Executive Summary

Background

Ammonia (NH_3) emissions to the atmosphere increased significantly during the 20th century, largely due to the intensification of agricultural production. Ammonia is a soluble and reactive gas that is emitted by volatilization from various agricultural nitrogen forms including urea, uric acid and mineral fertilizers. Emissions are dependent on various meteorological inputs like temperature and wind speed, and are higher in warmer drying conditions, with smaller emissions occurring under cooler wetter conditions. The transport of NH_3 by advection and convection and has a relatively short lifetime in the atmosphere, and NH3 readily deposits vertically to vegetative surfaces through the impaction of gases and particles. NH_3 emissions vary greatly at the local scale and effects of dry deposited NH_3 occur primarily close to the sources. As a consequence, nitrogen sensitive ecosystems close to sources are at high risk of negative impacts. Impacts of excess nitrogen can include eutrophication and acidification effects on semi-natural ecosystems that can lead to species composition changes. Agroforestry Ammonia Abatement (AAA) is a practical concept which uses both the dispersive effect of a barrier and the uptake of NH_3 into the tree canopy to mitigate NH_3 emissions. This work built upon the research carried out in Defra project AC0201, bringing together measurements, modelling and agroeconomic analyses to build a coherent assessment of the potential benefits and drawbacks of applying AAA strategies both on a local and national scale.

Objectives and methodologies

The project objectives were to achieve the following:

(1) To assess the efficacy of farm woodland features for the recapture of agricultural NH_3 emissions, through a combination of wind tunnel studies and numerical modelling, and to optimise their design.

(2) To quantify NH_3 recapture in silvopastoral systems through targeted field measurements and emission, dispersion and recapture modelling.

(3) To quantify the effect of upwind shelter for the reduction of NH_3 emissions from slurry lagoons through mechanistic emission modelling.

(4) To provide accessible guidance and IT based design tools that can be used by farm managers to optimise farm woodland design and estimate effects

(5) To demonstrate the practical feasibility of implementing farm woodlands as NH_3 abatement measures through case studies.

(6) To quantify the potential of farm woodlands for NH_3 mitigation at the UK scale.

(7) To provide the vehicle to demonstrate farm woodland management as an abatement measure to the UNECE process, and to establish a framework of how spatial woodland management could be accredited as NH_3 emission reduction.

Objectives (1) (2), (3), (5) and (6) were achieved. Objective (4) requires further development of the results from this project to provide a website and tool of use to farm managers. Though the timing of this research was not useful for the 2009 UNECE process (7) the results are available for inclusion in current and future policy discussions.

Project results and outputs

Physical Scenario Modelling

Understanding the physical and chemical process by which NH_3 is emitted into the atmosphere and then recaptured by trees was the subject of two parts of this project. This delivered novel modelling techniques and detailed estimates for many scenarios under which AAA could be applied.

1. *NH_3 dispersion-recapture*

- A desktop coupled model MODAAS-THETIS was developed allowing air turbulence calculations to be provided as input for the gas dispersion and recapture model allowing real atmospheric data to parameterise model runs. This model allowed the testing of multiple tree belt scenarios for AAA assessment.
- By applying different LAIs, LADs and widths of backstop AAA can result in percentage NH_3 recapture of up to 20% for sheltering housing and up to 45% for livestock under trees for realistic densities of vegetation.

2. *Slurry store emissions*

- A slurry store model was developed to have both wind speed and temperature as co-variables. Application of the model indicated both wind speed and temperature are important in determining the effectiveness of a tree belt.
- AAA effectiveness was found to increase with short length lagoons, taller trees and higher tree densities

Measurements

1. *Wind tunnel*

- A tree belt with a line source was constructed in a wind tunnel. Micrometeorological measurements were made and NH_3 recapture measured.
- Results show tree belts can result in percentage NH_3 concentration reduction of up 10-25% depending on the structure of the trees. From model intercomparison this was seen to be a function of both dispersion and recapture.

2. *Case study farms*

- Three case study farms had NH_3 monitoring transects set up for 7 months, resulting in a detailed dataset.
- Results in two of the case studies where an “open” transect was set up in parallel to the wooded monitoring transect significantly lower concentrations were measured beyond the tree belt, of up to approximately 40%.
- Case study sites illustrated that tree belts are being used on UK farms for many purposes including silvopastoral applications and therefore AAA can be achieved as a side benefit to those purposes if the tree planting density and geometry is applicable to AAA.

National FRAME modelling (1 km resolution)

1) *On-farm emission factor reduction*

- A set of revised emission factors for all UK livestock types were developed (using the 20% reduction in NH_3 for housing and the 45% reduction for livestock under trees) which theoretically reduced the emissions factors from farm activities due to AAA. These reduced emission factors can be described as 'on-farm' emissions as the tree recapture element can be seen as being part of the total farm emissions.
- Scenarios covering the poultry sector show small reductions in total nitrogen deposition even though the woodland systems were applied to large fraction of the total UK flock due to the low poultry emission factors
- For the cattle sector a total reduction of 2% was achievable with placing woodland structures around 20% of cattle housing and slurry stores.

2) *UK NH_3 abatement potential of woodlands*

- The potential changes in NH_3 concentrations in air and the deposition of reduced nitrogen due to AAA via re-afforestation on farms at the UK scale was assessed targeting hot-spots of NH_3 around the UK.
- In scenarios where the UK forest was increased by 25% and 50%, increased NH_3 dry deposition near the emission sources was observed. This is due to the lower forest canopy resistance compared to grassland and arable.
- The net effect of the AAA is decreases in wet deposition of reduced nitrogen and of dry deposition to semi-natural land. In the 50% scenario, changes in wet N deposition were up to 0.5 kg N ha^{-1}.(~12%). Higher decreases of up to 2 kg N ha^{-1} (~30%) for dry deposition were achieved for large areas of semi-natural land and forest.

Profitability analysis and agroeconomic considerations

1) *Farm scale analysis*

- The potential profitability of tree belts was assessed given knowledge of designs, performance, and recent price/grant information. In determining the potential profitability there are two key questions: 1) What is the farm giving up when land is taken for the new purpose 2) what is the farm gaining by adopting this new land-use
- The analysis results suggest that overall tree belts are not currently economically feasible in purely financial terms, however on a case by case basis there might be many different reasons for making the development of AAA approaches feasible. (see 2) below for discussion of including social costs of not implementing AAA.)
- There are several factors for and against AAA development: Against: Land opportunity costs, commercial rates for labour and machinery, establishment timescales, drawing in predators and wild avian species For: non-market, hard to value benefits *e.g.* silvopastoral agriculture, welfare considerations, public policy benefits, biodiversity/ecosystem service benefits, odour mitigation.
- For a farmer the decision to invest in AAA would be a case by case process to assess the ways in which the tree belt achieves a mixture of public and private benefits. Tradeoffs are likely to be favourable if the NH_3 emissions are very high, vulnerable habitats are nearby and if there is a convincing privacy and landscape character/value argument. Public financial recognition of any public benefits would of course help mitigate opportunity costs.

2) *NH_3 abatement as climate change mitigation*

- The cost-effectiveness of UK forestry measures aimed at climate change mitigation was assessed in a context in which implementation is motivated by NH_3 abatement. Two agroforestry scenarios were assessed looking at the total tonnes of carbon dioxide equivalent stored for each system after 40 years.
- Abatement is valued by following current Defra guidance on valuing the benefits to society of avoided air quality damage costs per tonne of pollutant (£1,972 per tonne NH_3, 2010 prices (central estimate). A range of £1,538 (low estimate) - £2,241 (high estimate) is used for analysis, while the social cost of carbon ranged from £47/tCO2 to £53/tCO2.
- Planting a shelterbelt downwind of a barn or slurry lagoon can be considered highly cost-effective from a climate change mitigation perspective. Woodland chicken farming would be cost-effective under central and high estimates.
- The choice of time horizon and how woodland planted is subsequently managed are critical issues in assessing cost-effectiveness under the low estimate.
- Inclusion of other ecosystem services (e.g. water quality, amenity and health benefits) associated with tree planting, as well as carbon substitution benefits, could be expected to further increase the estimated cost-effectiveness of the agroforestry options as climate change mitigation measures.

Discussion and Future directions

The combined modelling and measurement results from this project show that AAA carefully planned and implemented can lead to a significant decrease in NH_3 concentrations downwind from sources and a net decrease in emissions to the atmosphere. As such AAA systems could be used as a protective measure of downwind sensitive ecosystems. Use of existing woodland plantations and panting new forestry can both be used to mitigate emissions, though scrubbing of NH_3 at source and reuse would also be a solution. UK scale modelling shows that targeted application of tree planting around agricultural installations would have a modest effect by modifying 'on-farm' emission factors, however when the approach is targeted in regions hot-spot emissions, significant effects on NH_3 and N-deposition can be achieved. In many agricultural businesses there are no current economic advantages for converting valuable arable land to woodland without specific opportunity benefits (e.g. woodland egg price margins due to animal welfare considerations). However as the woodland egg example shows, when other considerations become relevant, AAA can be a useful approach.

Future work should consider: 1) Nitrogen flows in farm systems with AAA implemented and the net effect on both the reactive and GHG N budgets 2) Ecosystem service approaches for making AAA cost effect. 3) It would also be possible to modify the MODDAAS-AQUILON model into a relatively simple on-line model, which could be a useful online tool.