Best Management Practices

Vegetative Environmental Buffers to Mitigate Odor and Aerosol Pollutants Emitted from Poultry Production Sites

Joe Colletti, Steven Hoff, Janette Thompson and John Tyndall
Iowa State University

Abstract

In Iowa at a commercial poultry facility, we are assessing the ability of a multi-row vegetative environmental buffer (VEB) to mitigate odor, ammonia, and particulates. In 2004 and 2005 Eastern redcedar (*Juniperius virginiana),* hybrid willow (*Salix* X) and limber pine (*Pinus flexilis*) were planted in rows parallel to a pullet facility. Monitoring of microclimate conditions and ammonia, odor, and particulates (PM_{10} and $PM_{2.5}$) in perpendicular transects from the facility exhaust fans through the VEB is providing detailed data on flow, dispersion, capture, and throughput of the emissions. Tree species health is also being monitored. The expected impact is adoption of VEB systems as air quality best management practices to mitigate the air pollutant risks and to sustain the poultry industry, communities, and the environment.

Introduction

The poultry industry of today is facing environmental challenges relating to air and water quality. Kliebenstein (1998) suggests that the sustainability of industries within agriculture will be shaped by their collective ability to improve environmental impact technologies. Whereas odors from animal production are ubiquitous with agriculture and historically tolerated by rural communities, structural changes in the US poultry industry such as increased farm size and increased concentration of animal manure have caused more pervasive and offensive odor problems. With urban developments pushing into rural areas more people continue to be significantly affected by odor. Poultry odor nuisance may prove to be the most damaging to both rural communities, the poultry industry, and to state economies. Innovative best management practices to mitigate odor problems are needed.

The central thesis of this study is that vegetative environmental buffers (VEBs) can play significant roles in biophysically mitigating odor in a socio-economically responsible way thereby reducing social conflict from odor and dust nuisance (Malone and Van Wicklen, 2001; Malone and Abbot-Donnelly, 2001; Tyndall and Colletti, 2000).

Several recent important livestock producer outreach sources (MWPS, 2002; NPPC, 1995; Lorimer, 1998; OCTF, 1998; Jacobson et al., 1998) list tree systems (VEBs) as odor control practices but provide little physical, chemical, biological, or economic quantification as to their effectiveness.

A multi-state (Iowa, Delaware, and Pennsylvania) project is underway to quantify the efficacy of vegetative environmental buffers (VEBs), which are tree and shrub shelterbelts arranged in specific designs near and within poultry facilities, to provide cost-effective best management practice to facilitate the mitigation of odor, particulates, and ammonia, associated with intensive poultry production. Farm level monitoring and assessment of VEBs in these three states is backstopped by laboratory studies of tree/ammonia and tree/particulate interactions to lead to selection of effective and tolerant species. The farm level data will be used to simulate odor, particulate, and ammonia flow and dispersion with and without VEBs. Outreach activities will occur with collaboration of researchers, state poultry associations and government agencies. Integration of results including costs will guide producer best management decisions and inform policy decisions.

Methods

VEB Establishment

A multi-row VEB was established in two phases on a commercial poultry (pullet) farm in Northcentral Iowa. In the late summer 2004, 6 to 7 ft tall balled and burlapped Eastern redcedar (*Juniperius virginiana),* and a few test limber pine (*Pinus flexilis*) were planted in rows parallel to a pullet facility. The closest row, 25 ft from the exhaust fans, was only a partial row planted entirely with Eastern redcedar. All rows were spaced 10 ft apart and all conifers were planted 10 ft apart. Because of the limited supply of Eastern redcedar and hybrid willow (*Salix* X) in 2004 an additional planting occurred in the spring of 2005 to complete the VEB. The first three rows of the VEB closest to the building and fans (25 ft, 35 ft, and 45 ft) contain Eastern redcedar. The third row (45 ft) was planted to hybrid willow (1 ft cuttings) and Eastern redcedar and the most distant row (55 ft from the fans) was planted entirely to hybrid willow. The willows were planted 6 ft apart. The limber pine were included because of their drought tolerance capabilities, but because of the high cost per tree only a few test trees were planted in the conifer rows.

VEB Monitoring

VEB monitoring began in May 2005. In general, a Mobile Emissions Laboratory (MEL) was used to monitor semi-continuous ammonia and continuous PM10 data and this monitoring was supplemented with portable monitoring towers (PMT) installed every two weeks to capture odor, ammonia, hydrogen sulfide, and wind profiles upwind, within, and downwind of the installed VEB. The measurement methods along with some preliminary results are described below. Additionally, the effectiveness of the VEB to capture particulates was assessed by destructive sampling of tree foliage on the same schedule as the MEL/PMT sampling.

Mobile Emissions Laboratory (MEL)

A Mobile Emissions Laboratory (MEL) was installed on-site to monitor fan operation, PM10 inside the barn, ammonia concentration inside the barn, upwind, within, and downwind of the VEB. The MEL is a self-contained laboratory housing all data acquisition and gas/PM10 sampling hardware. Ammonia (NH_3) was measured using a chemiluminescence-based analyzer (Model 17C, TEI, Inc). Ammonia was measured semi-continuously at five locations including inside the barn, 1 m away from the exhaust fan, 1 m in front of the VEB, in the center of the VEB, and 1 m downwind of the VEB. These locations relative to the installed VEB are shown in Figure 1 with the MEL shown in Figure 2. Gas samples at each of these locations were sampled sequentially in 10-minute sampling blocks. A gas sampling system consisting of solenoids and relays routed gas samples from each location to the NH_3 analyzer for a total of 10-minutes each. Within this 10-minute sampling interval, the first 7-minutes were allowed for analyzer stabilization with the final 3-minutes used for analysis.

Dust sampling was conducted inside the pullet house at approximately 2m from the exhaust fan location using a Tapered Element Oscillating Microbalance (TEOM) Method (Model 1400a; Rupprecht & Patashnick Company, Inc). An installed pre-treatment head allowed particulates at and below 10 um to be sampled. PM10 sampling was continuous.

Portable Monitoring Towers (PMT)

The semi-continuous gas monitoring was supplemented with measurements conducted using three Portable Monitoring Towers (PMT) designed to capture velocity, gas, and odor profiles upwind, within, and downwind of the VEB. When installed, the PMTs were positioned at the locations shown in Figure 1. Each PMT consisted of a 9 m retractable tower with a 3-cup anemometer and a Teflon lined gas sampling tube at 1, 3, and 8 m from the ground surface. A typical PMT set-up is shown in Figure 3. For each sampling line, a vacuum box and sampling pump were used to pull sampled air into 10-L Tedlar bags, with duplicates sampled at each PMT location and within each PMT elevation. The Tedlar samples were then transported immediately to the Iowa State University Olfactometry Laboratory where odor concentration was assessed using the triangular forced-choice method (Model AC'Scent; St Croix Sensory, Inc). The PMT sampling was conducted to quantify the dispersion characteristics upwind and downwind of the VEB in an attempt to discretize between true VEB scrubbing performance and natural dilution of exhausted odorous air with downwind position. To help as well with this effort, two 6m tall diversion curtains (Figure 3) were raised during PMT sampling to minimize cross-wind effects and channel exhausted air through the VEB test section. A view as seen from the exhaust fan bank of the PMT set-up with the diversion curtains deployed is shown in Figure 4.

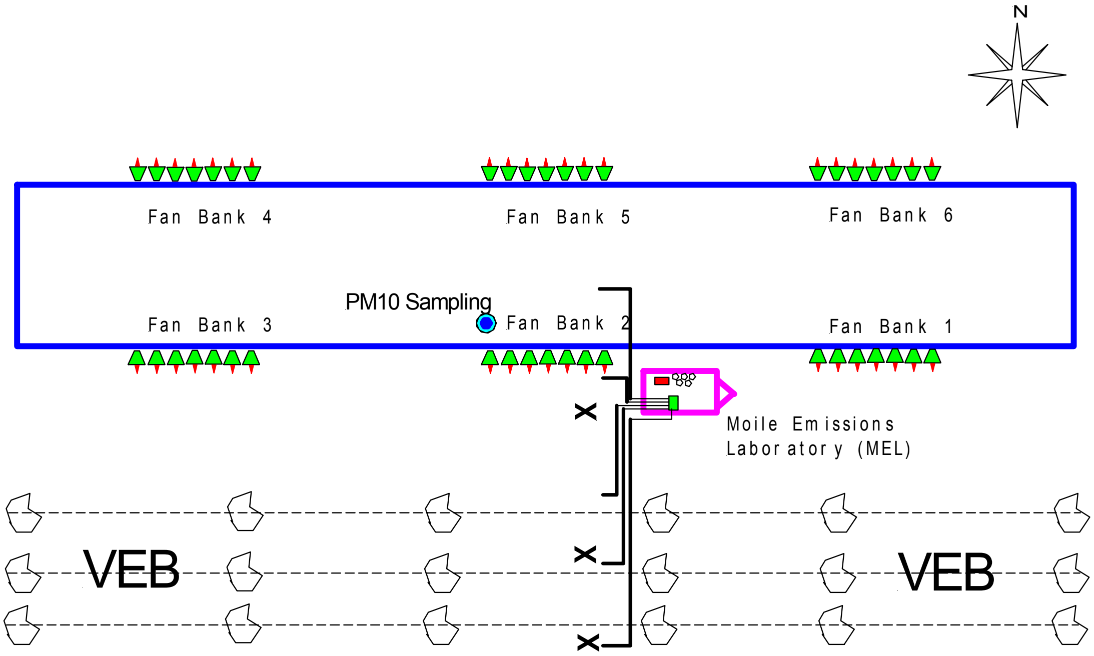


Figure 1. Pullet house monitored with the MEL, NH_3, PM10, and PMT sampling locations (x) relative to installed VEB

Figure 2. MEL shown installed on-site

Figure 3. PMT set-up with sampling diversion curtains extended

Assessing VEB Effectiveness

To assess effectiveness of the “young” VEB in trapping particulates, samples of species included in the VEB (Eastern redcedar and limber pine) as well as control specimens located at some distance from the VEB were collected 12 times on a biweekly schedule May-October 2005 (coordinated with the air quality MEL sampling regime). In the VEB, foliage samples were collected from the top and bottom halves of 2 sample trees located 35 feet from building fans and 3 sample trees located 45 feet from the building on each sample date.

Samples were washed with purified water and a dispersal agent using a flat-bed rotational shaker, and successively filtered to allow separation of coarse particulates, PM_{10} and $PM_{2.5}$. Quantity of particulate deposition was determined gravimetrically for each size class. Surface area for the foliage was determined for samples that were air-dried following the washing procedure. Samples were scanned using a digital scanner and processed using the ROOTEDGE image analysis program.

Figure 4. PMT set-up with diversion curtains shown from the exhaust fan bank looking through the VEB (Figure 1)

Results and Discussion

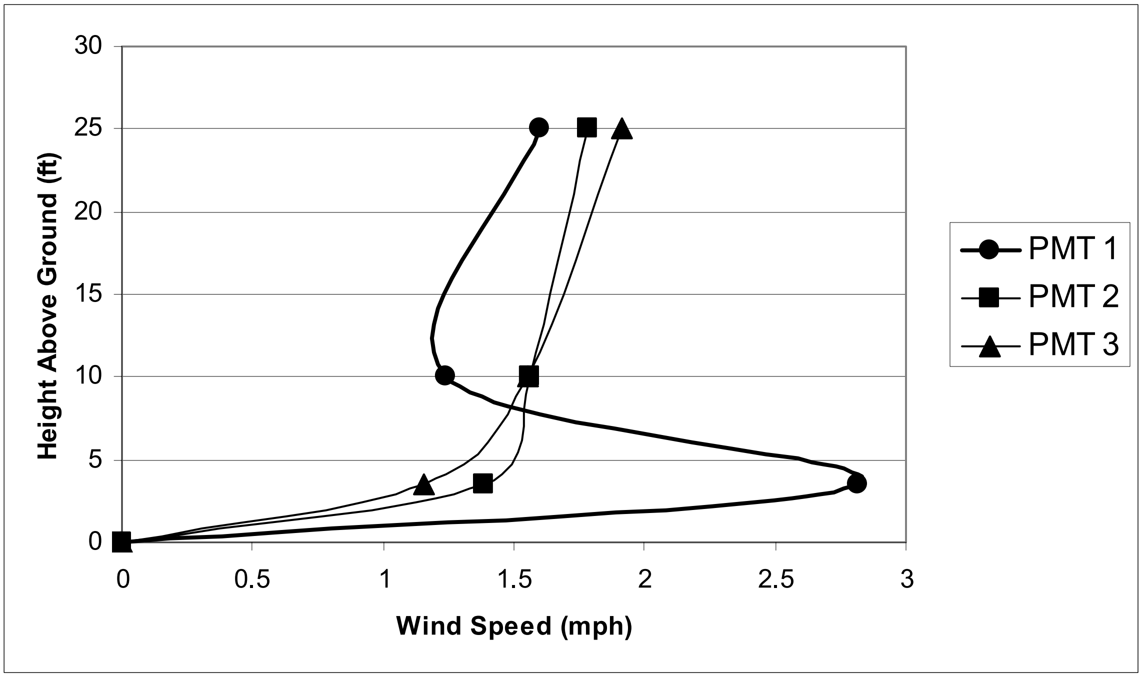
Emission Monitoring

The monitoring conducted to-date represents data collected from an immature VEB as shown in Figure 4. The monitoring results collected in 2005 will serve as base-line data to be compared as the VEB matures. Monitoring began in May 2005 and continued through December 2005, with monitoring planned again for 2006 and into 2007. To demonstrate the sampling procedures and available data for analysis, one typical monitoring day will be discussed during a day when the PMTs were implemented. Figure 5A&B show a very typical result from the PMT monitoring. The boundary layer wind speed profiles shown in Figure 5A clearly indicate the influence of the exhaust fan (PMT 1). Also, the corresponding odor concentration profiles shown in Figure 5B indicate the dilution effects as downwind distance from the exhaust fan increases. The challenge is to discretize the dilution effect that naturally occurs from entrained ambient air from the dilution or scrubbing influence of the VEB. Work continues in the development of methods to quantify the actual VEB effect.

VEB Particulate Capture

Preliminary data on total quantity of particulates captured by trees in the VEB indicate capture rates that are favorable according to levels reported in the literature (Table 1 shows data for one sample date). Control samples indicate relatively low levels of particulates under nearby ambient conditions away from the tunnel fans.

Additional data processing will allow determination of total leaf area within the VEB and estimation of total particulate capture, as well as information for each particle size fraction.



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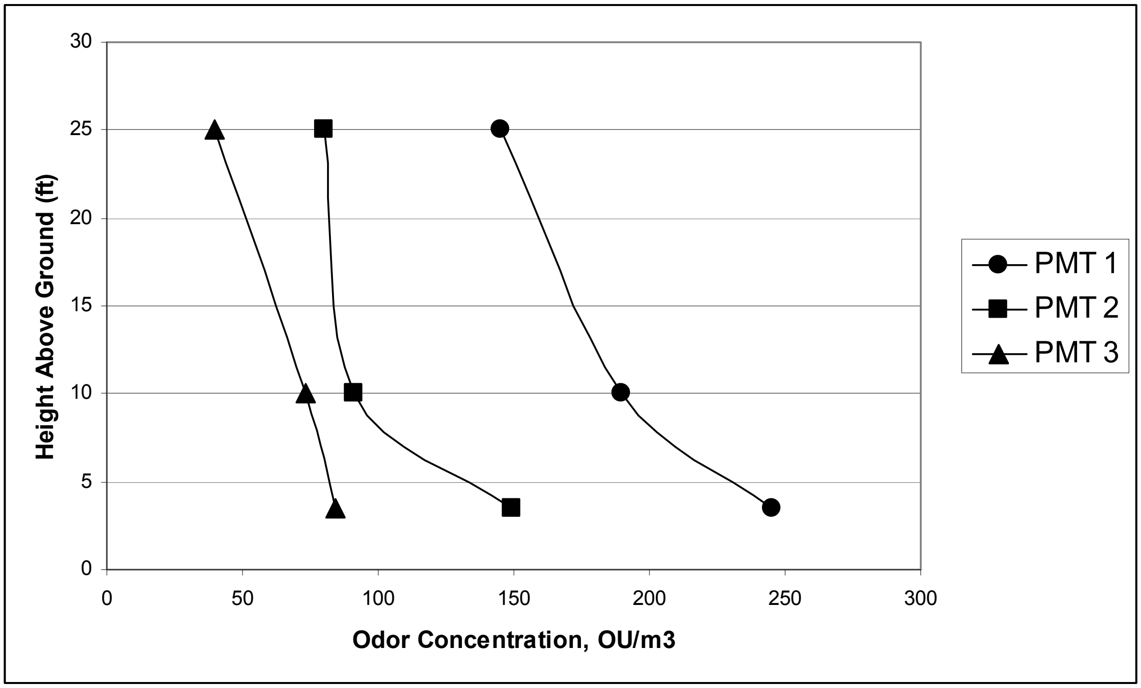

B

Figure 5. Boundary layer (A) wind speed and (B) odor concentration profiles measured between the exhaust fan and upwind of the VEB (PMT 1), within the VEB (PMT 2), and 1 m downwind of the VEB (PMT 3). The source odor concentration was 280 OU/m3 and the exhaust ventilation rate from the fans exhausting between the diversion curtains was 37.8 m^3/s during this PMT sampling event.

Table 1. Particulate capture (mg/cm^2) by Eastern redcedar and limber pine placed at 35 and 45 feet from building fans at a pullet facility for one sample date (October 10, 2005). Foliage was sampled from the top and bottom halves of VEB trees, and from one location on control trees.

Sample type	Total particulate matter, VEB samples (mg/cm^2)			Total particulate matter, control samples (mg/cm^2)	
Species / Tree part	Eastern redcedar (35')	Eastern redcedar (45')	Limber pine (45')	Eastern redcedar	Limber pine
Top	3.06	0.70	0.24	.06	.02
Bottom	4.02	1.49	0.38		

VEB Health

After one complete growing season in front of the banks of exhaust fans, it is apparent that the Eastern redcedar trees planted only 25 ft from the fans are highly stressed and may only survive and not thrive. Careful assessment of the health of these trees will be made early in the growing season of 2006.

Figure 6. A fall 2004 photo of particulate capture by Eastern redcedar from a three-month old VEB at a pullet facility in Northcentral Iowa. The trees are 25 feet downwind of the exhaust fans. Trees were balled and burlapped 6-7 ft tall trees when planted.

Conclusions

The initial results of the three-row VEB located 25 to 35 ft from the exhaust fans of a pullet facility are encouraging in terms of the ability of the VEB to capture particulates. Both visually (see Figure 6) and quantitatively the particulate capture is evident. The emission data suggest odor concentration dilution effects downstream of the fans. However, the separation of the natural, ambient dilution effect from the efficacy of the VEB to reduce odor by capture and transformation cannot be determined at this time.

Our initial evidence suggests that VEBs can be effective in mitigating poultry odor and other emissions by intercepting and diluting odor and particulates before these pollutants reach people downwind. With time we expect to quantify the efficacy of VEB in terms of retaining and transforming odor, ammonia, and particulates.

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Attenuation of Biogenic Emission of CH_4 and N_2O from Agriculture Field

S.N. Singh
Environmental Science Division, National Botanical Research Institute,
Lucknow, UP, 226 001 India.

Abstract

Methane (CH_4) and nitrous oxide (N_2O) are the two important biogenic greenhouse gases emanating from the agricultural fields. These gases are radiactively very active and hence, contribute significantly to enhanced greenhouse effect, despite of their low atmospheric abundance. These gases are generated in the soil by bacteria and emitted to the atmosphere from the soil surface and through plants. Although CH_4 is produced in the highly anoxic conditions, but N_2O is produced in both oxic and partial anoxic condition. In addition, their emission is regulated by various edaphic, plant and environmental factors. Since, India has a large area under cultivation, its contribution to GHE was surmised to be major. However, the estimates made by Indian scientists for CH_4 emission from paddy fields in Methane Campaign 1991 and MAC 1998 clearly indicated that Indian paddy fields contributed only 4.03 Tg CH_4 yr^{-1} which was found ten times less than the projected figure of EPA (37.8 Tg CH_4 yr^{-1}). Despite of this fact, we investigated a few options to mitigate CH_4 and N_2O fluxes from cultivated fields by modifying edaphic factors and also using the inhibitors. These effects may not necessarily stop the global warming, but would certainly help in postponing the danger of climate change coupled with other mitigation actions for various sources of methane and nitrous oxide.

The Undercutter Method of Summer Fallow Farming to Reduce PM10 Particulate Emissions

William F. Schillinger[1], Douglas L. Young[2], and Brenton S. Sharratt[3]
[1]Scientist, Department of Crop and Soil Sciences, Washington State University
[2]Professor, School of Economic Sciences, Washington State University
[3]Soil Scientist, USDA Agricultural Research Service, Pullman, WA

Abstract

Wind erosion is a major problem in the dryland winter wheat (*Triticum aestivum* L.) - summer fallow production region of the Columbia Plateau in eastern Washington and north-central Oregon. Several locations within the Columbia Plateau have failed to meet federal clean air standards for PM$_{10}$ emissions during wind storms. Alternatives to traditional intensive tillage during summer fallow were evaluated over a 13-year period at Lind, WA. The undercutter method of summer fallow farming employs a wide-blade V-sweep for primary spring tillage plus fertilizer injection, followed by as few as two non-inversion weeding operations. Tillage is reduced from the traditional eight operations to as few as three operations using the undercutter method. Averaged over years, there were never any differences between treatments in precipitation storage efficiency in the soil or in wheat grain yield. The undercutter method consistently increased surface residue, surface clod mass, and surface roughness compared to traditional tillage. The undercutter method appears to reduce soil loss and PM$_{10}$ emissions during high wind events. Due to the recent surge in the cost of diesel fuel and decline in the cost of glyphosate herbicide, the undercutter method of summer fallow farming has significantly higher net returns to the farmer compared to traditional tillage. Results show a ‘win-win’ situation for both wheat farmers and the environment.

Abbreviations: DMT, delayed minimum tillage; HRSW, hard red spring wheat; MT, minimum tillage; TT, traditional tillage; WW, winter wheat; SF, summer fallow.

Introduction

Drought, tillage, low production of crop residue, nonagregated soils with low organic matter content, and high winds often combine to leave soil vulnerable to wind erosion in the low precipitation (less than 300 mm annual) winter wheat – summer fallow (WW-SF) region of the Inland Pacific Northwest (Papendick, 2004). This region encompasses more than 1.5 million cropland hectares and is by far the largest cropping region in the western United States.

The main purpose of summer fallow is to store a portion of over-winter precipitation to enable successful establishment of winter wheat planted deep into moist soil the following August. Tillage during the spring of the fallow year is employed to break soil capillary continuity from the subsoil to the surface and create a 10- to 15-cm deep dry soil mulch to conserve water in the seed zone. Wheat farmers generally do not practice no-till (i.e., chemical) summer fallow because of increased evaporative loss of seed-zone soil moisture during the dry summer months compared to tillage. Elimination or reduction of tilled summer fallow by increasing the intensity of cropping, especially using no-till planting methods, has been shown to greatly reduce soil particulate emissions. However, to date, long-term efforts by farmers and researchers have not yet identified alternative cropping systems that can compete economically with winter wheat – summer fallow in the Inland Pacific Northwest (Nail et al., 2005; Schillinger and Young, 2004).

Traditional tillage practices are intensive and involve eight or more separate tillage passes over the field during the 13-month fallow period. Such intensive tillage operations often bury surface crop residue, pulverize soil clods, and reduce surface roughness. Blowing dust from excessively-tilled fields leads to recurrent soil losses and reduces air quality. Development and adoption of agronomically feasible, profitable and more environmentally friendly fallow management methods are needed. This paper describes research efforts that have led to a successful undercutter method of summer fallow farming to reduce dust emissions that also increase economic returns to wheat farmers compared to traditional intensive tillage practices.

Materials and Methods

Study Description

A 6-year tillage management study involving soft white winter wheat – summer fallow was conducted from August 1993 to July 1999 at the Washington State University Dryland Research Station at Lind, WA. Annual precipitation averages 244 mm. The Shano silt loam soil is more than two meters deep with no rocks or restrictive layers. The experimental design was a randomized complete block with three tillage treatments replicated four times. Individual plots were 18 by 46 meters, which allowed use of commercial-size farm equipment. Winter wheat stand establishment failed due to dry seedbed conditions during one year and plots were replanted to hard red spring wheat (HRSW). Wheat and fallow phases of the study were present each year. The three tillage management treatments were:

1) Traditional tillage (TT) – standard frequency and timing of tillage operations using implements commonly utilized by farmers.
2) Minimum tillage (MT) – standard frequency and timing of tillage operations, but herbicides were substituted for tillage when feasible and a non-inversion undercutter V-sweep implement (Fig. 1 and Fig. 2) was used for primary spring tillage.
3) Delayed minimum tillage (DMT) – similar to minimum tillage except primary tillage with the undercutter V-sweep was delayed until at least mid May. A complete description of field operations and timing for each treatment are described by Schillinger (2001).

Field Measurements

Volumetric water content measurements in the 180-cm soil profile were made immediately after grain harvest in late July (beginning of fallow), in mid March prior to primary spring tillage, and again in late August just before planting winter wheat. In addition, seed-zone water content was measured at time of planting. Soil surface cloddiness and surface roughness were determined at the end of fallow. Surface residue remaining from the previous crop cycle was measured several times throughout the fallow period. Winter wheat stand establishment was measured 21 days after planting. See Schillinger (2001) for detailed description of measurement techniques used in the experiment.

Economic Assessment

Standard enterprise budgets were constructed to assess the profitability of the three tillage systems (Nail et al., submitted; Janosky et al., 2002). Input prices are included at both 1998 and 2005 levels to show the potential for recent increases in diesel prices and decreases in glyphosate prices to favor the profitability of conservation tillage systems (Nail et al., submitted). Costs are based on the actual sequence of operations conducted on the research plots (Schillinger, 2001). Machinery costs assume farm-scale machinery typical of the region. Fertilizer, herbicide, seed and other input rates are those used during the experiment (Schillinger, 2001). Total costs include a prevailing market return for the farmer's land, machinery, and labor. Under such total cost budgeting, a "fair or normal profit" would be zero. Grain yields are those measured from the experiment. All cost and revenue figures are presented on a rotational hectare basis; specifically, for winter wheat - summer fallow, one half hectare of winter wheat and one half hectare of fallow. This ensures a standard $\$ \text{ha}^{-1}$ basis for comparison to differing crop rotations. Consistent with the experiment, it was assumed that winter wheat would fail once every five years necessitating replanting to hard red spring wheat. Consequently all costs are weighted 80% WW-SF and 20% for HRSW-SF.

The 1993-1997 5-yr average market prices of $\$144.02 \text{ Mg}^{-1}$ for WW and $\$187.22 \text{ Mg}^{-1}$ for HRSW were retained in order to hold constant all factors except input price changes (Janosky et al., 2002). These averages are only slightly higher than recent 5-yr average wheat prices. Government payments are not included in the net revenue results as the emphasis is on market profitability rather than on varying government payments.

Validation of Wind Erosion Control

In a separate study in 2005, soil loss and dust emissions were assessed from a Shano silt loam near Lind, WA. Adjacent summer-fallowed fields were managed using either traditional tillage or the undercutter method of conservation tillage. The treatments, each 2-ha, were cropped to winter wheat in 2004 and, following harvest, remained undisturbed (wheat stubble and straw on the soil surface) until the spring of 2005. Treatments were:

1) Traditional tillage – tandem disk to a depth of 13 cm on 2 May, injecting aqua N fertilizer on 6 May, and rod weeding on 10 May and 21 July.
2) Conservation tillage - undercutting + aqua N fertilizer injection to a depth of 13 cm with overlapping 71-cm-wide V-blades on 5 May, and rod weeding on 10 May and 21 July.

Winter wheat was grown along the south and west boundary of the experimental sites during the 2005 growing season to create a non erodible boundary; this boundary minimized the influx of airborne and eroded sediment for estimating soil and PM_{10} loss from each experimental site. Crop residue and soil physical properties were periodically measured throughout the spring and summer of 2005. Crop residue cover and biomass, stubble density and biomass, stubble height, near-surface soil water content, particle size distribution, aggregate size distribution, and roughness were determined after each tillage operation or high wind event. High wind events, defined by a period of time when winds are in excess of 6.4 m s^{-1} at a 3 m height, commonly occur during the spring and autumn in the Columbia Plateau (Saxton et al., 2000). These events, which result in soil erosion and elevated atmospheric dust concentrations, are the major cause for exceedances of the National Ambient Air Quality Standard for PM_{10} within the region (Sharratt and Schillinger, 2005).

Soil loss from traditional and conservation tillage was assessed by measuring the influx and efflux of soil from the experimental sites. High-volume air samplers, E-samplers, and BNSE airborne sediment collectors were deployed at the windward and leeward positions at each site to assess sediment moving into each site from the non erodible boundary (wheat field) and that leaving each site. High-volume samplers and E-samplers were positioned at a height of 1.5, 3, and 6 m above the soil surface. Creep collectors were used to measure surface creep and BSNE collectors were positioned at a height of 0.1, 0.2, 0.5, 1.0 and 1.5 m above the soil surface to assess saltation and suspension.

Results and Discussion

Figure 1. Haybuster^{TM} undercutter V-sweep blade with attached 3-bar spring-tooth harrow. As a primary spring tillage implement, the undercutter completely severs capillary pores to halt liquid water movement toward the soil surface as required to retain seed-zone water in summer fallow.

Figure 2. Primary spring tillage plus liquid aqua nitrogen injection with an undercutter V-sweep implement. Note that the majority of residue remains standing and undisturbed.

Residue and Surface Soils

Two to three-fold increases in surface residue cover was consistently retained with MT and DMT compared to TT at the end of the fallow cycle throughout the 6-year study (Fig. 3, Fig. 4, data not shown). When wheat straw production was low, the minimum quantity of surface residue (390 kg/ha) required for highly erodible soil for government farm program compliance could not be achieved or was marginally met using TT, whereas ample surface residue was always present with MT and DMT. On average, twice the surface soil clod mass and a rougher surface was achieved with MT and MDT compared with TT. See Schillinger (2001) for further details.

Agronomy and Grain Yield

Seed-zone water content at the end of fallow in the 6-year study was not affected by tillage treatment. This suggests that finely divided soil particles with the tillage mulch may not be as important for retarding evaporative water loss during the hot, dry summer as previously thought. Rather creating an abrupt break between the tilled and non-tilled layer with primary spring tillage, which severs capillary channels from the subsoil to the surface, appears to be the dominant factor regulating over-summer evaporative water loss.

Winter wheat seedling stand establishment (Fig. 4) was somewhat reduced in the MT and DMT treatments (data not shown) due to the larger quantities of surface clods compared to TT, as many seedlings were unable to elongate around clods that rolled into the furrow during planting. There were no differences in wheat grain yield among treatments during any year or when averaged over five years (Table 1).

Economics

Table 2 reports costs and net returns for the three tillage systems at both 1998 and 2005 input prices. As noted earlier, the costs are weighted averages of those for WW at 80% and for HRSW at 20%. Table 2 compares net returns over variable and over total costs of each tillage system for the two input price levels. The use of 2005 input prices instead of 1998 prices increases the total cost of TT, and reduces the returns over total costs of TT, by \$2.36 (rotational ha)$^{-1}$. The differences over input price levels for total cost and net returns over total cost are identical because revenue, based on experiment average grain yields and common crop prices, is constant for both input price levels. In contrast to TT, the 2005 input prices boosted profits for both MT and DMT. Total costs decreased and net returns over total costs increased by \$6.37 and \$6.30 (rotational ha)$^{-1}$ for MT and DMT, respectively (Table 2).

Table 1. Yearly and five-year average yield of wheat as affected by traditional tillage, minimum tillage, and delayed minimum tillage during the preceding fallow cycle. ns = not significantly different at the 5% probability level.

Tillage system	1995	1996	1997	1998	1999	Avg.
	Mg ha^{-1}					
Traditional tillage	1.79	3.52	5.13	3.89	2.32	3.33
Minimum tillage	1.91	3.76	5.20	3.89	2.69	3.49
Delayed minimum tillage	1.79	3.73	4.94	3.58	2.48	3.30
	ns	ns	ns	ns	ns	ns

Figure 3. A rodweeder (2-cm square rotating rod) was operated 10 cm below the soil surface two to three times during late spring and summer to control weeds in summer fallow. Ample residue in the minimum tillage treatment (shown here) provides protection from wind erosion.

Figure 4. Winter wheat seedlings in the minimum tillage fallow treatment. Percent residue cover after planting wheat achieved or exceeded 30% residue cover all six years of the experiment with minimum tillage and delayed minimum tillage, compared to traditional tillage that attained 30% cover only two out of six years.

Table 2: Net returns for three tillage systems for winter wheat - summer fallow farming using 1998 and 2005 production costs.†

		Net Returns Over Cost Using Input Prices††		Net Returns Over Cost Using 2005 Input Prices	
Tillage system	Revenue	Variable	Total	Variable	Total
	----------------------------------$ (rotational ha)$^{-1}$	------------------------------------			
Traditional tillage	247.73	100.90ab	-36.36b	91.95b	-38.72b
Minimum tillage	259.67	103.97a	-25.07a	105.86a	-18.70a
Delayed minimum tillage	245.56	93.29b	-27.88a	96.16ab	-21.58a

†Weighted average of 80% soft white winter wheat and 20% hard red spring wheat.

††Average net returns followed by the same lower case letter are not significantly different at the 0.05 probability level. $LSD_{.05}$ for the average net returns over variable costs per rotational hectare of the three tillage systems computed using 1998 input prices is \$9.96 ha^{-1} and \$10.02 ha^{-1} for 2005 prices. $LSD_{.05}$ for the average net returns over total costs per rotational hectare of the three tillage system computed using 1998 input prices is \$6.78 ha^{-1} and \$6.89 ha^{-1} for 2005 prices. For 2005 prices, net returns over total costs for minimum and delayed minimum tillage systems are statistically superior to traditional tillage at $P<0.000001$. For 1998 prices, net returns over total costs for minimum and delayed minimum tillage systems are statistically superior to traditional tillage at $P<0.01$.

The MT and DMT systems averaged significantly higher net returns over total costs under both 1998 and 2005 input prices compared to TT (Table 2). For 2005 prices, MT and DMT systems' net returns over total costs are statistically superior to those for TT at the $P<0.000001$ probability level. For the 1998 price scenario, the MT and DMT systems' statistical advantage over TT occurs at the $P<0.01$ probability level. The statistical advantage at 2005 prices of conservation tillage versus TT is preserved for returns over variable costs for MT, but not DMT (Table 2). The statistical advantage for DMT occurs for returns over total costs because fixed costs are relatively higher for TT than DMT and this widens the profitability gap. These results confirm that recent price shifts for diesel and glyphosate have strengthened the economic advantage of conservation tillage for winter wheat - summer fallow farming in this region.

Validation of Wind Erosion Control

Conservation tillage using the undercutter appeared to suppress erosion and dust emissions from the soil surface in comparison to traditional tillage during high wind events in 2005. The horizontal flux of suspended sediment was markedly reduced by an order of magnitude near the soil surface as indicated for the 7 - 23 June high wind event in Fig. 5. The largest reduction in flux occurred near the soil surface where protection afforded by larger aggregates and more wheat residue in conservation tillage effectively trapped mobile soil particles during high winds.

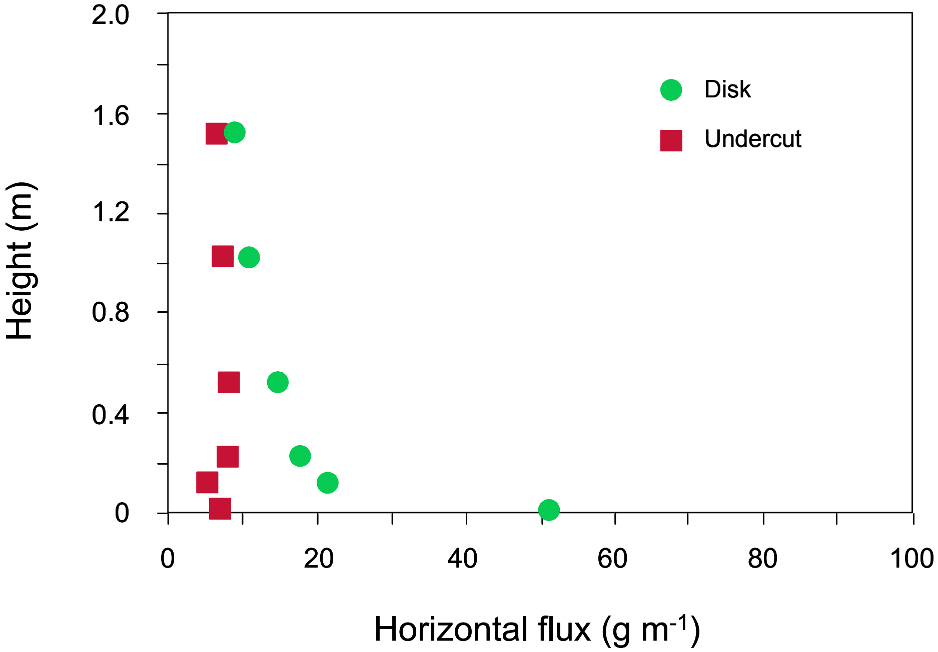

Figure 5. Horizontal soil flux as a function of height above soil surface with traditional (tandem disk) tillage and conservation (undercutter) tillage. Measurements were made during the 7- 23 June 2005 high wind event.

Loss of soil from the field site during the 7 - 23 June event ranged from 22 kg ha^{-1} for conservation tillage to 190 kg ha^{-1} for traditional tillage (Table 3). A reduction of soil loss using conservation tillage was also apparent during a high wind event earlier in the season (12 May – 7 June). However, these losses do not account for the sampling inefficiency of the BSNE for Shano loam, the predominant soil type at the field site.

Table 3. Loss of soil, determined from BSNE catch, from traditional and conservation tillage plots during high wind events in 2005 near Lind, Washington.

	Soil Loss	
Date	Traditional	Conservation
	---------------- kg ha^{-1}	------------------
12 May – 7 June	88	13
7-23 June	190	22

PM$_{10}$ concentrations were 50% less in conservation tillage compared to traditional tillage. Reduction in emissions is apparent by the smaller PM$_{10}$ concentration above the soil surface in conservation tillage (Fig. 6). The reduction in PM$_{10}$ emissions is more apparent nearer the soil surface and corresponds to the reduction in horizontal flux of larger soil particles. For the 23 May – 7 June event, emissions were reduced using conservation tillage to a height of about 6 m, which is the typical height of a dust plume during a high wind event on the Columbia Plateau (Fig. 6).

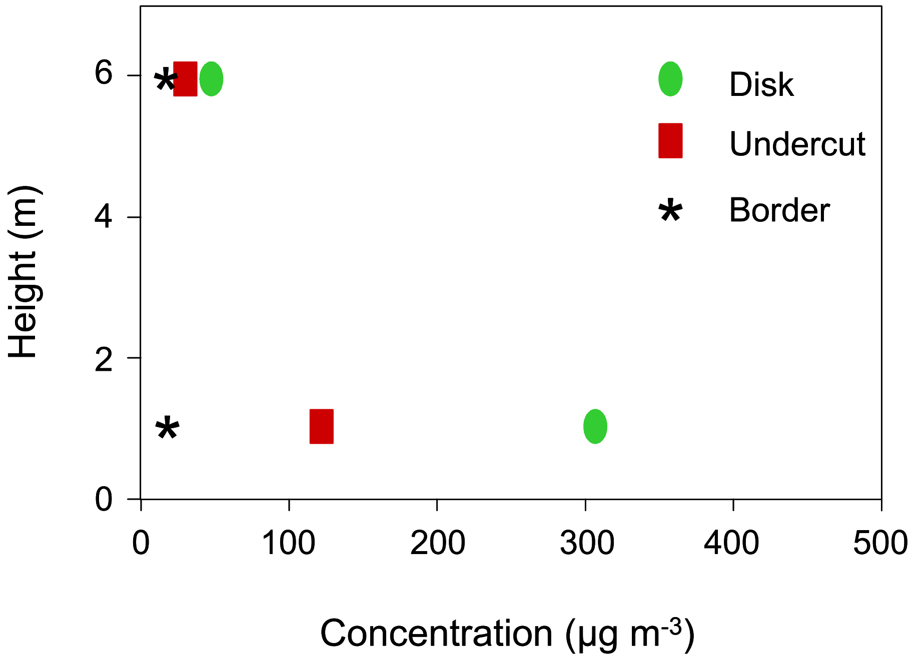

Figure 6. PM$_{10}$ concentration at various heights above the soil surface during the 12 May – 7 June high wind event. Concentrations were measured in traditional tillage and conservation (undercutter) tillage plots and at the upwind border of the experimental site.

Conclusions

Minimum tillage and delayed minimum tillage during fallow resulted in equal wheat grain yield and superior profitability compared to traditional tillage. Minimum tillage and delayed minimum tillage also provided more surface residue for better protection against wind erosion. This research showed that, with judicious use of herbicides, tillage operations during fallow can be effectively reduced from eight with traditional tillage to as few as three with delayed minimum tillage. If minimum tillage and delayed minimum tillage fallow management were widely practiced in the Columbia Plateau, it is reasonable to expect a sharp reduction in wind erosion and suspended dust emissions, with associated benefit to air quality. Minimum tillage and delayed minimum tillage, as outlined in this paper, will also benefit the economic livelihood of wheat farmers in the dry regions of east-central Washington and north-central Oregon.

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Assessment of the Ammonia Emission Abatement Potential for Distinct Geographical Regions and Altitudinal Zones in Switzerland

Harald Menzi and Beat Reidy
Swiss College of Agriculture, Zollikofen, Switzerland

Abstract

Abatement measures for a further reduction of agricultural ammonia (NH_3) emissions will have to be introduced in most countries of Europe in the foreseeable future. A detailed study on possible abatement measures and their potential in Switzerland was therefore conducted. As abatement strategies must be adapted to the prevailing production systems, the study differentiated between nine regions (3 geographical regions x 3 altitudinal zones), using data about current farm management from a recent stratified survey. Model calculations were performed with the N-flux model DYNAMO both for a scenario considering the implementation of all technically possible measures and one with measures considered realistically feasible.

Under the present situation, extended grazing of dairy cattle and measures concerning manure application offer the most efficient reduction potential. If all technically possible emissions abatement measures would be realized Swiss NH_3 emissions could be reduced by approximately 33%. The full realization of measures considered technically feasible would reduce NH_3 emission by up to 19%. The realistically feasible abatement is at least twice as high in the valley zone than in the mountain zone.

Introduction

Ammonia (NH_3) emissions are highly relevant from an environmental point of view due to their contribution to eutrophication and acidification of vulnerable ecosystems and their involvement in the formation of secondary aerosols. The UN Convention on Long-range Transboundary Air Pollution (UNECE 1999) as well as national policies therefore set emission ceilings. For example, the convention requires Switzerland to reduce NH_3 emissions from 59.3 to 51.9 kt nitrogen (N) between 1990 and 2010 while the Swiss Federal Council, based on considerations of critical load exceedence in vulnerable ecosystems, has set a long-term goal of 25-30 kt N. While emissions were already reduced by about 20% between 1990 and 2000, mainly due to a reduction of livestock numbers, a further reduction by 30-40% would still be necessary to meet the long-term goal.

As agriculture is the major emitter of NH_3 (over 90% in Switzerland) abatement measures for a further reduction of agricultural ammonia emissions will have to be introduced in most countries of Europe in the foreseeable future. This will require reliable and differentiated recommendations to farmers about the most promising and appropriate emission abatement measures and model calculations regarding the abatement potential. As a follow-up activity to the new Swiss NH_3 emission inventory (Reidy and Menzi 2006) a detailed study on possible abatement measures and their potential was therefore conducted. The project aimed to provide farmers as well as policy makers with relevant data and recommendations.

The emission abatement potential of measures depends on their efficiency under farm conditions as well as on their applicability. The applicability of different measures depends on the animal housing and manure management system as well on several other factors such as topography, climatic conditions and soil type. It can also be influenced by the skills of farmers and their social environment. Especially in Switzerland with its very variable topographical and climatic conditions the applicability of different measures and the emission abatement potential can therefore be expected to vary considerably from region to region and from farm to farm. To account for this, our evaluation differentiated between geographical regions and altitudinal zones and practical recommendations will be provided for different farm types.

Methods

Model calculations on the abatement potential were done with DYNAMO, an empirical mass-flow model following the N flow approach (Reidy and Menzi 2006). The model calculates emissions on the basis of the

N-flow through the manure handling chain using emission factors in percent of the relevant amount of nitrogen present at each stage of emission. Considered emission stages included animal houses and hardstandings, manure storage and application, grazing, mineral fertilizer use as well as crops and meadows. It is therefore well suited to take into account interactions between different emission stages and farm management parameters, e.g. the effect of measures in animal houses on emissions from manure storage and application.

For relevant current farm management parameters average values from the survey conducted in the framework of the emission inventory project (Reidy and Menzi 2006) were used. This stratified survey provided data from 1950 farms and differentiated between nine regions: the three geographical regions Eastern, Central and Northern/Southern Switzerland; for each region the valley zone, the hill zone and the mountain zone. Statistical data on livestock numbers and farming surface were taken from the official farm census for the year 2000.

Overall, about 60 different abatement measures were considered in the study. Their efficiency in reducing emissions was compiled from literature and Swiss research data. The applicability of each measures in the nine regions was assessed together with experts in the fields of feeding, grazing, animal housing, manure storage, manure application and fertilization. For each measure a technically possible and a realistically feasible reduction potential were defined. At both levels no economic restrictions were considered. The abatement potential for both levels was calculated for individual measures as well as for different scenarios of combined measures.

Results and Discussion

Under the present situation, extended grazing of dairy cattle and manure application measures offer the most efficient reduction potential. At the national level they could contribute a reduction of NH_3 emissions from agriculture of about 9.5% and 11% for grazing and manure application measures respectively, using the assumption of what would be technically possible. Using the assumptions of what would be realistically feasible, the reduction potential for grazing and manure application measures would be about 6% and 8%, respectively.

While there were no major differences between the different regions regarding the abatement potential for feeding, housing and manure storage measures, the abatement potential of grazing and manure application measures showed considerable regional differences. Figure 1 illustrates this using the example of the emission abatement potential for slurry application with trailing hose systems.

On a more aggregated scale, the realistically feasible abatement potential of low emission manure application measures ranged from 9% to 12% in the valley zone, from 4% to 6% in the hill zone and from 0% to 1.0% in the mountain zone.

If all technically possible emission abatement measures would be realized, Swiss NH_3 emissions could be reduced by approximately 33%. The full realization of measures considered realistically feasible would reduce NH_3 emission by up to 19%. The realistically feasible abatement is at least twice as high in the valley zone than in the mountain zone.

The applicability and the potential of measures for a specific farm do not only depend on climatic and topographic conditions, but are also strongly influenced by existing infrastructure and farm structure. The conclusions about the most appropriate emission abatement measures can therefore differ considerably from those derived for different regions. For example, for a farm with open slurry storage, covering slurry stores, especially if theses are newly constructed, is a high priority measure, while it is of secondary importance on the regional or national scale because around 80% of the stores are already covered.

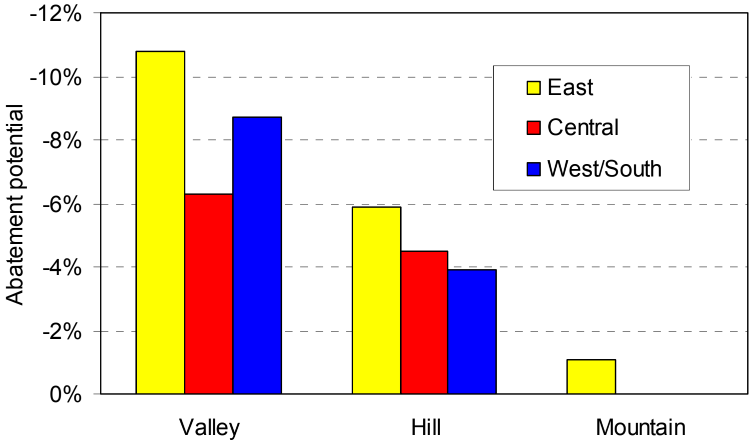

Figure 1. Estimated long-term ammonia emission abatement potential for slurry application with trailing hose systems in different regions of Switzerland. Results are given for the scenario "realistically feasible". Calculations were based on farm structure and livestock number data of 2000." The abatement potential in the central and west/south mountain region is zero.

Conclusions

There still is a considerable potential to reduce NH_3 emissions from Swiss agriculture. Nevertheless, even if all measures considered realistically feasible were fully implemented on all farms, the long-term goals could not be achieved without a considerable further reduction of animal numbers.

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Evaluation and Management of Ammonia Emissions from Poultry Litter

Philip A. Moore, Jr.[1], Dana Miles[2], Robert Burns[3], Dan Pote[4], and Kess Berg[1]
[1]Soil Scientist, USDA/ARS, Fayetteville, AR
[2]Soil Scientist, USDA/ARS, Mississippi State, MS
[3]Agricultural Engineering, Iowa State University
[4]Soil Scientist, USDA/ARS, Booneville, AR

Abstract

Ammonia volatilization from poultry litter results in high levels of ammonia in poultry facilities, which negatively impacts bird performance and worker health. Ammonia emissions from the houses also cause atmospheric ammonia contamination. Although there is a tremendous concern about these emissions currently, little quantitative data exists on the magnitude of ammonia fluxes from poultry litter. Hence, knowledge on the magnitude of these emissions, factors affecting emissions, and methods to control ammonia losses are needed. The objectives of this study were to: (1) measure ammonia volatilization from poultry litter in broiler houses and following land application, (2) evaluate the factors that affect ammonia losses from poultry litter, and (3) determine the impact of best management practices on ammonia volatilization. Four tunnel ventilated houses were equipped with ammonia sensors, anemometers, and data-loggers which continuously recorded the ammonia concentrations and ventilation (wind speed) at each of the windows in each house. In addition, ammonia, nitrous oxide and methane fluxes from the litter were measured using flux chambers. Nitrogen losses following land-application were evaluated using ammonia wind tunnels. Results of the study indicate that although ammonia emissions from one broiler house containing 32,000 birds can exceed the CERCLA reporting threshold of 100 lbs/day, losses are typically much lower than this value. An ammonia scrubber that attaches onto the exhaust fans of animal rearing facilities was developed and tested. The scrubber, which utilizes a dilute alum solution to capture ammonia and dust, was shown to significantly reduce ammonia concentrations in exhaust air from broiler houses. The aluminum in the solution, which is converted to aluminum hydroxide prior to land application as the pH of the solution is increased by ammonia, immobilizes soluble phosphorus (P), which reduces the risk of non-point source P runoff. Ammonia emissions from land applied poultry litter totaled 34 kg N/ha (15% of the total N applied). When the poultry litter was incorporated, ammonia losses were virtually zero (N loss was not different from unfertilized control plots). These studies indicate that there are several best management practices that can be utilized to reduce ammonia loss from poultry litter.

Introduction

Ammonia volatilization from poultry litter results in high concentrations of ammonia in poultry houses, which has been known to cause poultry production problems including increased susceptibility to viral diseases, reduced growth rates, reduced feed efficiency, decreased egg production, and blindness (Carlile, 1984). High ammonia levels in animal rearing facilities have also been shown to be detrimental to the health of agricultural workers (Donham, 1996). Carlile (1984) recommended that ammonia concentrations be kept below 25 ppm in poultry houses to reduce the incidence of negative performance associated with this gas. Keeping ammonia levels this low is not always easy for growers to do, particularly during the winter time when they are trying to minimize ventilation, because of the high cost of propane gas to heat the houses. As a result, ammonia concentrations can exceed 100 ppm in poultry rearing facilities.

Ammonia volatilization from manure also has a negative impact on the atmosphere, with respect to both acid precipitation and atmospheric N loading to aquatic systems (Ap Simon et al., 1987; van Breemen et al., 1982; Schroder, 1985). Ap Simon et al. (1987) indicated that animal manure is the dominant source of atmospheric ammonia in Europe. Van Breemen et al. (1982) indicated that ammonia plays an important role in acid precipitation. Another problem attributed to ammonia is N deposition into aquatic systems (Schroder, 1985).

Poultry producers have used a variety of manure amendments to reduce ammonia volatilization. Moore et al. (1995a, 1996) found that alum (aluminum sulfate) and phosphoric acid were the most effective compounds for reducing ammonia loss. Additions of alum to litter reduce the pH, which shifts the NH_3/NH_4 equilibrium toward NH_4. Moore et al. (1997) showed alum additions in commercial chicken houses reduced ammonia fluxes by 97% during the first four weeks of the growout and 70% during the entire flock. Moore et al. (1999, 2000) later showed that broilers grown in houses where the manure was treated with alum had better weight gains, improved feed conversions, lower mortality, and lower condemnations. Energy use (primarily propane use) was also lower in the winter when alum was used, due to lower ventilation requirements to remove ammonia (Moore et al., 1999, 2000). Several other benefits of treating poultry litter with alum have been noted. One of the primary benefits is alum reduces phosphorus runoff and leaching (Moore et al., 1999, 2000). Alum additions to litter have been shown to greatly reduce pathogens responsible for food borne illnesses (Line, 2002), including *Campylobacter* and *Salmonella*. Heavy metal and estrogen runoff from fields fertilized with poultry litter has also shown to be significantly lower when the litter has been treated with alum (Nichols et al., 1997; Moore et al., 1998). Moore and Edwards (2005) showed in a long-term study that aluminum uptake by crops, Al availability in soil and Al runoff are not affected by alum. Due to these improvements in productivity, alum is routinely used by the poultry industry; currently over 600 million chickens grown annually in the U.S. with alum.

While alum clearly is one best management practice (BMP) than can be used to control ammonia, other BMPs need to be developed and tested. The objectives of this work were to: (1) measure ammonia volatilization from poultry litter in broiler houses and following land application, (2) evaluate the factors that affect ammonia losses from poultry litter, and (3) determine the impact of best management practices on ammonia volatilization.

Methods

Four tunnel ventilated broiler houses (12.8 x 146.4 m) were equipped with ammonia sensors (Polytron I), anemometers, and data-loggers which continuously record the ammonia concentrations and ventilation (wind speed) at each of the windows. It should be noted that these electro-chemical ammonia sensors can became saturated with ammonia over time which can cause them to malfunction, hence, they must be replaced regularly. Thirty-two thousand broilers were placed in each house and were grown to 56 days of age. Fluxes of ammonia, nitrous oxide, methane, and carbon dioxide were also measured from the litter were also measured using flux chambers equipped with an Innova multi-gas analyzer. Total and inorganic N in the litter is also be evaluated throughout the year, as well as feed consumption, N content of the feed and N removed in birds, in order to construct a simple mass balance estimate of ammonia loss. Ammonia emissions following land-application were evaluated using wind tunnels from plots where litter had either been surface applied or incorporated. Litter was applied to small plots cropped to bermudagrass at a rate of 5.6 Mg litter/ha, which had 4% N (equivalent to 224 kg N/ha). Ammonia concentrations and air flows entering and exiting the wind tunnel were measured using anemometers that had been calibrated using the FANS system connected to data-loggers and phosphoric acid traps which were later analyzed for ammonium.

Results and Discussion

Ammonia Emissions from Broiler Houses

The average daily ammonia concentrations in the four houses during two flocks in early summer are shown in Figure 1. Although the average daily ammonia levels were always below 25 ppm, many times during the night they exceeded 80 ppm. High ventilation rates during the day result in lower ammonia. The average ammonia concentration in the houses was 16 ppm.

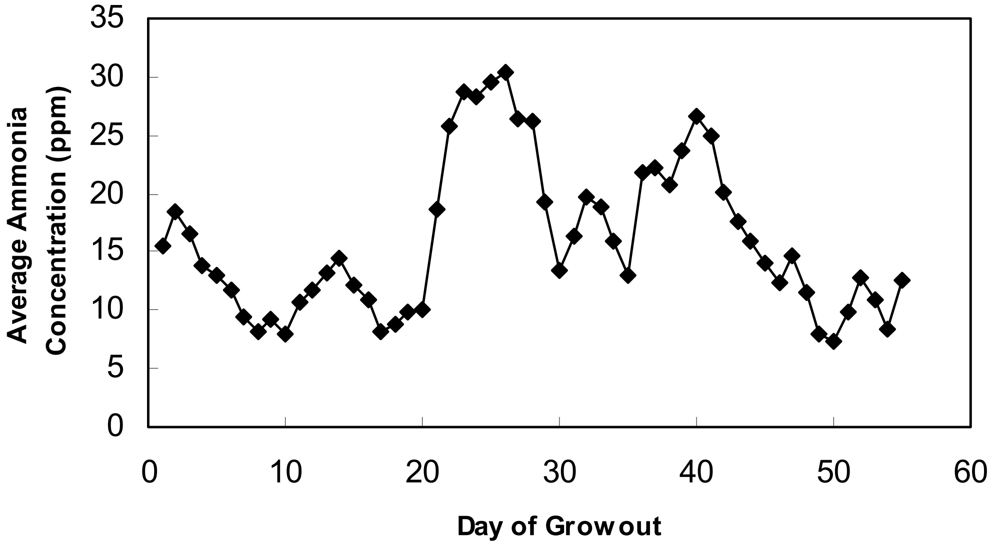

Figure 1. Average ammonia concentration in four broiler houses during two flocks.

The average daily ventilation rate increased as bird age increased (Fig. 2). Early in the flock, ventilation remained relatively constant at about 0.5 million m^3/day, but increased to 5 million m^3/day, by the time the birds were nearing 8 weeks of age.

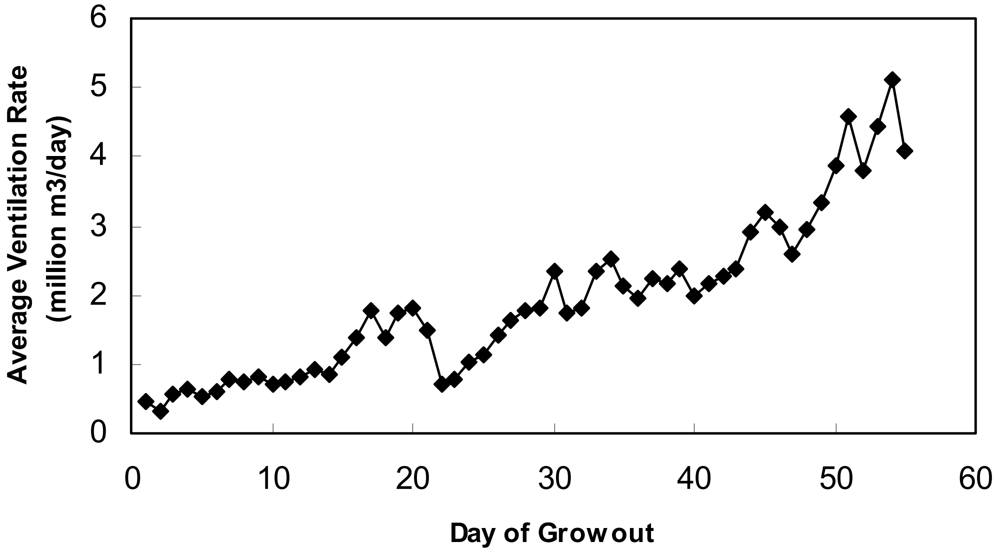

Figure 2. Average ventilation rate of four broiler houses during two flocks.

Ammonia emissions from the four houses started out relatively low (less than 5 kg/day), then increased until the 5th or 6th week of the growout, where it peaked at around 25 kg/day (Fig. 3). The average amount of ammonia emitted was 14.9 kg/day.

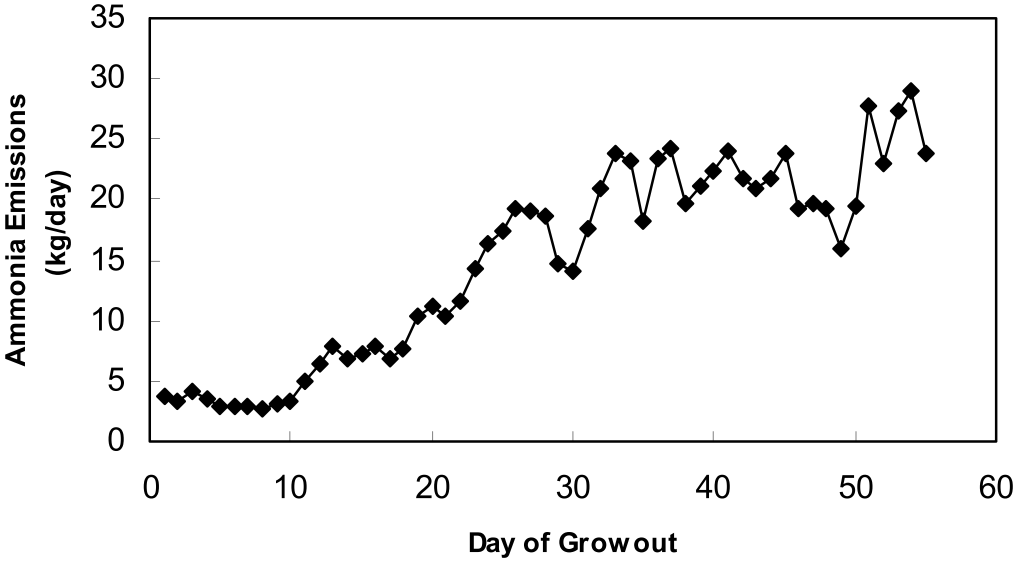

Figure 3. Average ammonia emissions of four broiler houses during two flocks.

Ammonia fluxes using small chambers were highly correlated to measured emissions, although the values tended to be higher (Fig. 4). One possible reason the fluxes could have been higher than actual emissions was the flux measurements were concentrated near the center 2/3^{rds} of the house (near the water and feed). Emissions are probably lower near the walls of the houses.

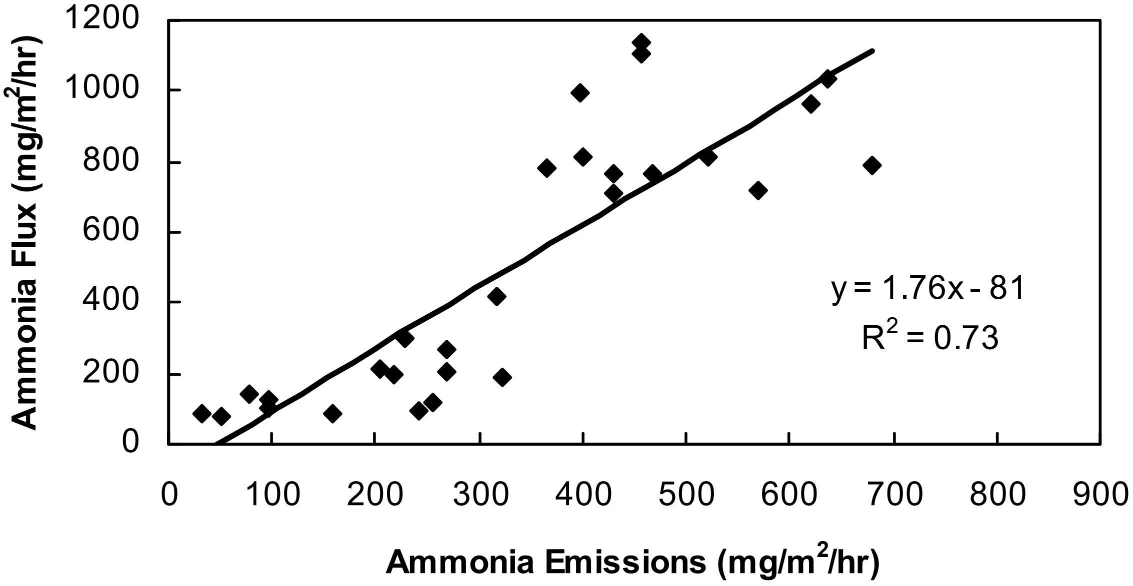

Figure 4. Relationship between ammonia fluxes using small chambers and ammonia emissions.

Ammonia fluxes stayed relatively low for the first three weeks of the growout, then increased sharply until week 5 (Fig. 5). The average ammonia flux was 501 mg/m^2·hr or about 22.5 kg/house/day. Nitrous oxide fluxes were low (10-20 mg/m^2·hr) and varied little throughout the growout (data not shown). These rates were equivalent to around 0.5 kg N_2O per house per day.

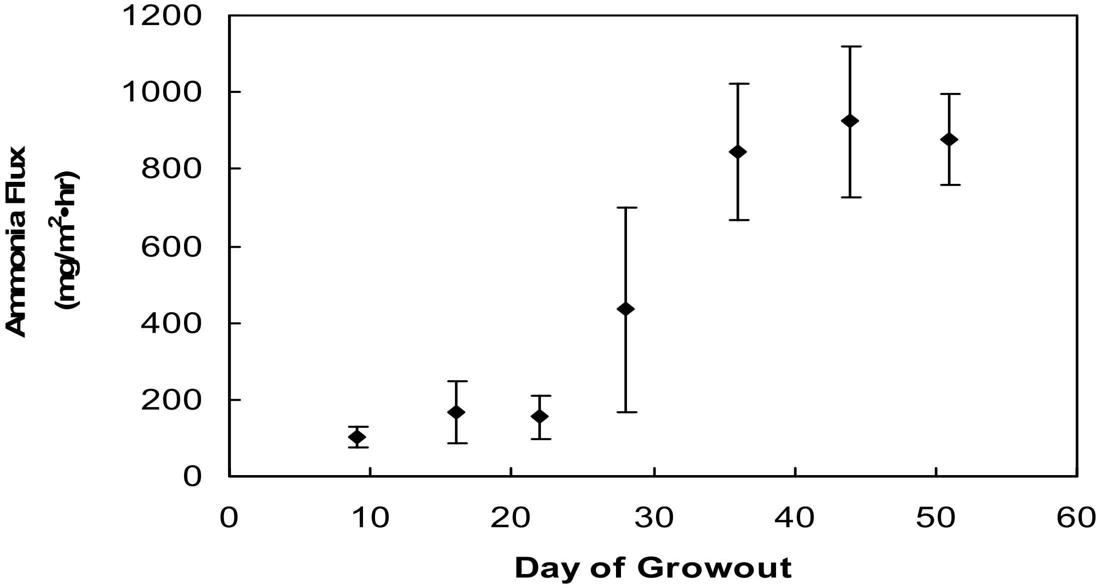

Figure 5. Ammonia fluxes from broiler litter in commercial houses as a function of bird age.

Development of an Ammonia Scrubber for Animal Rearing Facilities

A wet "scrubber" was developed to remove ammonia, particulate matter and pathogens from the air exhausted from animal houses. The prototype was constructed of wood. The scrubber has a 380 liter reservoir in the bottom filled with a dilute alum solution that is sprayed from the top of the box downward.

Figure 6. Ammonia and particulate scrubber for animal rearing facilities.

The amount of ammonium removed by the scrubber is dependent on the ventilation rate of the fan and on the ammonia concentration in the house. During the first test of the scrubber, which occurred in late spring, over 10 lbs of N were captured in a 24 hour period. This probably represents the best case scenario. During winter, when ventilation rates were lower, it took 3-4 days to capture this amount of N. When we first started using the scrubber, the trapping solution consisted of a 10% alum solution. One of the products created when ammonia reacts with the alum solution is the mineral ammonio-alunite [$NH_4Al_3(SO_4)_2(OH)_6$], which can be removed from solution. One of the other benefits of this technology is the reduction in soluble P in the soil once the spent scrubber solution is land-applied. Reducing soluble P should result in less P runoff and leaching. Therefore this technology provides benefits to both air and water quality.

Ammonia Emissions Following Litter Application

Ammonia emissions from small plots cropped to bermudagrass were near zero prior to litter application (Fig. 7). Once litter had been applied, losses from the surface application ranged from 1 to 7 kg N/ha/day. The peak after 12 and 13 days occurred after a small rain event. The total amount of N lost via volatilization during the two week period following application was 34 kg N/ha for the surface applied litter. This represents approximately 15% of the total N applied to the plots and over 100% of the NH_4-N applied (22 kg N/ha).

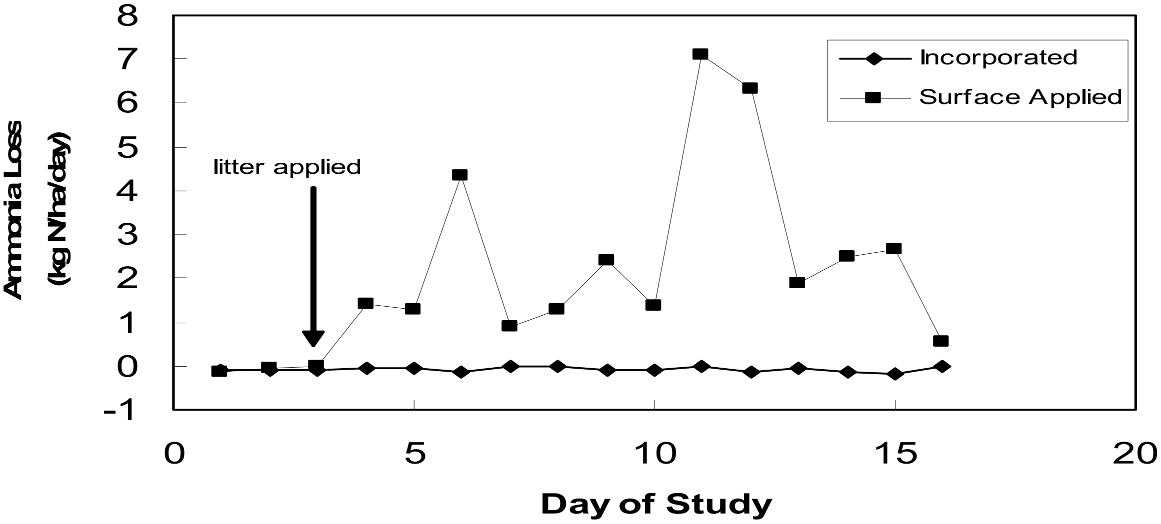

Figure 7. Ammonia emissions following poultry litter application to pastures

Earlier work by Pote et al. (2003) showed that incorporating litter into pastures significantly reduced phosphorus and nitrogen runoff compared to surface application. Litter incorporation has also been shown to increase forage yields by about 25% (Pote et al., 2003). The data in figure 7 indicate that improved yields may be due to improved nitrogen use efficiency.

Conclusions

Ammonia volatilization from poultry litter results in high levels of ammonia in poultry houses, which negatively impacts production. Average emission rates measured in this study were 14.9 kg/house/day (32.8 lbs/house/day). Ammonia emissions can be reduced with the addition of acidic compounds to litter, such as alum. Likewise, ammonia and particulate matter can be scrubbed from air exhausted from these facilities, allowing for the reuse of N as a fertilizer. Ammonia emissions from land-applied litter decreased to zero when litter was incorporated. These data indicate that there are several BMPs that can be used to reduce ammonia loss from poultry litter.

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