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Crop Production in Southern Britain: Precision Decisions for Profitable Cropping

Factors contributing to sustainable strawberry production

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Summary

In the UK strawberry production is very intensive, over the last 20 years yield has doubled and the harvest period greatly extended whilst the area used by the crop has been reduced. This rise in yield per hectare has been achieved by precision use of varieties, fertilizers, irrigation, polythene tunnels and pesticides. The challenge now is to improve long term sustainability of production whilst maintaining yield. The most important yield threatening disease of strawberry is powdery mildew caused by *Podospheara aphanis*. The work reported here assessed the use of silicon as a nutrient in contributing to delayed epidemic build-up and assessed the greenhouse gas emissions associated with the fungicides used to control the disease. The use of wild pollinators of the strawberry crop is also evaluated as a major contribution to sustainability when compared to the more normal practice of buying in pollinators.

Key words: sustainable, strawberry powdery mildew, silicon nutrient, pollinator, Greenhouse gas emissions

Introduction

UK strawberry crops are grown intensively, with a yield of 44,800 tonnes per annum worth £87 million (Dodgson *et al*., 2008). This intensification has been achieved over the last 20 years through the precision use of varieties, nutrients and polythene tunnels. Powdery mildew, *Podosphaera aphanis*, is a major fungal disease affecting strawberry production worldwide (Amsalem *et al*., 2006; Dodgson *et al*., 2008). The disease can result in yield losses of up to 70% of the crop (Dodgson *et al*., 2008). The fungus is characterized as a biotroph. Serious epidemics can reduce crop yields as a result of inadequate ripening of fruits, fruit deformation, poor flavour development and reduced storage time (Pertot *et al*., 2008). The pathogen infects strawberries in nearly all organs including leaves, flowers, fruits, petioles and peduncles, and is specific to strawberries (Amsalem *et al*., 2006; De Los Santos *et al*., 2003; Dodgson, 2007; Dodgson *et al*., 2008).

Silicon (Si) is the second most abundant element on the earth and its use for disease suppression offers an opportunity for more environmentally friendly disease control (Epstein, 1994). Silicon used in fertilizer can promote the growth of crops, improve the soil properties, reduce the toxicity of heavy metals in the soil and also increase plant resistance to pathogen infection (Lewin & Reimann, 1969). Barker & Pilbeam (2006) found that high concentration of silicon could inhibit the fungal spore germination and mycelium growth. Nowadays, silicon products have been used to control powdery mildew in cucumber, melon and rose (Dallagnol *et al*., 2012; Shetty *et al*., 2012).

Work at University of Hertfordshire has investigated the use of a silicon nutrient (Sirius) with and without potassium carbonate in a tank mixture to reduce disease severity (Fatema & Hall, 2012; Jin *et al*., 2013). It has been shown that this form of silicon can significantly reduce disease severity (Jin *et al*., 2013). The work reported here assessed the use of silicon as a nutrient in contributing to delayed epidemic buildup.

In the UK, insect pollinated crops accounted for 20% of UK cropland and 19% of total farmgate crop value in 2007 (Gallai *et al*., 2009). The economic value of pollination from managed and wild pollinators has been estimated at €153 billion globally (Gallai *et al*., 2009) and at £400 million per annum in the UK (POST, 2010). Bees (*Apidae)*, in particular European Honeybees (*Apis mellifera)* are the primary pollinators of most agricultural crops. Other wild bee species are also important pollinators and can be managed for crop pollination, including bumblebees (*Bombus spp*.), mason bees (*Osmia spp*.), alfalfa leafcutter bees (*Megachile rotundata)* and ground nesting solitary bees e.g. *Nomia melanderi* (Mayer *et al*., 2011; Richards & Kevan, 2002). In addition, hoverflies, also syrphidae, are regarded as the major flower visiting flies and they can be as important pollinator as bees in certain habitats or for certain crops (Willmer, 2011).

Although many plants including strawberries rely heavily on bee pollination, research demonstrated that bee species and other insects differ in their effectiveness and efficiency as pollinators of particular crops; some crops are better pollinated by species of native bee than by the honey bee (Mayer *et al*., 2011; Richards & Kevan, 2002; Winfree, 2010). Studies in the US found that native bee communities are frequent flower visitors in some agricultural contexts and could provide over 90% pollination services even for a crop with heavy pollination requirements e.g., watermelon, without the intervention of managed honey bees, even in areas of intensive human land use (Kremen *et al*., 2002; Winfree *et al*., 2007; Winfree, 2010). Other studies found that compared to honey bees, wild insects pollinated crops more effectively (Garibaldi *et al*., 2013; Mayer *et al*., 2011). Results suggested that visitation by wild insects promoted fruit set by twice as much as visitation by honey bees (Garibaldi *et al*., 2013). Another study showed that wild bees substantially increase the production of field-grown tomato (Greenleaf & Kremen, 2006*a*). In addition, native bees can also enhance honey bee effectiveness when present with honey bees (Greenleaf & Kremen, 2006*b*; Winfree, 2010).

Furthermore, research suggested that bee diversity is important in providing pollination services for a greater number of crops including strawberries (Kremen *et al*., 2002; Kremen & Williams, 2007; Winfree *et al*., 2007). A diverse community (46 species) of native bees could largely compensate for the loss of services provided by a domesticated pollinator (Kremen et al., 2007). Expanded use of other pollinating insects, such as bumblebees or red mason bees (*Osmia rufa)*, may provide growers with a more cost-effective means of ensuring optimal pollination services, particularly when other bee species are more effective pollinators of certain particular crops (Breeze *et al*., 2011).

Commercial strawberry cultivars *Fragaria × ananassa* Duch. are hermaphroditic and self-fertile. Most pollination is done by the combination of wind and gravity, with less than 60% of the pollination rate of achenes (Abrol & Gorka, 2009). Moreover, one of the major challenges for strawberry growers is the pollination of early crops in May when the fleece is removed.

Materials and Methods

Silicon fertigation trial

The field trial was set up in two commercial strawberry polythene tunnels in 'Blackberry Field' at Maltmas Farm, Wisbech in May, 2014. The silicon nutrient used was Sirius, applied twice a week in the fertigation tubes. In each tunnel has five beds of cultivar J*****. There are four treatments in total:

a) silicon (Sirius) only (at a concentration of 0.017% twice a week),
b) silicon plus commercial fungicides,
c) commercial fungicides only,
d) no silicon and no fungicides.

In Tunnel 2, all five beds receive silicon through the irrigation (fertigation) system twice every week. The first 10 m of each bed receives no fungicide spray (silicon only) and the remaining beds receive sprays in accordance with commercial practice (silicon plus fungicides). In the other tunnel (Tunnel 6) no silicon is applied. The first 10m of each bed receives no fungicides spray (no silicon no fungicides) and the remaining beds receive sprays in accordance with commercial practice (fungicides only). Samples for disease assessment were taken bi-weekly from 20 May 2014. On each sample date, in each tunnel, 15 leaves were taken from each 10 m stretch of the five beds from each treatment. Replications were provided by five beds in the tunnel. The pre-assessment was done on 08 April 2014 after which the crop was covered with fleece and mulch. All samples were placed in the sample bags and brought back to the laboratory. Samples were then be stored in a cold room (+ 4°C) and be assessed immediately.

The assessment for all four treatments was each based on 15 leaves per bed (five replicates of 15 leaves) every two weeks. Each leaflet of sampled leaves was placed under a dissecting microscope at ×10 and ×30 magnification to assess disease level, number and size of colonies. The disease level was expressed as % cover of colonies (amount of mycelium) per leaflet. The number of colonies was counted on each leaflet per leaf. Each leaf was photographed and the approximate size of each leaflet was measured by using software ImageJ.

Greenhouse gas emissions of fungicides used on the farm

The greenhouse gas (GHG) emissions can be expressed in total kg CO_2 equivalent (eq) hectare^{-1} (kg CO_2 eq ha^{-1}) or per tonne of output (kg CO_2 eq t^{-1}). The GHG emissions associated with fungicides application were calculated as (British Standards Institute, 2008): GHG emissions (kg CO_2 ha^{-1}) = fungicide application rate (kg a.i. ha^{-1}) × emission factor (kg CO_2)(kg a.i.)$^{-1}$.

Where kg a. i. is the active ingredient application rate, (kg CO_2)(kg a.i.)$^{-1}$ is kilograms of CO_2 equivalent per kilogram of active ingredient, the emission factor for fungicides is 3.303 kg CO_2 eq. kg^{-1} a.i. (DEFRA, 2007).

To calculate the GHGs associated with fungicide treated crops, the weight of active ingredient for the fungicide treatments was used together with the measured yields. Table 1 below provides information on fungicides used on strawberry crops in Blackberry field at Maltmas farm from 27th March to 4th July 2014. Fungicides were applied by using tank mix. The overall size of Maltmas field is 1.2 ha^{-1}.

In Table 1, % w/w (percentage weight/weight) is the number of grams of active agent in 100 grams of solution. This can then be converted to the active ingredient application rate by using the following formula: kg a. i. = % w/w *1000 * apply rate used by the farm.

Pollinator survey

The pollinator survey was carried out bi-weekly for a two-day period starting from April 29, 2014. Date, survey site and the strawberry variety grown on the site of each survey were provided in Table 2.

Each individual survey was timed for 30 minutes, the surveyor walked along the strawberry bed throughout the tunnel at a steady pace. Each tunnel (open or closed according to the weather) or open field without tunnels was divided into four sections: 0–45 m, 45–90 m, 90–135 m and 135–180 m. The group of pollinators, the number of pollinators and the location within the tunnel where the pollinators were present was recorded. Percentage of the flowering strawberry plants and numbers of flowers on randomly selected three plants from each section were counted. The weather data, tunnel status and hours/time of the day covered by survey was also recorded for each survey.

Table 1. *Summary of fungicide products applied in Blackberry field during the trial period*

Spray dates	Product common name	Proportion of active ingredient	Mode of Action	Apply rate
27/03/2014	Rovral WG	750 g kg^{-1} *iprodione*	2 (Inhibits RNA or DNA synthesis)	0.75 ha^{-1}
	Thianosan DG	80% *thiram*	M (Multi-sites activity, protective or preventive, inhibit fungi on the plant surface)	2.5 kg ha^{-1}
22/04/2014	Signum	26.7% w/w *boscalid* and 6.7% w/w *pyraclostrobin*	7+11 (Disrupts beta-tubulin assembly + disrupts cell wall synthesis)	1.00 kg ha^{-1}
01/05/2014	Signum	26.7% w/w *boscalid* and 6.7% w/w *pyraclostrobin*	7+11 (Disrupts beta-tubulin assembly + disrupts cell wall synthesis)	0.75 kg ha^{-1}
09/05/2014	Teldor	51% w/w *fenhexamid*	17 (Protein synthesis attachment of tRNA to ribosomal receptor)	1.00 kg ha^{-1}
	Nimrod	250 g L^{-1} (27.2% w/w) bupirimate and n-butanol, hydrocarbons	8 (nucleic acids synthesis)	1.00 L ha^{-1}
29/05/2014	Amistar	25% w/w *azoxystrobin*	11 (Disrupts cell wall synthesis)	0.75 L ha^{-1}
09/06/2014	Teldor	51% w/w *fenhexamid*	17 (Protein synthesis attachment of tRNA to ribosomal receptor)	1.00 kg ha^{-1}
18/06/2014	Teldor	51% w/w *fenhexamid*	17 (Protein synthesis attachment of tRNA to ribosomal receptor)	1.00 kg ha^{-1}
04/07/2014	Teldor	51% w/w *fenhexamid*	17 (Protein synthesis attachment of tRNA to ribosomal receptor)	1.00 kg ha^{-1}
	Nimrod	250 g L^{-1} (27.2% w/w) bupirimate and n-butanol, hydrocarbons	8 (nucleic acids synthesis)	1.00 L ha^{-1}

Table 2. *Pollinator survey details*

Survey date	Survey site	Strawberry variety
29–30 April 2014	Ladybird field tunnels	Sonata & Vibrance
	Blackberry field tunnels	J*****
13–14 May 2014	Ladybird field tunnels	Sonata & Vibrance
	Blackberry field tunnels	J*****
27–28 May 2014	Ladybird field tunnels	Sonata & Vibrance
	Blackberry field tunnels	J*****
10–11 June 2014	Blackberry field tunnels	J*****
	Pheasant field tunnels	Amesti
	Amelia 2 open field	Sonata

Table 2 cont'd		
Survey date	Survey site	Strawberry variety
24–25 June 2014	Blackberry field tunnels	J*****
	Pheasant field tunnels	Amesti
	Amelia 2 open field	Sonata
08 July 2014	Blackberry field tunnels	J*****
	Pheasant field tunnels	Amesti
	Amelia 2 open field	Sonata
22–23 July 2014	Blackberry field tunnels	J*****
	Pheasant field tunnels	Amesti
	Amelia 2 open field	Sonata
05–06 August 2014	Blackberry field tunnels	J*****
	Pheasant field tunnels	Amesti
	Amelia 2 open field	Sonata
19–20 August 2014	Blackberry field tunnels	J*****
	Pheasant field tunnels	Amesti

Table 3. *Results of the silicon trial from four treatments in tunnels 2 and 6 showing average disease level per leaflet, average number of colonies per leaf area between April and July, 2014*

Assessment date	Average disease level per leaflet (%)	Average number of colonies per leaf	Average disease level per leaflet (%)	Average number of colonies per leaf	Average disease level per leaflet (%)	Average number of colonies per leaf	Average disease level per leaflet (%)	Average number of colonies per leaf
	No silicon no fungicide		Fungicide only		Silicon only		Silicon + Fungicide	
08/04/14 (Pre-assessment)	0.02	0.12	0.03	0.10	0.02	0.05	0.03	0.07
20/05/14	0.04	0.16	0.03	0.12	0.06	0.13	0.04	0.11
03/06/14	0.22	0.56	0.06	0.13	0.07	0.21	0.05	0.19
17/06/14	0.91	2.24	0.08	0.31	0.08	0.33	0.07	0.2
01/07/14	3.16	6.24	1.10	2.97	1.66	5.40	0.61	1.69
15/07/14	10.3	26.48	1.8	5.39	6.24	24.68	0.82	2.83
29/07/14	12.42	45.29	2.06	6.71	10.69	41.71	1.08	4.27

From the table below (Table 4), it can be seen that GHG emissions of fungicides account for over 75% of overall GHG emissions of all pesticides applied during the trial period. Herbicides and insecticides only represent less than a quarter of total GHG emissions. As for the individual pesticides, fungicide thiram (Trianosan DG) and herbicide diquat dibromide (Diquat) produced higher level of GHG emissions.

Table 4. *GHG emissions of pesticides used at Maltmas Farm during the trial period*

Spray dates	Pesticide type	Product common name	GHG emissions of pesticide application from 1.2 ha^{-1} strawberry field (kg CO_2e)
27/03/2014	Fungicide	Rovral WG	2.230
		Thianosan DG	7.927
22/04/2014		Signum	1.324
01/05/2014		Signum	0.993
09/05/2014		Teldor	2.021
		Nimrod	0.991
29/05/2014		Amistar	0.743
09/06/2014		Teldor	2.021
18/06/2014		Teldor	2.021
04/07/2014		Teldor	2.021
		Nimrod	0.991
04/03/14	Herbicide	Diquat	4.435
04/03/14		Shark	0.059
27/03/14	Insecticide	Equity	0.951
27/06/14 and 08/07/14		Ralis L	0.709
GHG emissions of all pesticides			30.149
GHG emissions of all fungicides			23.284

Pollinator survey

Results suggested that hoverfly and bumblebee are the major pollinator groups of strawberries at Maltmas Farm (Table 5). Hoverflies were found to be present during almost every individual walk throughout the survey, but they didn't appear to be abundant until June. The number of hoverflies surveyed reached at a peak in July, possibly due to the warm weather in this month. Also, compared to the open field, the number of hoverflies was found to be extremely abundant in the tunnel.

Bumblebee is another major pollinator group of strawberries. They appeared early in the season and were present throughout the season. They were found to be present both in the tunnel and open field and their number of individuals at each survey did not show too much difference between dates and sites of the survey.

Mining bees were also important strawberry visitors. They were found to be present on all survey dates with a relatively stable level of presence. Up till July, this survey did not find honeybees as frequent strawberry visitors at Malmas farm. In general, there were few honeybees found in the tunnels between April and July, whilst they were more active in the open field especially under the favourable weather condition.

Table 6 below suggested that in general, pollinators were found to be most abundant between 10 am to 4 pm from April to July. Hoverflies were found to be present throughout the day from the morning as early as 7 am till the end of survey time at 8 pm. The most active period for hoverflies are between 10 am to 12 pm, but they were also found to be relatively active in the morning compare to other groups. The most active time for bumblebees is between 10am to 1 pm. Their

Table 5. *Average number of individuals from each pollinator group counted during a 30 mins survey walk in each survey field*

Survey date	Pollinator group / Field name	Bumblebees	Honeybees	Mining bees	Hoverflies	Butterflies & Moths
29–30 April	Ladybird Field tunnel	5.00	0	1.83	0.67	0.33
	Blackberry Field tunnel	0	0	0	0	0
13–14 May	Ladybird Field tunnel	4.00	1.33	2.56	0.67	0
	Blackberry Field tunnel	3.33	0.10	0.70	0.10	0.20
27–28 May	Ladybird Field tunnel	0	0	0	1.00	0
	Blackberry Field tunnel	0	0	0.17	2.50	0
10–11 June	Blackberry Field tunnel	6.00	0	1.00	8.57	0.14
	Pheasant Field tunnel	3.50	0.25	1.13	13.25	0.25
	Amelia open field	13.00	0.67	5.83	2.50	0
24–25 June	Blackberry Field tunnel	4.40	0.60	0.40	13.60	0
	Pheasant Field tunnel	3.00	0.17	1.50	51.83	0.50
	Amelia open field	6.17	13.13	1.13	9.00	2.13
08 July	Blackberry Field tunnel	6.50	1.25	1.25	51.25	3.00
	Pheasant Field tunnel	7.00	1.80	0.60	201.60	2.00
	Amelia open field	1.33	0.75	0.75	13.75	0
05–06 August	Blackberry Field tunnel	0	2.33	0.17	13	1.83
	Pheasant Field tunnel	0.17	0.5	0.5	16.33	3.67
	Amelia open field	0.5	0.5	0.5	11.75	0.25
19–20 August	Blackberry Field tunnel	1	1	0.3	7.17	3.5
	Pheasant Field tunnel	0.17	0.5	0	4.5	3.17
Average number of pollinators counted during a 30 mins walk per field		2.92	1.26	0.97	19.42	1.28

level of activity decrease before 10 am and after 5 pm. The number of honeybees reached at a peak between 2 pm and 3 pm. They exhibited minimum activity in the early morning and after 5pm. As to the mining bees, their level of activity remained steady throughout the day with a slight peak between 12 pm and 2 pm.

Table 6. *Average number of pollinators from each group counted during a 30 mins walk in relation to the time*

	Average number of pollinators from each group counted during a 30mins walk				
Survey time	Bumblebees	Honeybees	Mining bees	Hoverflies	Butterflies & Moths
7:00–8:00	0	0	0	2.00	0
8:00–9:00	0.82	0.29	0.71	39.00	1.18
9:00–10:00	3.87	1.77	0.70	35.50	5.40
10:00–11:00	6.70	1.97	2.47	125.23	2.50
11:00–12:00	9.73	1.40	3.73	77.00	2.00
12:00–13:00	8.00	3.33	4.00	19.67	4.50
13:00–14:00	5.80	2.80	3.53	33.13	3.30
14:00–15:00	6.54	10.79	2.33	31.13	5.54
15:00–16:00	7.50	4.72	2.73	17.55	3.09
16:00–17:00	8.23	0.74	2.46	15.58	0.90
17:00–18:00	3.33	0.20	0.20	13.27	1.10
18:00–19:00	4.17	0.33	0.50	8.70	0
19:00–20:00	2.17	0.67	0	11.33	0.30

Table 7 presents the relations between the abundance of pollinators from each group and sections they appeared inside the tunnel. In average, hoverflies showed the highest number of presence throughout the tunnel. There were more number of hoverflies found between 45–90 m and the south end of the tunnel (135–180 m) where it faces open grounds and a line of raspberry tunnels. Bumblebees showed higher presence in the middle section of the tunnel, while honeybees maintained a relatively low but stable level of presences throughout the tunnel. Solitary bees were found to be more abundance near the south entrance of the tunnel (135–180 m) possible due to more sufficient sunshine at that end which provides good heat source for bees.

Table 7. *Pollinator presence in relation to tunnel sections Entrances of tunnels are north facing*

Pollinator group / Tunnel section		Honeybees	Bumblebees	Solitary bees	Hoverflies	Butterflies & Moths
0–45m	Average number of pollinators counted per 30 minute from each section of tunnel	0.19	0.28	0.07	3.23	0.21
45–90m		0.24	0.60	0.21	6.83	0.39
90–135m		0.14	0.67	0.09	5.21	0.34
135–180m		0.14	0.42	0.27	6.61	0.52

Discussion

The results of the silicon trial indicated that silicon nutrient in the fertigation can give good disease control if used with commercial fungicides. Fungicides treatment with weekly application of silicon held the epidemic build-up at a very low level throughout the trial. Even the treatment with silicon alone has helped to reduce disease severity than the control treatment. Also, it has been noticed that the epidemic build-up in silicon treatments started one week later than treatment without silicon input. The silicon appears to enhance the plant defence mechanism thus delay the epidemic build-up (Jin *et al*., 2013). Many studies have showed that silicon benefits plant growth by reducing biotic stresses such as disease, pest, and abiotic stresses such as chemical stress (metal toxicity, nutrient deficiency) and physical stress (radiation, UV, drought) (Ma, 2004; Ma & Yamaji, 2008). Previous studies also showed that high rate silicon nutrient alone as well as with K50 (potassium carbonate) successfully held the epidemic build-up of *P. aphanis* (Jin *et al*., 2013). Therefore the use of silicon nutrient could potentially reduce the use of fungicides thus contribute to the sustainable production of strawberries.

GHG emissions of fungicides account for over 75% of overall GHG emissions of all pesticides applied during the trial period, suggesting reduce the use of fungicides could play a big part in reducing the overall GHG emissions. Since disease control is the priority to farmers compared to GHG reduction, farmers will not be willing to take the risk of changing to those fungicides that produce less GHG emissions but may also be less effective in controlling epidemics. Therefore using silicon in the fertigation system could be an option. A further evaluation of the use of silicon in reducing carbon footprint of the fungicide sprays could be undertaken in the future study.

Compare to honeybees, wild pollinators are the major pollinator for commercial strawberries at Maltmas Farm. In particular, hoverflies and bumblebees are found to be the most active. Pollination by insects has been shown can improve seed quality resulting in heavier seeds, higher oil and reduced chlorophyll contents (Bommarco *et al*., 2012). The presence of pollinators reduces both the length of flowering and the number of flowers produced by the plants, resulting in the shorter duration of blooming period (Sabbahi *et al*., 2006). In relation to the forage time during the day between different groups, hoverflies were found to be present from as early as 7am till 8pm with the most active period between 10am and 12pm. Bumblebees also came out earlier and stayed active for the most of the day. Their activity decreased before 10am and after 5pm while honeybees emerged later during the day and reached at a peak between 2pm and 3pm. Similar results have also been found by Li *et al*. (2006) and Chen *et al*. (2011), which showed that *Bombus terrestris* had the higher working frequency than honeybee. Furthermore, they also found that strawberries visited by *Bomba*. species had lower malformation rate than those visited by *A. mellifera*. There are slight differences of the site preference between pollinator groups. Since Maltmas farm only relies on wild pollinators to provide pollination to their crops, it is important to improve farmland management to provide a favourable habitat to wild pollinators. Highly managed landscape is likely be dominated by flowering perennial plants and to receive frequent fungicides and herbicides applications, results in poor diversity of plant communities that favour wild pollinators (Hendrickx *et al*., 2007). Conservation of diverse agricultural landscape is of primary importance for the conservation of wild pollinators.

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