently less runoff than the surface plots during the first events after application (Fig. 2). Small ridges created by the Subsurfer’s incorporating action retain surface flow (Pote et al., 2009; Kibet et al., 2011). Correspondingly, sediment and nutrient loads were significantly curtailed with subsurface litter application. Moreover, loads of the major nutrient components, nitrate N and dissolved P, were significantly reduced in the first events after subsurface application as compared to those for surface application (p < 0.0001 and p = 0.003, p < 0.0001 and p = 0.004, respectively).

Conclusions

This study clearly demonstrates that the fertility benefit for both surface and subsurface litter application is comparable to that from mineral fertilizer and that subsurface application of poultry litter has environmental benefits in the form of reduced ammonia emissions and surface nutrient losses. The advantages of subsurface application of poultry litter provide strong justification for including this technology as part of litter redistribution programs, to minimize the impact of litter applications in areas where it is imported.

References


