Report

Bealey, W.J.; Braban, C.F.; Famulari, D.; Dragosits, U.; Dore, A.J.; Nemitz, E.; Tang, Y.S.; Twigg, M.; Leeson, S.; Sutton, M.A.; Loubet, Benjamin; Valatin, Gregory; Wheat, A.; Helfter, C.; Coyle, M.; Williams, Adrian; Sandars, Daniel L. 2012 *Agroforestry for ammonia abatement summary report. Draft.* CEH/Defra, 19pp. (Unpublished)

Agroforestry for Ammonia Abatement Summary Report

Draft

WP1a Modelling of turbulence across complex shelter belts

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Objective

In order to assess the air flow through a tree canopy and the amount of ammonia taken up by the vegetation it is necessary to have a method by which the turbulence of the air. The aim of WP1a is to evaluate the effect of the canopy structure on the turbulence and the deposition processes: this is achieved by coupling of two models: MODDAAS and AQUILON. The AQUILON model is an Eulerian *k*-ε turbulence model designed for within canopy as well as usual planetary boundary layer transfer. The MODDAAS model is a Lagrangian stochastic (LS) model for gaseous dispersion coupled with a multi-layer exchange model including a stomatal compensation point. The funding from this program allowed the setup of a new computer cluster to work on this.

Methodology

The two models are coupled using the output of the AQUILON model as the turbulence input for the MODDAS model, namely: *u* and *w* (horizontal and vertical components of the wind velocity), σ_u and σ_w (standard deviation of *u* and *w);* (the cross-correlation between *u* and *w);* ε (the dissipation rate of the turbulent kinetic energy). AQUILON outputs *u, w,* and ε, but does not give directly σ_u and σ_w. It only outputs *k* which is by definition:

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The coupling between the two models hence requires determining an objective procedure to partition *k* into its horizontal and vertical components. This was developed to be based on the Lagrangian and Eulerian description of scalar dispersion statistics within the atmospheric boundary layer (see e.g. Csanady, 1980).

We set 2 hypotheses:

Hypothesis 1. Following Taylor (1921), the vertical diffusivities in the Lagrangian approach (K_z^L) and the Eulerian approach (K_z^E) must be equal when t is much larger than the Lagrangian time scale T_L*:*

when —

Hypothesis 2. *The ratio* σ_u / σ_v *is arbitrarily set to a constant value* α_{uv} *in the whole domain.* This hypothesis is true in neutral stratification and for a flat terrain. Since AQUILON is only set for neutral conditions, it justifies (in a first approach) this assumption, which reads: $\sigma_u / \sigma_v = \alpha_{uv}$

Under the two hypotheses,**MODDAS and AQUILON can be coupled with only two parameters (α_w and α_{uv})**, of which α_w can be constrained (by theoretical considerations) to 0.37, while α_{uv} is empirically set to 1.25.

The outcome of the coupling was tested using a ***comparison of the MODDAS-Particle version of the MODDAS model output and the AQUILON model*** for a maize pollen experiment (see Jarosz et al., 2005). This gave an insight into the differences between the LS model and the Eulerian model for predicting dispersal. Initial comparisons suggested that MODDAS predicted larger concentrations near the source, however it was noted that this is a feature of any LS models. In order to analyse the actual sensitivity of MODDAS and to compare it to what the Eulerian model would give, a random walk version of the MODAAS model (MODDAS-RW) was written. This model should behave exactly as Eulerian models (see Rodean, 1996). A comparison was then done between the LS and RW, and the conclusions were that the RW model diffuses more rapidly, but the two models match relatively well for x > x_{source} + 4 m (see Figure 1), i.e. the model is robust greter than 4 m downwind of the x=0 position.

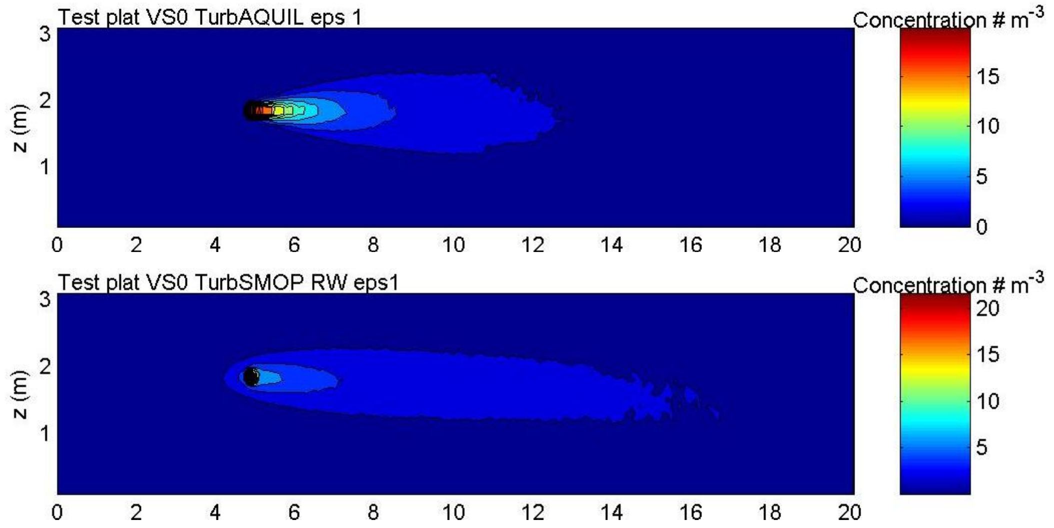

Figure 1downwind of a 100 µg m-3 s 1 source located in the volume 0.2 x 0.2 m2 at x = 5 m and z = 2 m. up LS model. down RW model

Further sensitivity analysis showed that the RW model is much more sensitive to a change in ε than the LS model: so the embedding of an RW module into MODDAS provides a satisfactory sensitivity for our applications.

Conclusions

- The coupling of the AQUILON and MODDAS models was carried out successfully
- The RW model is sensitive as expected to changes in ε.
- The LS model is almost not sensitive to ε whereas it should be.
- The LS and the RW models give similar concentrations for $t / T_{Li} > 4$ when $\varepsilon = \varepsilon_{Aqui}$.
- The coupled models were applicable for use in the subsequent parts of the SAMBA project.

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WP1b - Modelling of turbulence across complex shelter belts - Simulation of the wind-tunnel experiment

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Following the theoretical study to couple the AQIULON and the MODDAS models in section 1a, the coupled model has been used to simulate the flows and concentration field in the wind-tunnel experiment conducted in WP1c. The wind tunnel set up is schematised in Figure 1. Two source heights were used at 0.1 and 0.5 m above the bales. A set of 4 sonic anemometers were used to sample simultaneously the space around and within the tree spaces. The wind tunnel flow was modelled with AQUILON with Leaf Area Density (LAD) at heights (z) was modelled as given in Figure 2. The LAI was equivalent to 5 m2 m-2.

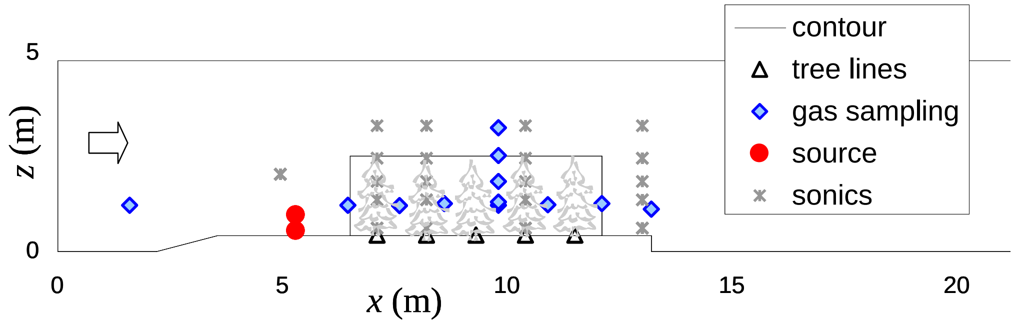

Figure 2Wind tunnel schematic

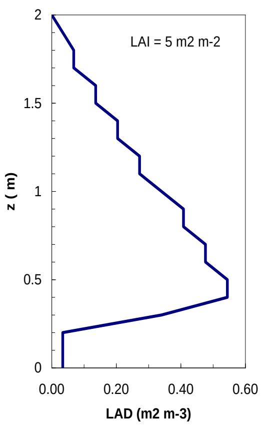

Figure 3 LAD (z)

Results

AQUILON gives an overall good correlation of the scheme flow in the trees area but tends to give a much larger vertical component of the wind speed above the canopy. AQUILON reproduces overall quite well the measured profiles. The modelled stress is much larger than the measured one and is larger at the top of the canopy indicating that the shear stress production by the mean flow is probably too large, due to the fact that the simulation does not reproduce the presence of the roof, which forces the flow to be horizontal.

The simulated inert tracer concentration in the wind tunnel is shown in Figure 3 for the low flow conditions at a source height of 0.5 m above the bales (0.9 m from the ground). This indicates that the tracer goes through the trees. Figure 10 also shows that the tracer mixing is increased by the presence of the trees quite efficiently.

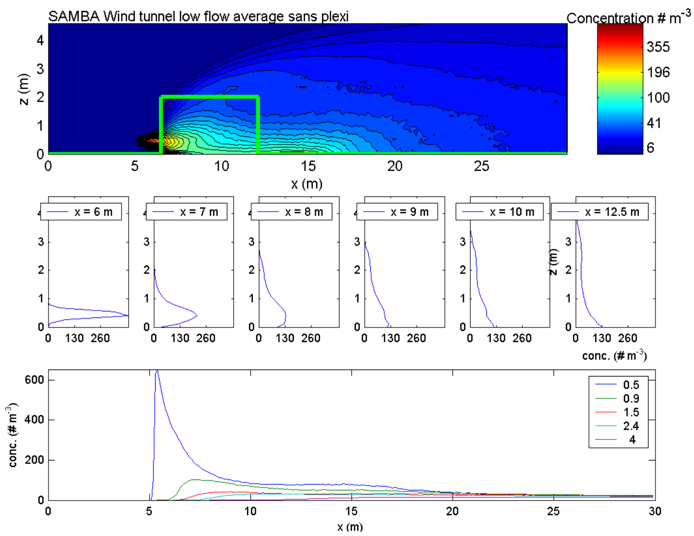

Figure 4 Concentration of an inert tracer modelled by MODDAS-AQUILON at a source strength of 100 µg m 1 s 1. The top panel shows a contour plot of the concentration, the middle panel shows the vertical concentration profiles and the bottom panel shows the horizon

Figure 4 shows deposition of ammonia onto the canopy. The profiles are similar in shape to Figure 9, but are depleted in the canopy as well as downwind from the canopy due to dry deposition. The depletion is of the order of 10 to 15% for this case where ammonia deposition has been artificially enhanced in the model by setting the relative humidity to 100%.

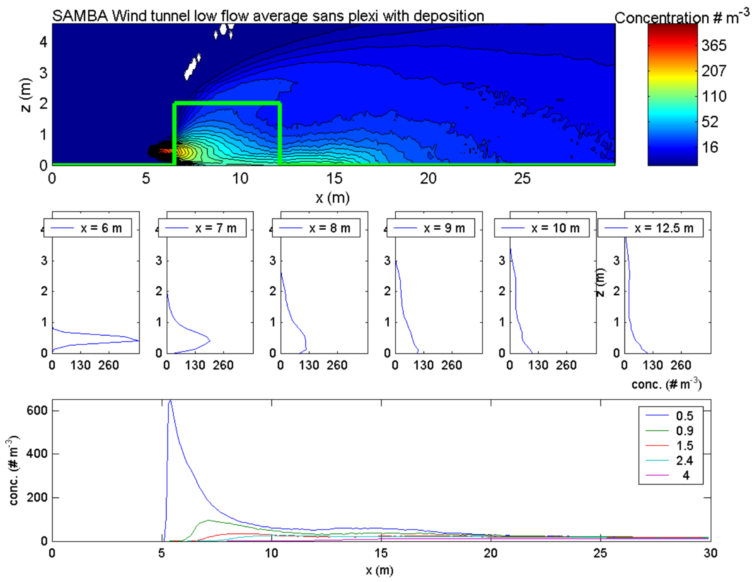

Figure 5 Concentration of ammonia modelled by MODDAS-AQUILON for the low flow rate of the wind tunnel for a source strength of 100 µg m 1 s 1. (see Fig. 3 for panel details)

The deposition was maximal at the edge of the canopy and the height of the source and showed a wing-shape, with decreasing deposition rate as the concentration decreases, but also as the boundary layer resistance decreased (Figure 11). The total deposition is roughly equal to 23 µgm^{-1} s^{-1}, which represents a 25% of the emission.

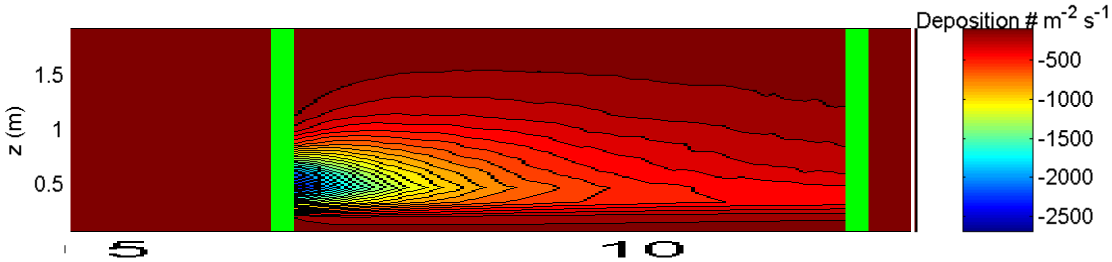

Figure 6 Deposition map (in ng m-2 s-1) in the canopy modelled by MODDAS-AQUILON for the low flow rate of the wind tunnel for a source strength of 100 µg m 1 s 1. Green bars are start and end of canopy

Conclusions

- The turbulence structure in the wind tunnel was evaluated by averaging the measurements.
- The modelled flow in the wind tunnel shows similar patterns as the measured ones but with larger turbulence magnitudes.
- Any overestimation is explained by the fact that the model does not take the roof into account. In such conditions, the modelled flow is less constrained in the vertical and the shear stress is larger. Some trials to include the roof have shown that the kinetic energy, vertical wind velocity and the shear stress magnitudes get into much closer values to those observed.
- The modelled inert tracer shows an effect of the canopy in increasing the mixing efficiently and in channelling the tracer below the canopy top.
- The modelled maximum ammonia deposition represented about a quarter of the emission, and depleted the concentration by 10 to 15%.

WP2a: Experimental quantification of NH_3 capture by an overhead tree canopy.

Famulari D., Braban C.F., Wheat A., Coyle M., Helfter C., Nemitz E., Sutton M.A.

Introduction

The objective of this study was to assess in the field the efficacy of a woodland for the recapture of agricultural ammonia emissions by release of ammonia underneath the canopy and measure the recapture characteristics. The NH_3 capture efficiency of a short crop dense, closed canopy has been found to be very effective (see e.g. Nemitz et al., 2000). However, the efficiency of trees and bushes as would typically be used in a silvo-pastoral system (where livestock range beneath a tree canopy), has not been quantified previously and the proposed experiment led to some logisitic and scientific issues.

Methodology

A Forest Research plot within the Forest of Ae was identified as having suitable spacing and size for a release experiment (Figure 1). The hybrid larch plantation is within a wider Forest in Southern Scotland which is subject to prevailing winds from the South West. A network of ½"tubing with 0.1 mm pinholes drilled into the tubing at regular 1m spacing (400 release points in total, Figure 2) was laid across the floor of the woodland. Calculations of the pressure drop across the tubing network showed that the flow through each of the pinholes should be within error the same, and indicative flows were checked and found to be present at all the far points of the release network.

Figure 7 : Forest of Ae site; release network tubing is visible running across the woodland floor

There was a co-release of NH_3 and CH_4 with the NH_3 being detected using a photoacoustic instrument (Nitrolux, Pranalytica) and the CH_4 being monitored using a tuneable diode laser spectrometer (TDL). Methane in this experiment is used as a tracer gas, as it does not interact with plants for the concentrations at the order of magnitude we used.

The original plan had been to use the TDL for both species but the NH_3 channel was not functional at the time of this experiment. The Nitrolux has a lower time resolution than the TDL therefore interpretation of NH_3 and CH_4 data together was not quantitatively useful. In addition to the chemical measurements the wind profile, turbulence above and within the canopy (using a moveable micro-sonic anemometer), ambient meteorological conditions, leaf area index (LAI) and leaf wetness were monitored. Experiments were carried out over the period September – October 2009.

Conditions and equipment performance were very variable during this time period (Figure 3) including periods of complete calm and highly variable time).

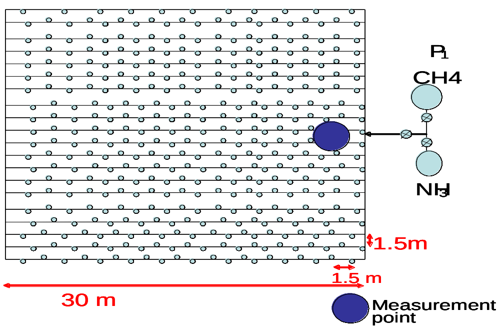

Figure 9: Measurement release network schematic

Figure 8 Schematic Layout of Undercanopy release experiment

Results

Several experiments to release NH_3 and CH_4 were attempted during the deployment. One example is shown in Figure 10. Due to measuring the ammonia at several heights and variability in the wind speed and direction during that and similar experiments , it was not possible to calculate uptake fractions from the data.

Average LAI values ranged from 4.95 to 4.37 from the beginning to the end of the experiment. The LAI data were then analysed and used for the LAD profiles used for the modelling in WP2b.

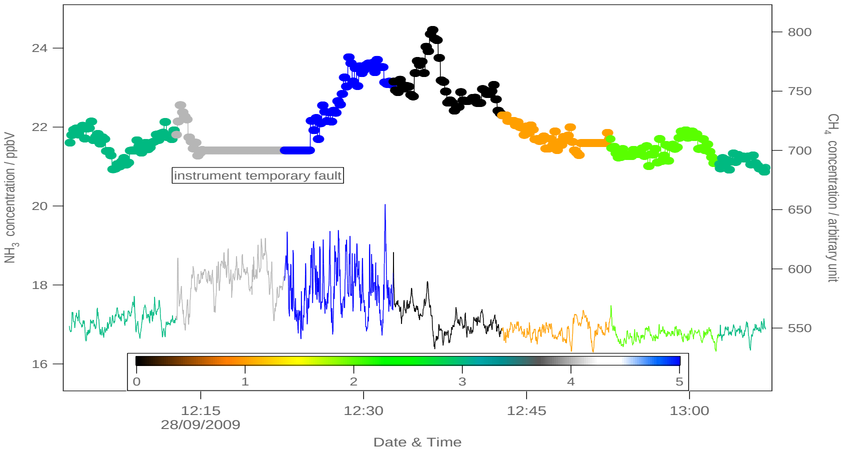

Figure 10 Ammonia and methane release experiment. Colours represent measurements made at different heights through the canopy

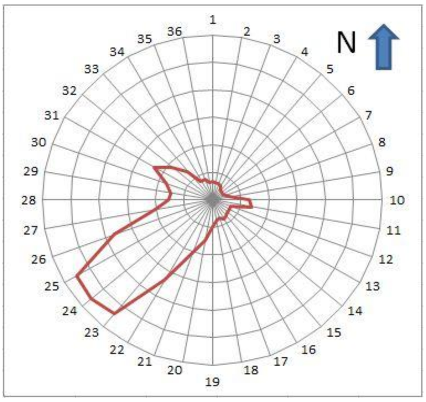

Figure 11 Wind Rose for Ae experiment

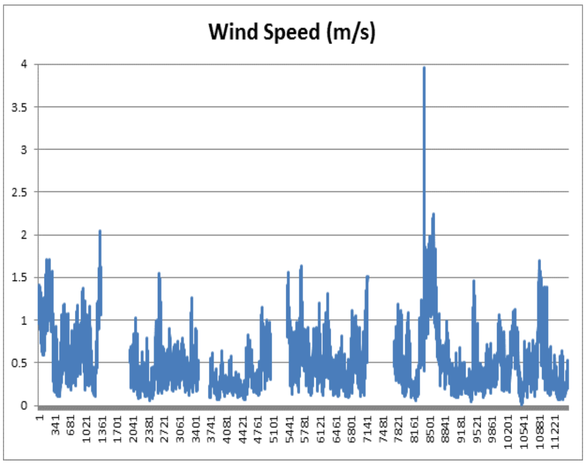

Figure 12 Wind Speed for Ae experiment

Meteorology measurements

A 5 week period of turbulence data above and within the canopy along with the wind profile and meteorological data. The turbulence data was provided to B Loubet as it was a useful data set for validation and improvement of the MODDAA model. The presence of the canopy changes radically the turbulence patterns, and measurements are very valuable to describe and transfer it into model.

Conclusions

All turbulence data acquired during this field experiment were then used to improve the parameterisation of the AQUILON model, a second order closure turbulence model that predicts the flow and turbulence field of complex structures.

WP2b - Modelling of shelter-belt and understory scenarios

Loubet B., Bealey W.J., Braban C.F., Famulari D.F., and Sutton M.A.

The MODDAS-AQUILON is a flexible model that can be used to examine the ammonia abatement potential of different agro-forestry structures in the landscape. The model is based around a forest schema as shown in Figure 13, taking into account height of canopy (z), leaf area density (LAD), width of canopy (X), source strength (Q) and source width (Xs).

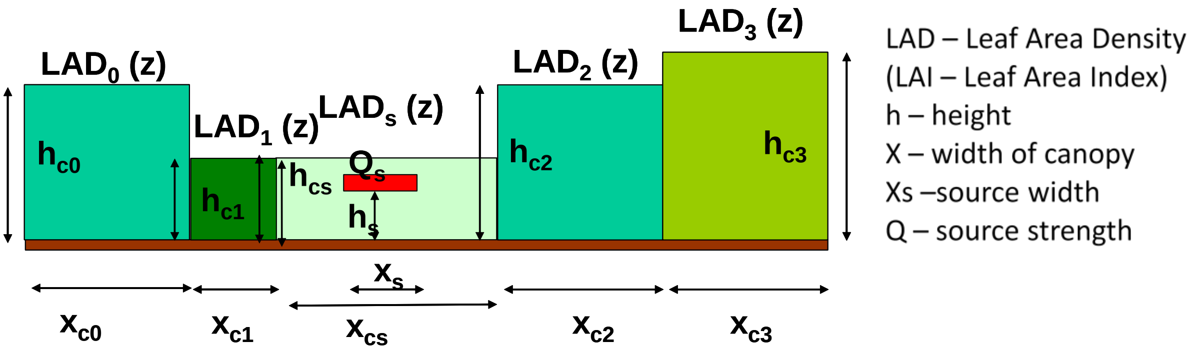

Figure 13. General Scheme of the woodland and source geometry that will be tested in the scenarios.

3 ammonia sources scenarios were modelled:

1. a "housing" scenario where the source was emitting at between 2 m and 2.5 m height, 4-5m wide, and with a source strength of 300 kg NH3-N yr (Figure 14 LHS)
2. a "lagoon" scenario, in which a lagoon was considered emitting from 0.1 to 0.2 m high, with a source strength of 393 kg NH3-N yr (Figure 14 LHS)
3. an "under-storey" scenario, in which the source (free-range chickens) was considered to be at 0.1-0.2 m high under the canopy, with a source strength of 625 kg NH_3-N yr (Figure 14 RHS)

These scenarios were combined with a range of meteorological situations, noting that MODDAS-AQUILON can only run for neutral cases. The wind speed at 50 m was set to 5 m s^{-1}.

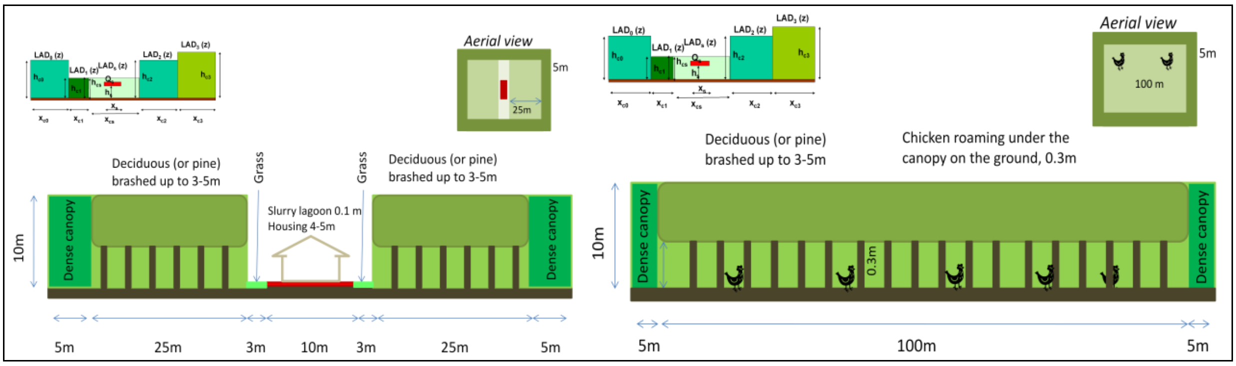

Figure 14 LHS: Housing and lagoon scenario; RHS Under storey source.

Five canopy characteristics were modeled and the deposition parameters used were such as to reproduce a maximum deposition:

Results

In the housing runs the maximum deposition simulated was 28%. The total deposition does not change with or without symmetrical layouts. The comparison of runs show that a "Christmas tree" profile with 15-20% of the bottom of the trunk free of leaves is most beneficial for NH_3 deposition. Having a wider backstop increases deposition from 16 to 25%. Moreover, most of the deposition is occurring in the backstop and that the proportion deposited in the main canopy remains stable but decreases when the width of the backstop increases. The deposition in the backstop is not proportional to the size of the backstop. The increase of the main canopy width when the backstop width is set to 50 m does increase the deposition significantly in the main canopy but in the mean time it does decrease the deposition in backstop. The increase of the canopy height from 10 to 30 m with a constant LAI leads to a decrease in the deposition rates is due to an increase in the turbulent mixing at the source location (asymmetrical run), because of the high canopy. A symmetrical run should however be done to see whether in such a case the sheltering of the incoming canopy decreases this mixing effect. In the understorey runs, the deposition increased from 15% to 37% for a backstop canopy increasing from 0 to 50 m (LAI main canopy = 3, LAD main canopy=99). The percentage deposited in the main canopy increased linearly with the canopy LAI and a canopy LAD denser at the top of the canopy was less efficient in capturing NH_3 than a homogeneous LAD

The NH_3 concentration in the "housing" runs was, as expected, maximum at the NH_3 source, decreasing with distance. For the symmetrical scheme, the canopies tend to increase the vertical dispersion and also the backward dispersion due to the increased turbulent kinetic energy (Figure 5 Top Panel). The asymmetrical scheme, shows a downwind decrease in the concentration inside the canopy, but there is a subsequent increase in concentration after the canopy due to a zone of calm air (wind speed below 1 m s-1). The scheme with a wider main canopy and wider backstop leads to decrease in the concentration in the canopy which is however not a lot different from the concentration field with a smaller main canopy. However, the concentration is background levels on the other side of the canopy. In the case of the lagoon, the same behavior is observed for the concentration with or without an upwind main canopy.

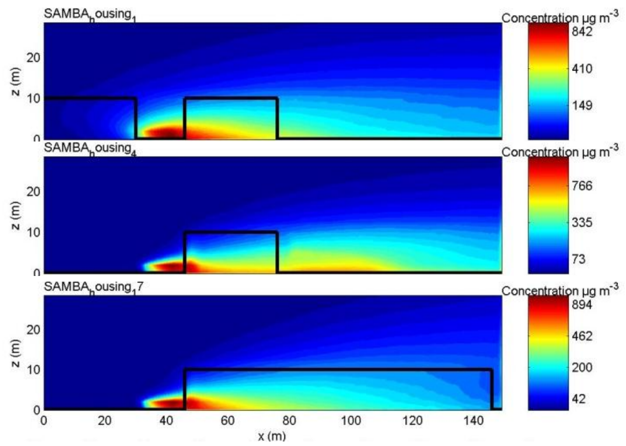

Figure 15 Concentration field in "housing" Shelter belt shown in black outline

For the "understorey" runs, the concentration can be vary significantly depending on the canopy density (LAD and LAI). Indeed, with a quite open canopy (run 6, LAI=1), the maximum concentration reaches a level similar to the maximum concentration in the "housing" case, but when the canopy is very dense (run 7, LAI=6), the concentration reaches more than 4000 µg NH_3 m^{-3} (Figure 6). This can be explained by the very small level of turbulence and wind speed in the canopy in the dense scenario,

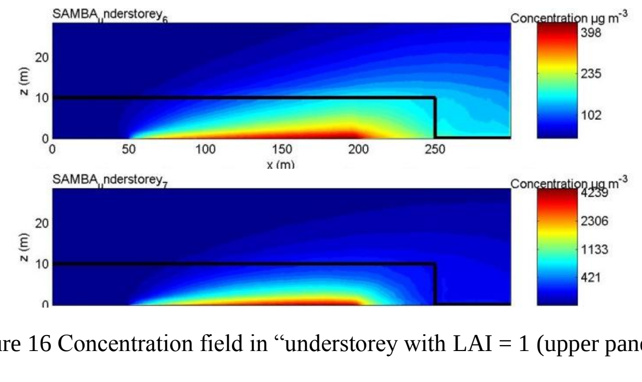

Figure 16 Concentration field in "understorey with LAI = 1 (upper panel) and LAI = 6 (lower panel).

The deposition patterns in the housing runs follow the concentration patterns but are also affected by the LAD patterns (Figure 4). Figure 7 shows the difference of having no back-stop (top panel) to a 50m back-stop (lower panel).

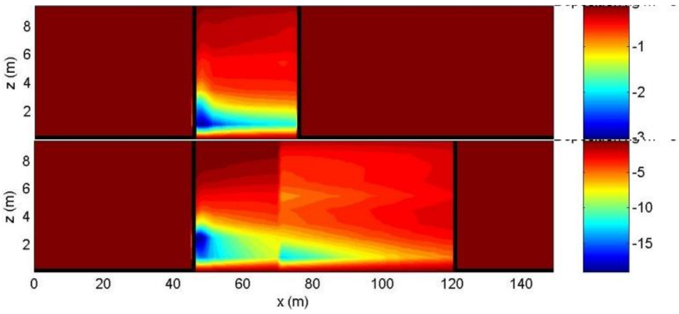

Figure 17 Deposition patterns in "housing" runs with and without backstop (normalized by the source strength).

Interestingly, deposition to main canopy structures (15%) with lower LAIs (LAI=3) can have higher recapture efficiency than denser back-stop canopies (LAI = 6) of a similar width (12%) as the main canopy is sufficiently wide enough to capture most of the ammonia. The deposition pattern in the "understorey" runs varied a lot depending on the concentration levels and the LAI and LAD patterns. Figure 8 illustrate this when comparing a situation with a quite open canopy (LAI= 1), with a situation with a dense main canopy (LAI=6). The deposition is only significant in the backstop for the less dense canopy (22% recapture) while is very large throughout the main canopy in the dense canopy scheme (60% recapture).

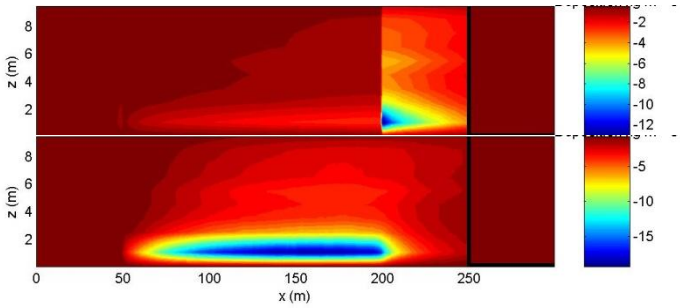

Figure 18 Deposition patterns in the "understorey" LAI = 1 (upper panel) and LAI = 6 (lower panel) (normalized by the source strength)

Conclusions

- maximum deposition rates were 28%, 19% & 60% in the housing, lagoon & understorey set-ups respectively.
- deposition rate increased roughly proportionally with LAI if the LAI and the LAD are identical in the main and the backstop canopies.
- The increasing main canopy width does not proportionally increase the deposition rates.
- The canopy with a dense and homogeneous LAD favors deposition, while canopy with a dense crown and an open trunk space is less effective at recapture.
- When the source is close to the ground (lagoon and understorey setups) a dense canopy near the ground should be favored rather than a canopy with a dense crown.
- Taller canopies with identical LAI lead to smaller deposition rates

Note that under real conditions there is a potential for saturation of the surfaces exposed high loads of NH_3. Therefore, it should be stressed here that the estimated deposition was a maximum, with a small cuticular and stomatal resistance and a zero soil and plant compensation point. In reality, the deposition should indeed be smaller due to a smaller relative humidity, a smaller radiation, and a larger compensation point. Additionally, the predicted deposition is large and therefore, the canopy and the ground are likely to "saturate" and therefore the cuticular resistance is likely to increase, especially under dry conditions. Moreover, the soil and canopy compensation point may also increase with time leading to decrease in the recapture efficiency.

3a. Modelling NH_3 volatilisation from sheltered slurry stores: Windbreaks and slurry lagoons effects of wind and temperature, the Thermal-Volatilisation Effect (TVE) Model

Adrian Williams, Cranfield University

Introduction

In this work the Thermal-Volatilisation Effect (TVE) Model for understanding the effect of wind breaks on ammonia emissions from slurry lagoons is developed. There were two main approaches taken to develop the TVE model: 1) thermal model using a more mechanistic emissions formulation and 2) volatilisation modelling of temperature changes in lagoons that could drive part of the mechanistic ammonia emissions. The TVE model used was derived from that of Olesen and Sommer (1993). It was developed further by Webb et al. (2005) and assessed by Theobald et al. (2005). Once the thermal and volatilisation model developments were combined into the TVE model, the ammonia emissions were run over a year using the wind speed reduction factors of 10% to 100% coupled with the temperatures that were simulated (above) as input values. The main parameter values were (pH: 7.5; initial TAN: 1 $kg.m^{-3}$, depth 1m; initial lagoon T (August start): 17°C; initial lagoon T (November start): 8°C).

Results

The TVE model was validated against two sets of experimental data for different lagoons in North Bedfordshire for which there were consistent data set for all required variables (Lagoon 1:~ 1000h 1 x 18 x 24m; Lagoon 2: 2780 h, 2 x15 x35, Scotford and Williams, 2001). The lagoon temperatures were measured were about 0.3 m below the surface. The TVE model generally simulated measure temperatures well. The overall effects of sheltering were to increase the simulated summer temperature and decrease the simulated winter temperature. The annual average emission rate was 1.3 g NH_3-N m^{-2} d^{-1}, which is well within reported rates (0.4 to 5.7) and close to mean of 1.7 applied in the UK inventory by Misselbrook et al (2006).

The effects of wind breaks on volatilisation rates were calculated by running the model with the wind speeds and lagoon temperatures as had been previously simulated. The crucial observation is that the use of wind breaks still reduces the RAER when both wind speed and temperature effects are integrated into one model. The minimum RAER was 39%, (61% reduction in emissions).Note that this would not apply over the full lagoon surface, therefore is an upper estimate.

Table 1 Effect of wind break in relative ammonia emission rate (RAER) on annual basis (n.b. 100% is normal, without wind break)

Wind speed reduction factor	RAER compared with normal	Fitted curve
10%	39%	39%
25%	62%	61%
50%	82%	83%
75%	93%	94%
100%	100%	99%

The fitted curve for RAER against wind speed reduction factor (w) took the following form with parameter values in ER = A + B*exp (k w)

The modelled changes in wind were integrated with the RAER effects. Wind break heights of up to 10 m were analysed with an average lagoon width of 50 m (Williams, 2002). Note RAER estimates were applied for up to 120 m. Effectiveness increased with height and decreased with distance across the lagoon (e.g.Figure3 LHS). The effect for a 50 m wide lagoon ranged from a reduction in ammonia emission rates in the range from 7% to 26%. The overall ammonia reduction effect is somewhat larger than was previously estimated (AMBER).The error is quite high, with an average coefficient of variation (CoV) of 44%, indicative of range for an unknown windbreak. TVE model errors were examined using Monte Carlo simulations leading to an error estimation for the models of CoV = 7.1%. The errors estimated do not include those from pH or surface crusting.

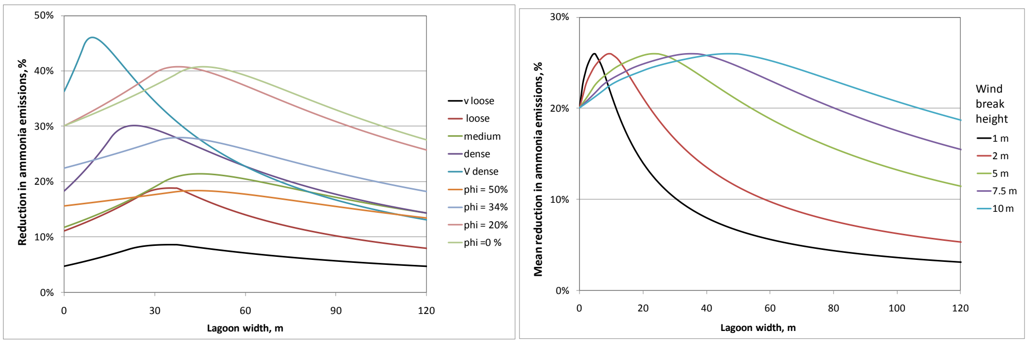

Figure 19 LHS:Effect of a 7.5 m high wind break on relative ammonia emission reduction with integrated thermal and emissions model; RHS: Averaged effects of wind breaks of all porosities on relative ammonia emission rates across slurry lagoon

Discussion

The revised modelling of NH_3 volatilisation from sheltered slurry stores presented here gives a nuanced interpretation of the effects of windbreaks. Temperature clearly affects the seasonal emission rate and in turn is affected by wind speed. The large wind speed effect previously observed was larger again in the TVE model due to a much more mechanistic understanding of the relationships between wind speed temperature and the mass transfer of ammonia. The results are plausible and intuitive but they have not been independently tested against emissions measurements and that instantaneous ammonia emission rate is the surface pH which is not easy to predict. The range of benefits is reasonably large, reflecting the potential range of heights and porosities that a windbreak may have. The effectiveness will tend to increase over time as trees grow and it is essential not to assume the largest benefits immediately. The results in Table 2 indicate that the benefits of a windbreak roughly double as it grows from 1 to 5m height and then doubles again at 10m. One other benefit of windbreaks is that the source of emissions of not only ammonia, but also malodours is masked. This simple physical screening is likely to reduce the public perception of a source of odour, although we make no claims about the potential for mitigating malodours *per se*. Effectiveness is highest for short lagoons, higher trees and higher denisities of trees, however it is important not to assume the best case, but the average and to consider the other impacts and implications the windbreak may bring to the farm environment.

Table 2 Summary of effect of windbreaks of different heights and densities on the reduction in ammonia emissions from a 50 m wide lagoon

Height of wind break	**Nominal density of wind break (average of three simulations)**		
	Low	*Medium*	*High*
1	5%	8%	8%
2	7%	12%	14%
5	10%	18%	21%
7.5	13%	24%	29%
10	12%	23%	27%

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WP3b: Profitability analysis of trees and woody shelter belts on livestock farms for ammonia abatement and carbon sequestration

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Introduction

In WA0179, Theobald et al. (2003) indicated that a 30-60m woody belt around strong ammonia point source, such as intensive livestock housing was the most cost effective compared to other designs. This work revisits the potential profitability of such shelter or woody belts given better knowledge of design and performance, with recent price and grant information, comparing original and improved designs. In determining the potential profitability there are two 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 enterprise”? The default management model is assumed to be one of grant-aided establishment followed by least-cost maintenance and harvesting.

Establishing woodland is a long-term proposition. Near future costs have to be covered by uncertain future returns. Discounted Cash Flow (DCF) is applied (Warren,1982). At the end of 40 years, the belt will be in a state of equilibrium management. The financial life cycle of a tree or woody crop can be analysed in three stages; establishment, maintenance and harvesting. The 2009/2010 prices and costs have been obtained (Nix, 2010, ABC, 2010). Establishment covers:1) obtaining the land, 2) ground preparation, 3) planyting 4) tree protection. The Silsoe Whole Farm Model (SFARMOD, Annetts and Audsley 2002) was used to quantify the opportunity cost of losing one hectare of productive agricultural land. Two farm type cases exist: arable providing land for pig and poultry and grass-arable farm types providing land for dairy. Annual rainfall and soil types have been evaluated and farming systems with high value crops incur the greatest financial penalties. Combining results with WA0178 results to current cost terms gives an appreciation of how relative farm profitability changes over time and thus perhaps a fairer reflection of the opportunity costs of tying land into the woody belts over a very long term (Table 1). Preparation cost might include spraying, sub-soiling, ploughing and seed bed cultivation. The model allows for ground work, weed control, fertilising, liming, grazing protection. Maintenance allowances are made.

Table 1 A comparison of the marginal cost of one ha in 2010 terms for arable (2002 & 2010) and arable with grassland (1995, 2002, & 2010)

Arable Annual Rainfall, mm			
Soil	*600*	*900*	*1200*
Light	544 (516 to 572)	580 (554 to 607)	602 (521 to 682)
Medium	595 (485 to 705)	618 (577 to 660)	633 (600 to 665)
Heavy	601 (463 to 740)	610 (556 to 665)	593 (585 to 602)
Dairy Annual Rainfall, mm			
	600	*900*	*1200*
Light	723 (423 to 900)	772 (366 to 1074)	754 (313 to 1218)
Medium	755 (381 to 984)	822 (334 to 1070)	829 (284 to 1213)
Heavy	781 (325 to 1106)	846 (289 to 1161)	813 (256 to 1160)

Grants are available for the planting of farm woodlands and are regionally devolved in the United Kingdom, details change over time. The grant values used in this analysis were the English Woodland Grant Scheme. Currently, there are sources of support for the woodland, but they are regionally devolved and subject to change. The English Farm Woodland Payment Scheme (FWPS) is one source and with it the Single Farm Payment (SFP). As with all grants the eligibility and rules need to be checked. Removal of trees and other biomass could be modelled as a maintenance cost rather than a yield. However, Nix (2010) does quotes values for thinnings and we assume similar costs.

Scenarios

Three basic designs that have been looked at: The first design stems from WA0178 (4 zones: 1 shrubby intake, a broadleaf, a conifer and a tight hedge back stop). The second design is a 1 brashed broadleaf zone woody one unbrashed conifer zone. The third design is a conifer backstop to a woodland animal enterprise. The first design has two depths (30 and 60 m). The second design is to enclose point sources such as existing poultry houses and slurry tanks. The size of the protected facility changes the relative amounts of the broadleaved and conifer components because the conifer component wraps around the edges to provide the back stop effect. We have considered facilities that are 50m, 100m 200m, and 400m long and are protected through 180 degrees on the downwind side.

There is an additional design choice of the depth of conifer back stop with choices being 5m, 15m, 25m, and 50m. The third design offers the same four depths of back stop choices as the second design.

The Net Present Value (NPV) results are shown in Table 2. All scenarios return negative NPVs, which shows the trees by themselves would not be financially viable. When analysing the biggest term is typically the opportunity cost of the land, typically representing 62% of costs. Thus the exact value of such land to the farm and farmer is key. One challenging term in any DCF is the discount rate as it contains a subjective component. Higher discount rates imply a lower NPV, which are significant here. Often for Green investments there is high initial outlay followed by long term benefits; in this case a small discount rate is more flattering. That is not the case here.

Table 2 Net present values of all scenarios, £ha planted

	Wood belt depth	**30m**	**60m**		
Design 1		-£12,966	-£11,735		
Design 2	**Backstop depth**	**5m**	**15m**	**25m**	**50m**
50m building		-£12,299	-£13,883	-£15,154	-£12,498
100m		-£12,185	-£13,525	-£14,525	-£12,326
200m		-£12,126	-£13,292	-£14,022	-£12,137
400m		-£12,095	-£13,156	-£13,686	-£11,972
Design 3 (backstop only)		-£15,832	-£16,913	-£14,011	-£11,738

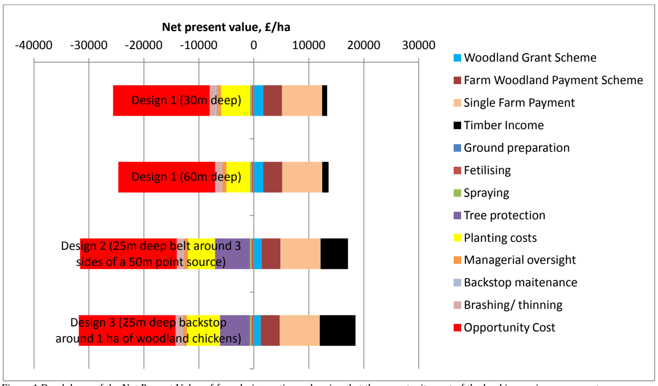

Figure 1 Breakdown of the Net Present Value of four design options, showing that the opportunity cost of the land is a major component

Discussion

The results here suggest that woody belts are not economically feasible in purely financial terms. On a case by case basis there might be a different story. There are several factors for and against:

1. Land opportunity costs: These are local to the farm. We have assumed that the land will be commercially attractive lowland with good access and farming potential.
2. Commercial rates for labour and machinery costs are assumed, which may be available at marginal cost
3. The establishment, over 40 years, of a steady state uneven-aged woody belt to provide long-term continuity of the ammonia abatement is an ideal assumption in many ways.
4. There is non-market and hard to value benefits from tree planting, such as privacy, landscape character.
5. There are some theoretical negative factors e.g. drawing in predators and wild avian species
6. There may be numerous public policy benefits, such as carbon sequestration, biodiversity, rural aesthetics
7. We have not considered alternative ammonia mitigation investments e.g. flue gas scrubbers.

Conclusions

In summary for a farmer the decision boils down to being prepared to invest in a case by case way in the woody belt to achieve a mixture of public and private benefits. These tradeoffs are likely to be favourable if the ammonia emissions are very strong, the vulnerable habitats are very vulnerable, vocal, and close, and there is a convincing privacy and landscape character/value argument. Public financial recognition of any public benefits would of course help mitigate opportunity costs.

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WP4a,b,c - Assessment of the abatement potential of farm woodlands at the UK scale

Dore A.J., Bealey W.J., Dragosits U., and Sutton M.A.

The FRAME model was applied at a 1 km resolution across the British Isles to assess the influence of national scale re-afforestation on ammonia concentrations in air and the deposition of reduced nitrogen.To assess the influence of afforestation on recapture of ammonia, three land cover scenarios were generated. These consisted of the baseline scenario (0) as well as increases by 25% and 50% in total forest cover across the UK (scenarios 1 and 2 respectively). Tree planting was targeted to be near emission sources where ammonia concentrations are highest and thus maximise re-capture potential. Trees were only planted on arable and grassland, with the other land cover categories (semi-natural ecosystems (excluding woodland) and urban) remaining unchanged. Tree cover was increased by scaling the existing forest cover with the ammonia emission data (or by adding new forest in grid squares with no tree cover). A summary of the changes to land cover is illustrated in Table 1. The spatial distribution of forest cover for the baseline scenario and the change between the baseline and the +50% scenario (2) are illustrated in Figure 1.

Table 1. Percentage of land cover types for the baseline and 25% and 50% afforestation scenarios.

	arable	forest	grass	semi-natural ecosystems	urban	water
0. BASELINE	23.0	11.7	22.3	33.8	6.6	2.6
1. + 25%	21.7	14.7	20.6	33.8	6.6	2.6
2. + 50%	20.4	17.6	19.0	33.8	6.6	2.6

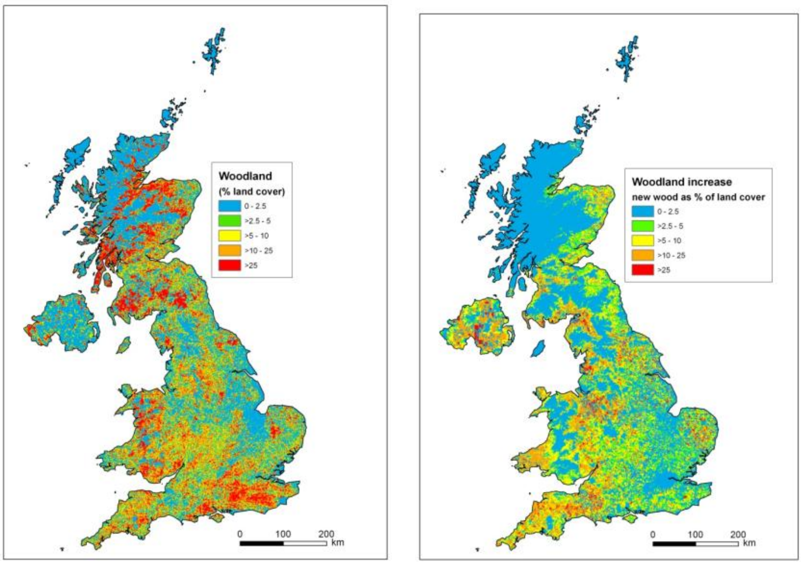

Figure 20 Forest distribution in the UK. Percentage of land cover which is woodland for the baseline scenario (left); Percentage of land which is new woodland for the +50% scenario (right)

Results

The results from FRAME for the baseline scenario for ammonia concentration in air as well as deposition of reduced nitrogen are illustrated in Figure 3. Agricultural ammonia concentrations in the UK are highest across areas of cattle farming in the western parts of the country, as well as in localised hot spots around intensive pig and poultry farms. This distribution is reflected in the map of dry deposition of reduced nitrogen, which is primarily due to the deposition of locally emitted ammonia gas. A different pattern is evident for wet deposition of reduced nitrogen, due to the chemical transformation of ammonia gas to ammonium aerosol and resulting long range transport. Wet deposition is highest in the high precipitation upland areas of Wales and the Pennines.

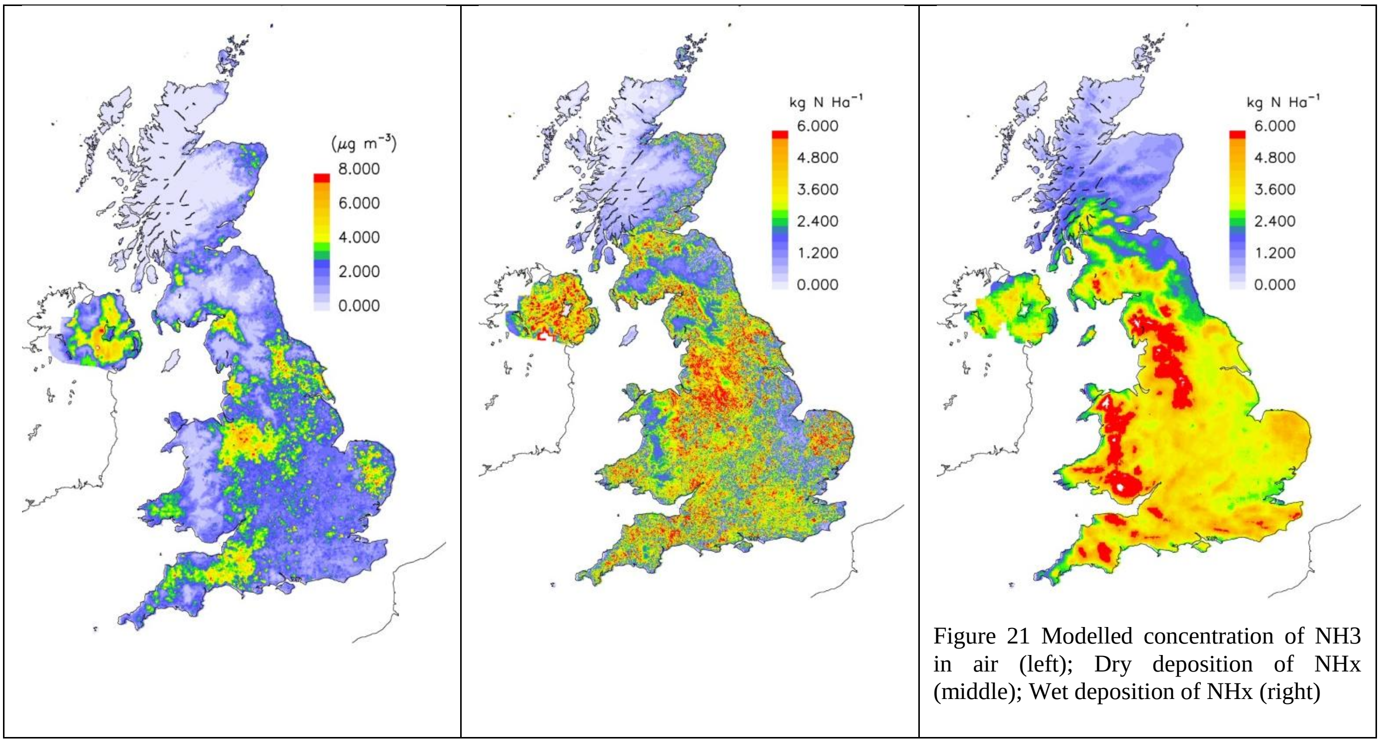

Figure 21 Modelled concentration of NH3 in air (left); Dry deposition of NHx (middle); Wet deposition of NHx (right)

The modelled scenarios with increased woodland led to an increase in dry deposition of ammonia gas near the emission sources due to the lower canopy resistance of forest compared to the land cover types which it replaced (grassland and arable). The reduced availability of ammonia gas in the atmosphere resulted in decreases in wet deposition of reduced nitrogen and of dry deposition to sensitive ecosystems (i.e., semi-natural land).

Figure 4 illustrates the decrease in reduced nitrogen deposition resulting from implementation of scenario 2 (50% national increase in forest cover). Significant reductions in nitrogen deposition were achieved with this scenario. In areas of high wet deposition (the Pennines and Wales), the change in wet deposition was up to 0.5 kg N ha-1. Higher decreases of up to 2 kg N ha-1 for dry deposition were achieved for large areas of semi-natural land and forest. While the deposition per unit area of forest decreased, it is important to note that total mass of reduced nitrogen deposited to forest increased due to the national increase in forest area. This is generally considered to be beneficial, as new deposition would be directed to plantation forests in agricultural areas, reducing the impact on established natural forest ecosystems.

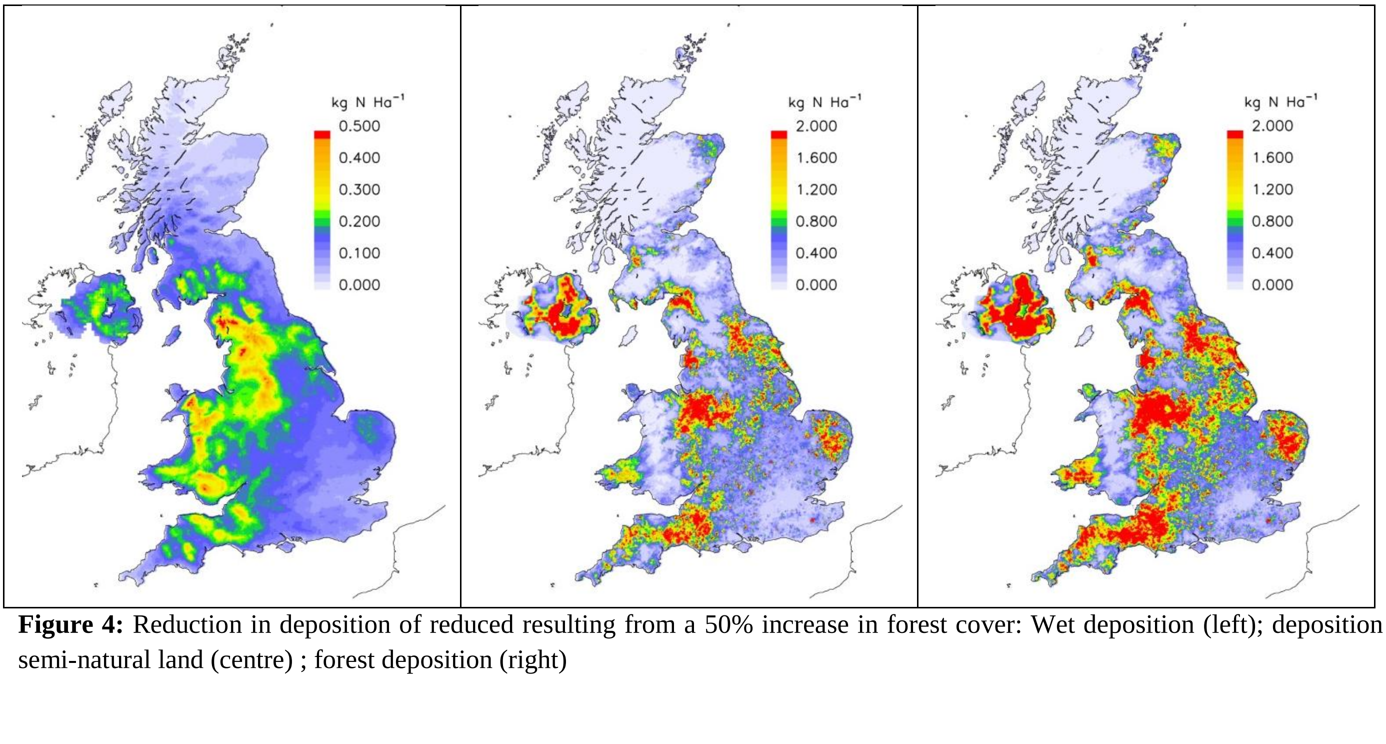

Figure 4: Reduction in deposition of reduced resulting from a 50% increase in forest cover: Wet deposition (left); deposition to semi-natural land (centre) ; forest deposition (right)

The FRAME model was also used to calculate a budget of the total mass of nitrogen entering and leaving the domain of the United Kingdom. The national reduced nitrogen budget for the three scenarios is illustrated in Table 2. The two tree planting scenarios result in significant changes to the fate of emitted ammonia, resulting not only in significant increases in dry deposited reduced nitrogen and decreases in wet deposited reduced nitrogen, but also in decreased export of reduced nitrogen in air leaving the UK (which contributes to the long range transport of air pollution in Europe).

Table 2: The UK mass deposition and export budgets for simulations 0, 1 (+25%) and 2 (+50%)

Gg N-NH$_x$	0. BASELINE	1. + 25% forest	2. + 50% forest
Dry Deposition	61.5	68.0	73.5
Wet Deposition	81.1	79.1	77.4
Total Deposition	142.6	147.1	151.0
Export	121.4	116.9	113.1

In Table 3, changes in NHx deposition and export for tree planting scenarios 1 and 2 are expressed as percentages relative to the baseline scenario. It can be seen that the influence of a 50 % national scale increase in forest cover in the UK targeted at high ammonia emissions areas would result in a 19.5% increase in dry deposition, a decrease of 4.5% in wet deposition and a 6.9% decrease in the export of reduced nitrogen.

Table 3: Changes to the UK mass deposition and export budgets for scenarios 1 (+25%) and 2 (+50%)

(Gg N-NH$_x$)	1. (Gg N-NH$_x$)	2. (Gg N-NH$_x$)	1. (%)	2. (%)
Dry Deposition	6.4	12.0	10.4	19.5
Wet Deposition	-1.9	-3.6	-2.4	-4.5
Total Deposition	4.5	8.4	3.2	5.9
Export	-4.5	-8.4	-3.7	-6.9

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Cost-effectiveness of Agroforestry options for Ammonia Abatement as Climate Change Mitigation measures

Gregory Valatin, D. Sandars, C.F. Braban, B. Bealey

Introduction

The cost-effectiveness of UK forestry measures aimed at climate change mitigation has been a focus of several recent studies *(1, 2, 3).* Fewer studies have examined this for options aimed primarily at other objectives. The current study is one such case. It complements previous results by focusing upon the cost-effectiveness agroforestry measures in a context in which implementation is motivated by ammonia abatement.

The cost-effectiveness analysis focuses on the same two scenarios considered elsewhere in this report. The first (option 1) involves planting 0.5 ha of trees (0.125 ha of broadleaves fringed on three sides with a 0.375 ha conifer backstop) downwind of a barn or slurry lagoon. The second (option 2), a free-range woodland chickens scheme, involves planting the equivalent of 1.675 ha of trees (0.8 ha of broadleaves and 0.875 ha of conifer backstop) over an area of 1.875 ha downwind of poultry housing. Carbon estimates were obtained from CEH's C-FLOW model for planting beech yield class (YC) 6 (with intermediate thinning) and sitka spruce YC 12 (with no thinning). These were chosen to represent broadleaf and conifer components respectively of the two agroforestry options. The estimates were obtained for a 100 year time horizon, *(3),* upon which the cost-effectiveness estimates reported in the Read Report *(4)* were based. The climate change cost-effectiveness is also analysed over an initial 40 year period The extent to which the carbon benefits associated with the two scenarios can be accounted for in estimating climate change mitigation cost-effectiveness depends upon their permanence

Current government guidance on estimating cost-effectiveness in appraisal and evaluation *(5 p.25)* recommends deriving the cost-effectiveness of a measure by dividing its net present value (NPV) excluding the present value of the carbon benefits by (the negative of) the total tonnes of carbon dioxide equivalent saved. Whether a measure is cost-effective is then determined by comparing the cost per tonne of carbon dioxide equivalent abated with the relevant cost comparator based upon estimates of the social value of carbon. The ammonia abatement potential is assumed to increase linearly from zero to a maximum after 40 years in each case. A maximum abatement potential of 4.35 and 0.53 tonnes of ammonia per hectare per year are assumed for option 1 and option 2, respectively. This abatement is then valued by following current Defra guidance *(6)* on valuing the benefits to society of avoided air quality damage costs per tonne of pollutant of £1,972 per tonne of ammonia at 2010 prices (central estimate). A range of £1,538 (low estimate) to £2,241 (high estimate) is used for sensitivity analysis. Ideally cost-effectiveness estimates should also take into account wider impacts on the provision of ecosystem services associated with land use change. Drawing upon a review of previous studies (e.g. ref 7), suggest from limited evidence that value may range from £30-£300/ha/yr, depending on the priority status of the woodland.

Table 2: Cost Assumptions (£ per ha of project area per year)

	Option 1 (housing/lagoon shelterbelt)	Option 2 (woodland chickens)
Agricultural Opportunity Cost (p.a.) [1]	£595	£311
Establishment Cost (yr 0)	£8,635	£6,182
Management Costs (yr 1 onwards)	£22	£22
Fertiliser and spraying Costs (yrs 1-4)	£93	£93
Fencing Costs (yr 4 onwards)	£84	£38
Backstop Maintenance Costs (yr 5 onwards)	£10	£10

Results

Table 3 summarises the present values of the cost and benefit estimates associated with the two scenarios for the 40 year time horizon, along with corresponding NPV estimates (including carbon benefits). The positive NPVs for option one indicate that even over the shorter 40-year time horizon this scenario offers positive net benefits from a societal perspective. This also holds for central and high estimates for the woodland chickens scheme (scenario 2), although apparently not if woodland management is assumed to subsequently revert to 40-year rotations of felling and replanting (low estimate). The latter conclusion might be reversed, however, were carbon substitution benefits associated with subsequent timber use, or further types of ecosystem services (e.g. water quality and amenity values), also accounted for.

Table 3: Present Values over 40-year time horizon (£/ha at 2011 prices)

	Option 1 (housing/lagoon shelterbelt)			Option 2 (woodland chickens)		
	Low	Central	High	Low	Central	High
Forestry Costs	£28006	£24349	£22553	£14756	£14756	£14756
Wood Production	£881	£881	£27	£743	£743	£46
Ammonia Abatement	£57719	£74007	£84102	£7032	£9017	£10247
Habitat and non-use	£188	£2313	£5311	£168	£2066	£4765
Carbon Sequestration	£3157	£21217	£33825	£2737	£17743	£28288
NPV	£33913	£74070	£100712	-£4075	£14813	£28590

The cost-effectiveness results are presented in Table 4. As implied by the NPVs in Table 3, these suggest that the agroforestry measures considered under option 1 are highly cost-effective from a climate change mitigation perspective. Indicative estimates over a 40 year time horizon for delivering carbon savings of between -£220/tCO_2 to -£123/tCO_2 (central estimate) compare very favourably with the estimated cost-effectiveness comparators based upon the discounted social value of carbon that range from £44/tCO_2 to £46/tCO_2. For option 2 the results imply indicative cost-effectiveness estimates for delivering carbon savings over a 40 year time horizon of between -£1/tCO_2 to £56/tCO_2, with a central estimate of £8/tCO_2. Extending the time horizon to 100-years increases the cost-effectiveness of each scenario.

Table 4: Cost-Effectiveness (£ per tonne of carbon dioxide at 2011 prices)

		Option 1(housing/lagoon shelterbelt)		Option 2 (woodland chickens)	
Time frame	Basis	Estimate	Comparator	Estimate	Comparator
40 years	Low	-£220	£44	£56	£44
	Central	-£123	£46	£8	£46
	High	-£147	£46	-£1	£46
100 years	Low	-£542	£44	£30	£44
	Central	-£270	£46	-£8	£46
	High	-£165	£45	-£12	£44

Concluding remarks

The results suggest that of the two agroforestry scenarios, option 1 (planting a shelterbelt downwind of a barn or slurry lagoon) can be considered highly cost-effective from a climate change mitigation perspective. While option 2 (woodland chickens) is cost-effective under central and high estimates, the choice of time horizon and how woodland planted is subsequently managed are critical issues in assessing its 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.

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