Silvoarable agroforestry: an alternative approach to apple production?

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Abstract: Novel land use systems that integrate woody species into the agricultural landscape have the potential to balance productivity with protection of the environment and the maintenance of ecosystem services. Integrating top fruit production into an agroforestry system, where woody species are integrated with arable crop production, may have a beneficial effect on the control of plant pathogens such as apple scab (*Venturia inaequalis*). However, the introduction of such systems into European high-yielding traditional apple production systems will meet substantial obstacles as the approach affects not only agronomic performance but also well-established fruit production traditions. This paper reports on research that evaluated an apple-arable agroforestry approach as a sustainable strategy for reducing copper inputs in organic and low input systems using two contrasting case studies; Wakelyns Agroforestry in Suffolk, and Whitehall Farm, Cambridgeshire. The results presented here focus on three elements that are likely to be impacted by an agroforestry systems approach to apple production: (i) yield and quality of apples; (ii) emergence of primary and secondary pests and diseases; and (iii) impact on management activities. Potential synergies and tensions are identified and discussed.

Keywords: *Venturia inaequalis***,** alley cropping, organic

1. Introduction

Novel land use systems that integrate woody species into the agricultural landscape have the potential to balance productivity with protection of the environment and the maintenance of ecosystem services (Jose, 2009). An emphasis on managing rather than reducing complexity promotes a functionally biodiverse system with both ecological and economic interactions between trees and crops and livestock (Lundgren, 1982). Although the potential of agroforestry-based agricultural systems has been demonstrated in principle (Quinkenstein et al., 2009), information on their usefulness in the context of European low-input production systems is lacking. Also, the introduction of such systems into high-yielding traditional European apple production systems will meet substantial obstacles as the approach affects not only agronomic performance but also well-established fruit production traditions. As part of the European FP7-funded project 'Innovative strategies for copper-free low-input and organic farming systems (CO-FREE, www.co-free.eu)', we have been evaluating an innovative apple/arable agroforestry system as a potentially sustainable strategy for reducing copper inputs in organic and low input systems. The aim is to provide information on the potential of agroforestry in the European context.

Integrating top fruit production into an agroforestry system, where woody species are integrated with crop production, may have a beneficial effect on the control of plant pathogens such as scab (*Venturia inaequalis*) due to a number of mechanisms:

- A greater distance between tree rows in agroforestry systems, with crops in the adjoining alleys, is likely to reduce the spread of pathogens. This has been recorded for crop pathogens in agroforestry systems (Schroth et al., 1995) but the evidence for tree pathogens is inconsistent (Schroth et al., 2000).

- Lower densities of trees compared with orchards favour increased air circulation which has been shown to reduce the severity of scab by reducing leaf wetness duration (Carisse & Dewdney, 2002).
- Regular cultivations within the crop alleys will incorporate leaf litter into the soil, thus enhancing decomposition and reducing the risk of re-inoculation from overwintered scabbed leaves the following spring.

This research aimed to evaluate an apple-arable agroforestry approach as a sustainable strategy for reducing copper inputs in organic and low input systems using two case studies; Wakelyns Agroforestry, Suffolk, UK and Whitehall Farm, Cambridgeshire, UK. The results presented here focus on three elements that are likely to be impacted by an agroforestry systems approach to apple production: (i) yield and quality of apples; (ii) emergence of primary and secondary pests and diseases; and (iii) impact on management activities.

2. Methods

2.1 Case-study systems

Case Study 1: Wakelyns Agroforestry, an organic silvoarable research site, was established in 1994 on 22.5 ha in eastern England (52.36ºN, 1.36ºE). Within the 2 ha apple-arable agroforestry system, a diverse mix of 21 varieties of apple trees on MM111 rootstock are interspersed with seven timber species, in north/south rows with 12 m-wide crop alleys between adjacent rows. Cereals, potatoes, field vegetables and fertility-building leys are grown in rotation within the alleys. The apple trees cover 2.5% of the land area in the 2 ha system. A local modern 0.6 ha organic orchard acted as a benchmark for comparison.

Research at Wakelyns was carried out in 2012 and 2013. The experimental design at Wakelyns consisted of four plots, each plot including two tree rows and the crop alley in between, with 7-10 apple trees in each plot interspersed with timber trees. At Clarkes Lane Orchard there were also four plots, each plot consisting of two tree rows and the narrow grass alley in between.

Figure 1. Mixed apple and timber tree system at Wakelyns Agroforestry, Suffolk, UK

Case Study 2: The agroforestry system at Whitehall Farm is more commercial than that at Wakelyns Agroforestry in terms of design and scale. Whitehall Farm is a 100 ha organic arable farm on high quality soil near Peterborough, in eastern England (52.53°N 0.18°W). Previously managed as an intensive arable system, the eastern half of the farm entered into organic conversion in 2007, while the rest entered conversion in August 2009. In October 2009, 4,500 apple trees, consisting of 13 varieties were planted in rows running NE/SW 27 m apart, with 3 m spacing of trees within rows. The understorey was sown before tree planting with a 3 m band of nectar flower mixtures and legumes. The 24 m remaining between rows is cropped on an organic rotation including cereals, vegetables and legume fertility-building leys. Late maturing apple varieties have been chosen to allow harvesting of the alley crops first. Research at Whitehall Farm was carried out in 2014 and 2015. Three apple varieties were chosen for inclusion in the research, based on number of replicated rows available and their degree of scab resistance, to include the susceptible variety Bramley, the moderately resistant variety Falstaff and the resistant variety Red Windsor. For each of the varieties, three rows were sampled, with four assessments per tree and with 100 assessments in total per sample (i.e. 25 trees), and two samples per row (i.e. six samples per variety). There was no local commercial organic orchard to use as a benchmark and so Willock Farm, a local heritage orchard, was used as a comparison. In the orchard, all apple trees were assessed, with four assessments per tree.

Figure 2. Organic apple silvoarable system at Whitehall Farm, Cambridgeshire, UK

2.2 Yield and quality of apples

Case Study 1: In autumn 2012 and 2013, all apples harvested from each site were graded as Class I/Class II/processing/waste and weighed per class and variety. The grading followed Commission implementing regulation (EU) No 543/2011 available at www.gov.uk.

Case Study 2: In autumn 2014 and 2015, all apples were harvested at Whitehall Farm by commercial pickers and total yields per variety obtained. As the apples were destined for juicing, just prior to harvest four apples per tree were graded as Class I/Class II/processing/waste to assess quality, with 100 assessments in total per sample, and two samples per row (i.e. six samples per variety).

2.3 Pests and diseases

Case study 1: Pests and diseases were assessed in the plots at three points – small fruits in July 2012 and 2013, large fruits in August 2012 and 2013, and the harvested apples (September to November 2012 and 2013). Scab levels and incidences of other pests and diseases in the agroforestry and orchard plots in 2012 and 2013 were compared statistically using t-tests, using R version 2.10.0 (R Development Core Team, 2009). Each sample consisted of 100 plant units chosen randomly from all trees in the plot area (i.e. 100 small developing fruits; 100 large fruits pre-harvest; 100 harvested fruits). Each plant unit was thoroughly inspected for eggs, insects or insect damage and diseases.

Case Study 2: Pests and diseases were assessed in the plots at two points before harvest – small fruits in July 2014 and 2015, and large fruits just prior to harvest in September 2014 and 2015. For each of the three varieties, three rows were sampled, with four assessments per tree and 100 assessments in total per sample, and two samples per row (i.e. six samples per variety). Scab levels and incidences of other pests and diseases in the three variety plots at Whitehall and Willock Farm orchard plots in 2014 and 2015 were compared statistically using one-way ANOVAs with 'treatment' (Bramley, Falstaff, Red Windsor, Orchard) as a fixed factor, using R version 2.10.0 (R Development Core Team 2009). Where a significant effect was found, *post-hoc* pairwise comparisons of means were performed using Tukey's HSD test to identify significant differences between treatments.

2.4 Impact on management activities

To identify the main management benefits and challenges of integrating apple and arable production systems, a case study approach was used. Semi-structured interviews were conducted with key informants from innovative silvoarable apple systems. Four silvoarable apple systems located in East Anglia, the East Midlands and the South West of England were selected as case study sites. Interview methods followed those outlined by Pretty et al. (1995), involved both face-to-face and telephone interviews, and took between 30 and 120 minutes. All interviews were recorded and supported by notes. Questions covered three main themes: (i) motives for establishing silvoarable agroforestry, (ii) observed benefits and challenges in regards to the main management activities of both arable and apple production, and (iii) the future adoption of silvoarable agroforestry within the UK. All interviews were transcribed and interview notes added to the transcripts. Content analysis was used to identify dominant topics and concepts, coding the interviews thematically using the software QDA Miner 4 (Provalis Research, 2015). Further analytical steps followed those outlined by Hennink et al. (2010) and included development of thick descriptions for each topic to explore the context and meaning of each issue, cross-case comparisons to highlight patterns across interviews, grouping codes into meaningful categories and exploring the relationships between these categories.

3. Results

3.1 Yield and quality of apples

Case Study 1: Apple production in England in 2012 was severely affected by heavy rain from April to June and late frosts, with some fruit farmers reporting losses of up to 90% of their crop. In the agroforestry and orchard sites, some varieties failed to set fruit (e.g. Cornish Gillyflower at Wakelyns; Spartan and Winter Gem at Clarkes Lane Orchard), or had very low fruit set. In addition, high levels of scab impacted on yields at the orchard (see below) and so the resulting total apple yields were very low (Figure 3). Yields within the agroforestry were higher; even allowing for the fact that apple trees cover only 2.5% of the area (tree plus understory). Comparing yields with standard figures from the Organic Farm Management Handbook (Lampkin et al., 2014) by calculating the yield of 100% agroforestry apples (i.e. multiplying by 40), the yields from the agroforestry compare favourably with standard yields (Class I & II: 15.7 t/ha from the agroforestry vs. 14 t/ha from orchards at peak production). Apple yields in 2013 were substantially better than in 2012. Yields within the organic orchard were 2.24 t/ha (Class I, II and processing) compared with 0.72 t/ha from the agroforestry (Figure 3), which when scaled up to 100% apples, again compares favourably with standard figures (Class I & II: 19.25 t/ha from the agroforestry vs. 14 t/ha from orchards at peak production (Lampkin et al 2014)).

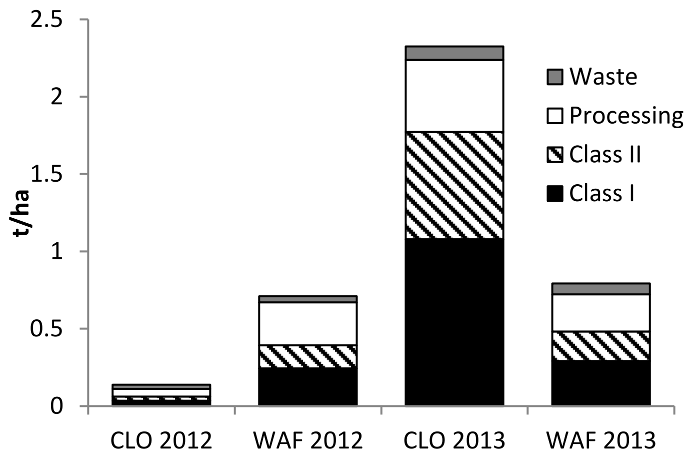

Figure 3. Apple yields (t/ha) from the agroforestry (WAF) and orchard (CLO) sites in 2012 and 2013. NB. Apple trees account for 2.5% of land area in the agroforestry system.

Case Study 2: In the agroforestry system, tree rows account for 10% land area with 85 trees/ha; scaling up to 100% apples, yields in 2014 ranged from 0.25 t/ha to 5.95 t/ha and in 2015 from 1.36 t/ha to 15.18 t/ha (Table 1), which compares with standard yields for 5 year old orchard of 3 t/ha and an organic orchard in peak production (6-11 years) of 14 t/ha (Lampkin et al., 2014). There was a wide range of yields from different varieties and in the two years, with two of the low yielding varieties (Falstaff, Bramley) in the same field, which may indicate problems with pollination or mineral deficiency although these two varieties also had high levels of scab in 2014. There was a higher proportion of processing apples in 2014 compared with 2015 (Figure 4).

Table 1. Yields of apples in the agroforestry system at Whitehall Farm, 2014 and 2015

Variety	Average kg / tree		Agroforestry 85 trees/ha t/ha		100% apples t/ha	
	2014	2015	2014	2015	2014	2015
Pinova	2.71	3.35	0.23	0.28	2.30	2.85
Fiesta	3.12	1.60	0.27	0.14	2.65	1.36
Red Devil	2.85	4.35	0.24	0.37	2.42	3.70
Limelight	2.99	5.43	0.25	0.46	2.54	4.62
Red Windsor	1.44	4.63	0.12	0.39	1.22	3.94
Rajka	7.00	7.67	0.60	0.65	5.95	6.52
Falstaff	0.55	3.91	0.05	0.33	0.47	3.32
H Russett	2.25	7.25	0.19	0.62	1.91	6.16
Saturn	0.29	4.86	0.02	0.41	0.25	4.13
Bramley	0.41	4.36	0.03	0.37	0.35	3.71
Adams Pearmain	6.90	9.48	0.59	0.81	5.87	8.06
Ashmeads Kernel	1.72	4.60	0.15	0.39	1.46	3.91
Chivers Delight	1.79	17.86	0.15	1.52	1.52	15.18

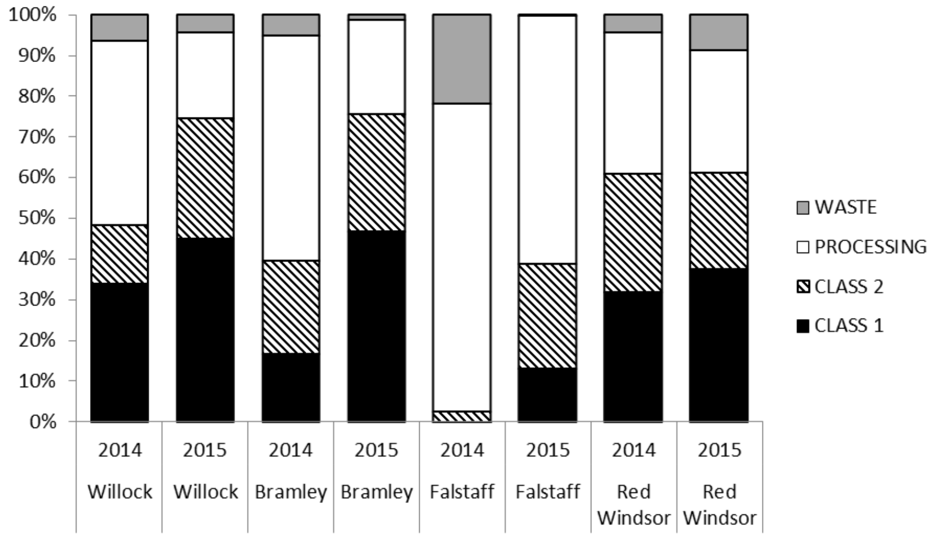

Figure 4. Percentage of each class in pre-harvested fruits 2014 and 2015

3.2 Pests and diseases

Case Study 1: Neither the agroforestry apple trees or orchard trees are sprayed for scab, and there were high levels of scab in both systems in 2012 (Figure 5). However, scab levels of both small and large fruits were over twice as high in the orchard compared with the agroforestry site and analyses showed a statistically significant difference (small fruits $t = 4.25$, $p < 0.01$; large fruits $t = 3.44$, $p < 0.05$), but there were no significant differences between scab levels in the harvested agroforestry and orchard apples (Table 2). There was a higher incidence of insect damage to small developing fruits by sawflies ($t = -3.29$, $P < 0.05$, Figure 6a) and to large fruits by codling moths ($t = 3.94$, $P < 0.03$) in the agroforestry system compared with the orchard (Figure 6b, Table 2). At harvest, capsid damage was significantly higher in the agroforestry apples ($t = -4.57$, $P < 0.01$; Figure 6c). In 2013 scab levels of both small, large and harvested fruits were several times higher in the orchard compared with the agroforestry site (Figure 5) although due to wide variation within sites, there was only a significant difference between sites in the small fruits ($t = 3.11$, $P < 0.05$; Table 2). In the small fruit, statistically significant differences were found only for occurrences of open flesh (likely caused by birds, $t = -4.37$, $P < 0.05$, Figure 6d). In the large fruit, there were significantly higher levels of aphid damage ($t = -3.17$, $P = 0.05$) and moth damage ($t = -2.66$, $P < 0.05$) in the agroforestry, and significantly higher levels of codling moth damage in the orchard ($t = 8.69$, $P < 0.01$, Figure 6e). There were no significant differences found in the harvested fruit (Figure 6f).

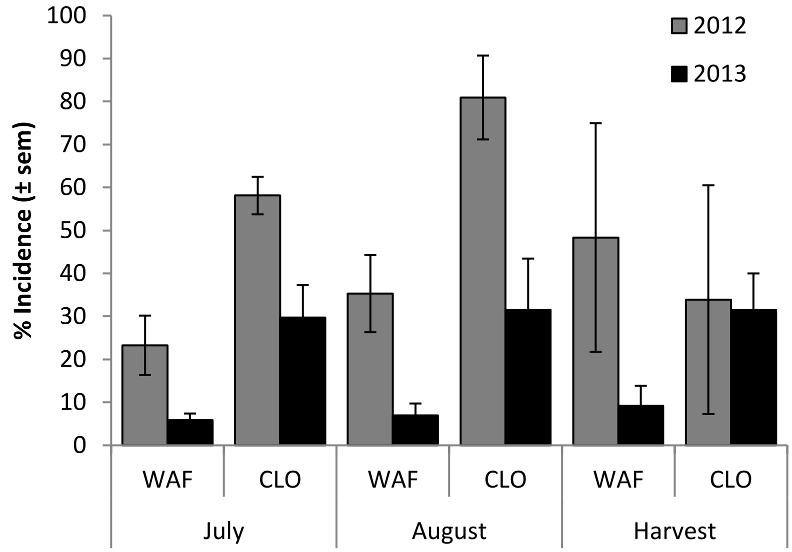

Figure 5. Mean scab incidence per plot in the agroforestry (WAF) and orchard (CLO) in 2012 and 2013

Table 2. P-values of t-tests comparing diseases and pests in the agroforestry and orchard plots

	Small fruit		Large fruit		Harvested fruit	
	2012	2013	2012	2013	2012	2013
Scab	**	*	*	NS	NS	NS
Sawfly damage	*	NS	NS	NS	NS	NS
Capsid damage	NS	NS	NS	NS	**	NS
Codling damage	NS	NS	*	**	NS	NS
Aphid damage	NS	NS	NS	*	NS	NS
Moth damage		NS		*		
Open flesh	NS	*	NS	NS	NS	
Brown Rot			NS	NS	NS	NS

* P ≤ 0.05; ** P < 0.01; *** P < 0.001, NS = not significant, Blank = no incidences recorded

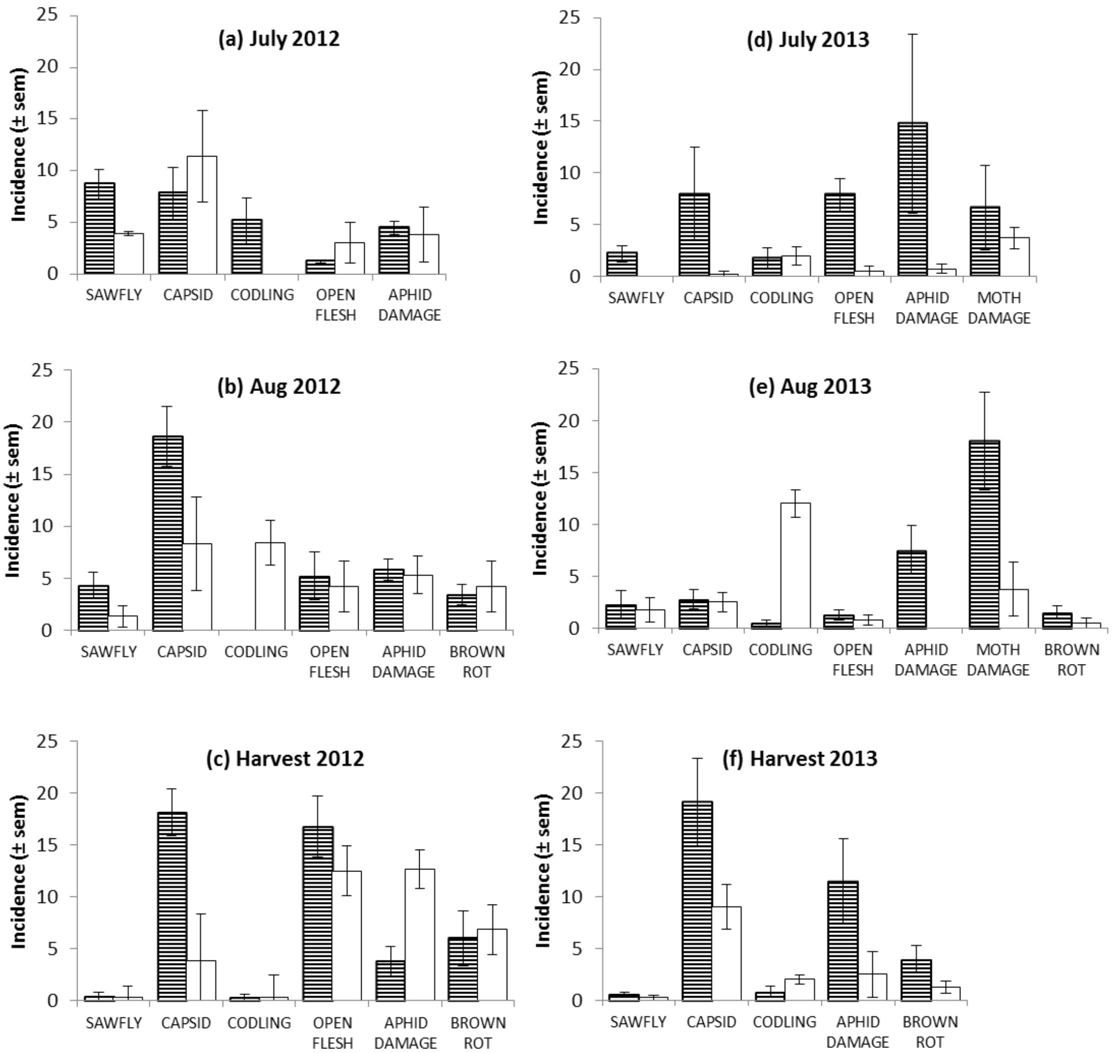

Figure 6a-f. Pest and disease damage to fruit in the agroforestry (striped bars) and orchard (white bars) in 2012 and 2013

Case Study 2: In 2014, there were high levels of scab in the Bramley and Falstaff varieties in the agroforestry, despite Falstaff being a moderately resistant variety (Table 3, Figure 7a). The Red Windsor apples maintained their resistance to scab. Levels of scab in the orchard were just under 20%. Analysis of variance identified a highly significant difference between all samples in both the small fruit ($F = 93.54$, $P < 0.001$) and large fruit ($F = 279.9$, $P < 0.001$). Scab levels were overall lower in 2015, although analyses found a significant difference in both the small fruit ($F = 50.93$, $P < 0.001$) and large fruit ($F = 193.7$, $P < 0.001$); this difference was due to much higher levels recorded in the Falstaff plots (Figure 7b).

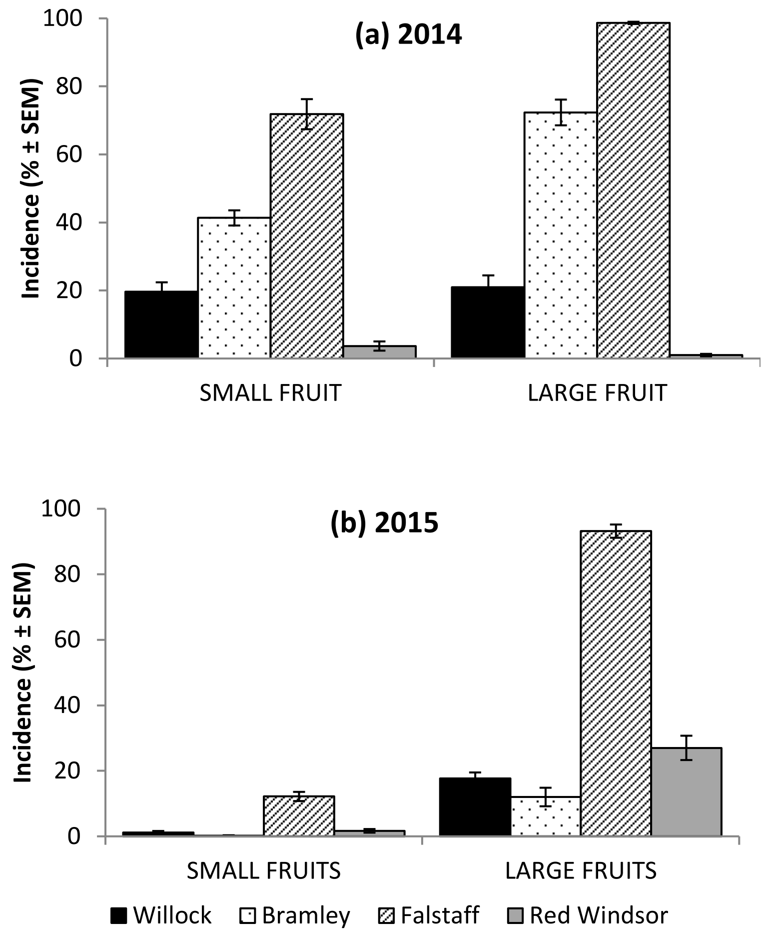

Figure 7. Mean scab incidence per plot at Whitehall Farm and Willock Farm orchard in July and September 2014 (7a) and 2015 (7b)

Table 3. P-values of ANOVAs comparing diseases and pests in the agroforestry and orchard plots in 2014 and 2015

	Small Fruit (July)		Large Fruit (Sept)	
	2014	2015	2014	2015
Scab	***	***	***	***
Sawfly damage	*	***	NS	NS
Capsid damage	***	***	***	NS
Codling damage	***		***	NS
Open flesh	NS	*	***	***
Aphid damage	NS	**	*	*
Brown Rot	NS		***	***
Moth damage	***	NS	***	***
Earwig damage				***

* P≤0.05; ** P<0.01; *** P<0.001, NS = not significant, Blank = no incidences recorded

A range of secondary pests and diseases were recorded in the agroforestry and orchard systems in 2014 and 2015 (Figure 8, Table 3). In 2014, moth damage was common in the Bramley and Falstaff apples, as were open flesh wounds caused by insects and/or birds, while Red Windsor suffered high levels of capsid damage (Figure 8a and b). In 2015, sawfly damage was the main problem in the developing fruits, despite the removal of infected fruit in the agroforestry systems in June 2015, with highest levels in the Willock and Falstaff small apples ($F = 39.71$, $P < 0.001$, Figure 8c). In the large fruit, Bramley apples suffered from higher levels of moth damage ($F = 25.59$, $P < 0.001$) and earwig damage ($F = 79.99$, $P < 0.001$, Figure 8d).

3.3 Impact on management activities

(i) Motives for establishing silvoarable agroforestry

The most commonly held objective was economic diversification. Perceived benefits of diversification included enhanced biodiversity, reduced economic risk, and resilience to climate change. The second most common objective was improved biodiversity, with interviewees citing habitat creation and improved pest-predator balances as a desired consequence. Individually held motives for implementing silvoarable agroforestry varied with farm location and business type and included soil protection and extended cropping season. Three out of the four case study systems were thought to have been successful in meeting the main objectives behind their implementation, with the fourth case study being too recently established to draw conclusions.

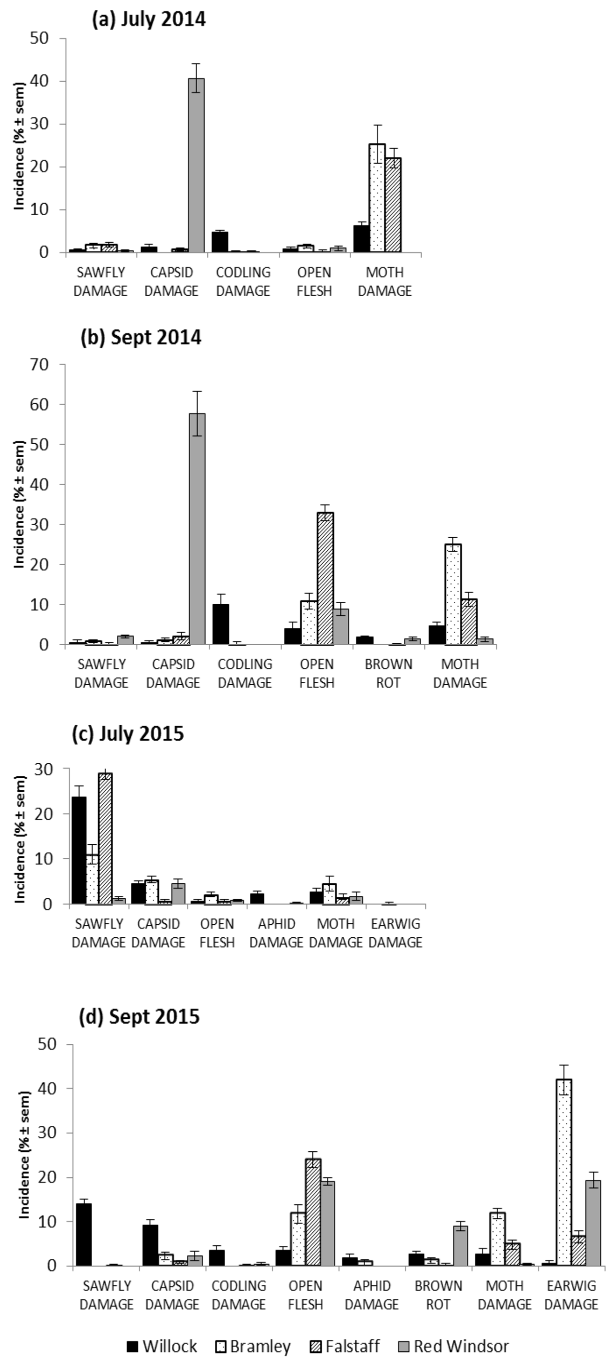

Figure 8a-d. Pest and disease damage to fruit in the agroforestry and orchard plots in 2014 and 2015

(ii) Observed benefits and challenges in regards to the main management activities of both arable and apple production

One of the main benefits of agroforestry identified by farmers was the provision of shelter for arable crops, vegetables, and reducing soil erosion. A second important benefit highlighted by farmers was for biodiversity, with reported increases in small mammals, farmland birds and increased habitat for beneficial insects and one farmer reported reductions in pests and disease within their system. Weed management was identified as one of the main management impacts associated with silvoarable systems. There was a general consensus that effective management of the understory is required to ensure tree rows do not become a reservoir for arable weeds. A number of trade-offs were identified in regards to pests. Although one farmer reported increased biodiversity they also recognised not all increases had been positive, highlighting an increase in deer presence. Similarly, another farmer reported that although the trees provided shelter for early vegetables, they also provided cover for rabbits and had observed increased rabbit damage as a consequence. Apple storage also presented a challenge to three out of the four farmers due to product perishability and limited on-farm storage facilities. Being predominantly arable farmers, most had little experience of managing trees before establishing their agroforestry system and so a lack of knowledge in terms of both technical design and operation of silvoarable systems was a major challenge during system establishment.

(iii) Future adoption of silvoarable agroforestry within the UK

In regards to adoption, all farmers stressed the importance of knowledge transfer between farmers already managing silvoarable systems and those interested in implementing them. Farmer-led adoption was evident with two of the case study systems having been inspired by an earlier adopter. A lack of supporting subsidies and conversion grants within the UK for agroforestry was recognised by all of the farmers as a major barrier to system adoption. Farm tenancy was raised by three of the farmers as an issue for agroforestry adoption due to the long lifespan of trees in comparison to tenancy agreements.

4. Discussion

Yields at Wakelyns in 2012 and 2013 were comparable with standard figures when scaled up from 2.5% land area under apple production to 100% apples, and even at just 2.5% cover, appeared to out-perform the organic orchard used for comparison. With so few apple trees, this would probably not be acceptable for large scale apple producers who rely on economies of scale. However, this approach could work well in a diverse, potentially small-scale system such as a market garden, where apples could contribute to direct marketing channels such as vegetable box schemes or farm shops. Having such a wide range of varieties within the system means that harvesting would occur over a longer period. This requires careful planning and may be a challenge for selling to wholesalers if only small amounts are ready at any one time. New approaches to marketing could address this problem, for example, creating mixed bags of varieties, categorizing by taste, e.g. 'sweet' apple bag, or 'sharp' apple bag; or by making more of a feature of the varieties if going into vegetable box schemes e.g. 'apple of the week'.

In the more commercial system at Whitehall Farm, tree rows account for 10% land area with 85 trees/ha; scaling up to 100% apples, yields compared well with standard yields. Considering that the apple trees at Whitehall were planted only in 2009 and so the system is still establishing and developing, the apple yields look promising, with some varieties performing much better than others.

Neither case study systems spray to control for scab or other diseases or pests, and scab was detected in both systems during the years of study. At Wakelyns, scab levels were several times lower than in the nearby organic orchard in both 2012 and 2013. Although no firm general conclusion can be drawn from this case study, it appears as if there may be indications of a potential positive impact on reducing scab levels within the agroforestry. This could be due to the very low densities and high diversity of apple tree varieties. Also, that while some varieties may fail to set fruit or have high levels of scab, the high diversity of apple varieties within the agroforestry means that other varieties will compensate and so buffer against extreme losses of yields. However, further research will be required to confirm this theory.

Scab was recorded in the apples at Whitehall Farm at quite high levels, particularly in 2014, and in one variety (Falstaff) in 2015, although the resistant variety Red Windsor maintained its resistance. However, the apple varieties studied seemed to perform poorly, while other varieties in the system yielded well and had fewer pests and diseases, which demonstrates the value of planting a wide range of varieties. The varieties were planted in blocks, which is likely to have facilitated the spread of pests and diseases, despite the crop alleys in between tree rows. It may therefore be better to mix varieties within the rows and fields, although this then becomes a challenge to manage and harvest efficiently.

In both case study systems, the impacts of secondary pests and diseases varied between the agroforestry systems and the orchards, This supports previous research on agroforestry systems that while some pests are reduced in agroforestry systems, other pest groups may be observed in higher numbers, and shifts in relative importance of pest groups may present novel management problems and influence crop choice (Griffiths et al., 1998).

This study provided useful insight into the potential benefits and management challenges associated with novel silvoarable apple systems. Although farmers reported a number of management issues and unforeseen challenges in the design, establishment and on-going operation of their systems, they also spoke of substantial benefits in terms of product diversification, increased biodiversity, reduced soil erosion, and the provision of shelter, with most believing that their systems had been successful in meeting their objectives, suggesting such benefits may well outweigh any management inconveniences. Nevertheless, a number of approaches to mitigating the management impacts of integrating apple and cereal production were identified. These included appropriate system design, de-synchronization of management activities, effective management of tree-crop competition and weeds, and the ability of farmers and contractors to adapt management practices.

Evidence of farmer-led adoption suggests farmers perceive silvoarable apple systems to be viable, implying scope for wider uptake within England. However the interviews also identified a number of substantial knowledge gaps. This calls for not only further documentation of existing systems but further trials on their establishment, operation and commercial performance. As recognized by all five of the farmers interviewed, in addition to continued research, favourable policy changes and conversion grants will be required for wider adoption of agroforestry-based apple production within the UK.

Potential synergies and tensions

Combining apple production with arable production aims to maximize synergies between the different components while minimizing negative interactions. Potential synergies within the two case-study systems, including those identified by the farmers, include increased biodiversity resulting in increases in natural enemies; high diversity of apple varieties reducing diseases and spreading risk from crop failure; and shelter from trees reducing wind impacts on arable and vegetable crops. However, trade-offs were also identified. For example, encouraging apple pollinators in an arable system using floral mixtures as at Whitehall Farm may also lead to increases in certain pests e.g. capsids. And while there may be benefits of increasing varietal diversity, reducing tree densities and encouraging mixed plantings of varieties in terms of reducing the spread of disease, this would have implications for efficient harvesting, management and marketing.

5. Conclusion

The two case study systems provided contrasting approaches to agroforestry-based apple production in terms of scale and design. The low density, high diversity approach at Wakelyns Agroforestry seemed to have benefits in terms of reducing disease levels, and could work well in a diverse, potentially small-scale system such as a market garden, where apples could contribute to direct marketing channels such as vegetable box schemes or farm shops. The commercial silvoarable system at Whitehall Farm showed that an agroforestry approach *per se* is not successful at reducing scab levels. However, if combined with careful selection of resistant varieties and, if possible, mixed planting of varieties, the other benefits that agroforestry brings, particularly to arable systems, may make this approach attractive to arable farmers looking to diversify their enterprises or protect their farms against environmental problems.

6. Acknowledgements

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