Shropshire Growers Discussion Group

Establishing Potato Cyst Nematode Trap Crops

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Summary and Key Points

Questions:

1. Can *S. sisymbriifolium* and *S. scabrum* be grown effectively when sown 'late' in June or 'very-late' in July?
2. Do *S. sisymbriifolium* or *S. scabrum* need to be sown deeper than the recommended depth?
3. Does *S. scabrum* show growth potential in Shropshire & Ormskirk?

Answers:

1. Planting at Ormskirk at the late or very late timings did not appear to be viable especially with the rainfall patterns experienced.
   Planting in North Shropshire at the 'late' (end of June) timing, shows some potential on the sandy loam soils but weed control and soil moisture can be particularly important especially on the clay loam soils.
   Planting at the Very late timing in North Shropshire did not produce a suitable crop and is therefore not viable.
2. Planting deeper than the recommended planting depth shows no benefit at the 'late' timing but some benefit for the 'very late' timing'.
3. *Solanum scabrum* shows good growth potential in North Shropshire but could not be established at Ormskirk.

The potato cyst nematodes, *Globodera pallida* and *G. rostochiensis* are serious pests of potatoes causing up to 80% yield losses. Currently with very few commercially acceptable resistant cultivars and the need for rotation lengths greater than 7 years to control the pest, the most common means of their control is with the use of nematicides. Organic growers cannot use these agrochemicals and with many being phased out under EU/UK law non-organic growers too will struggle to make commercial potato production viable without a suitable means of PCN control. For a significant number of years there has been the potential of using specialist crops which can control PCN, trap crops, but optimum planting dates for the commercially available *S. Sisymbriifolium* are in May/June when traditional crops are still growing. The purpose of the field trials described here therefore were to investigate the effect of sowing these crops outside of the recommended timing of mid-May, with no irrigation, and thus sowing **'late'** and **'very late'**. In addition, the trials investigated if sowing deeper, 1.5cm and 3cm, rather than the recommended, 0.5-1cm, could improve establishment and subsequent growth of *Solanum sisymbriifolium* where no irrigation was used, and also how an alternative 'potential' species, *S. Scabrum,* would perform under these conditions relative to *S. Sisymbriifolium*. The two sowing dates/times selected were based on the earliest times available to co-operating growers without loss of other cropping i.e., after forage rye at the end of June, in non-planted potato land, or cauliflower and carrot crops, plus the second date at the end of July when no crops would ordinarily be present. <u>Please note: The dates that the trap crops were sown at are classed as 'late' and 'very late' compared to the recommended dates/times given by the seed</u>

suppliers Produce Solutions and the results from these trials cannot be seen as sowing recommendations.

Background:

1. Two sites in North Shropshire were planted with both Solanum species at the end of June and a site in Ormskirk was similarly planted in Early July.
2. Three sites in North Shropshire and one in Ormskirk were planted with both Solanum species at the end of July.
3. Crops were planted using commercial equipment.

Key findings:

1. The two species planted in late-June in North Shropshire, were slow to emerge and establish however:
    a. The 'late' end of June *S. sisymbriifolium* crop at Caynton grew steadily throughout the growing season and was still growing with little senescence in early December. However, even at the 'late' end of June planting date *S. sisymbriifolium* did not reach the biomass reported to be necessary for effective PCN control. Planting at this 'late' date may be possible but requires further investigation and changes to crop density, nutrition and agronomy to encourage better growth to be effective against PCN.
    b. The *S. scabrum* planted 'late' at the end of June at Caynton lacked uniformity but produced good ground cover where established. It grew steadily until early-November when cold weather caused significant frost kill. Similarly, planting of this species at this 'late' date may be possible but still requires further investigation and changes to crop nutrition/agronomy to encourage better growth.
    c. Growth of both species at the Lilyhurst site started quite well but subsequent wet weather caused severe waterlogging on the clay loam soil, which then retarded both crop species significantly. Weeds quickly became a problem at this site.
2. The crops planted in Ormskirk, 'late' in early-July and 'very late' in early August, failed to emerge until a significant time after planting and then only sporadically. The high rainfall shortly after planting on both occasions were the most likely cause of poor emergence and establishment.
3. The emergence of the 'very late' planted crops at Caynton, Tibberton and Lilyhurst were slow to emerge and very patchy, which confirms that 'very late' sowing is not suitable for these crops in North Shropshire.
4. Planting at 1.5cm was better than at 3cm for the 'late' planted crops but not the 'very late' planted crop at Caynton where 3cm gave better growth.
5. *Solanum scabrum* can be grown similarly to *S. sisymbriifolium*, it grows at a similar rate and appears to have a more extensive root system but it is not as cold tolerant a *S sisymbriifolium,* which may actually be a benefit.
6. It is concluded that:
    a. Planting of these trap crops should continue to follow current supplier recommendations for depth and timing.

b. It appears that planting in late June in North Shropshire may have potential but changes to agronomy still need further investigation.
c. There is no benefit to planting deeper than current recommendations.
d. There is no evidence that planting in early July in Ormskirk is acceptable for these crops, but further trials would be helpful.
e. Neither crop species grows well in soil which retains excessive moisture or where significant rainfall follows planting.

Further work areas suggested:

- Planting in early and late June for both *S. sisymbriifolium* and *S. scabrum* to compare growth and PCN population management.
- Crop agronomy: Inter row cultivation for weed control and possible herbicide use.
- Crop nutrition.
- Precision drilling of pure seed and potential of 'primed' seed to aid reduce seed rates but produce better emergence may be beneficial.

Shropshire growers discussion group, Innovative farmers meeting 27th Aug 2020. Plot 1 Solanum sisymbriifolium

Contents

Introduction

The UK potato industry produced an average of 5.45Mt potatoes during 2010-2019, for use in the ware, processing and seed sectors, figure 1 (AHDB, 2020), accounting for 68% of UK demand and valued at 771m in 2019 (Defra, 2020). In order to sustain these levels of production producers have to maintain a high level of crop management including reliable crop protection from pests and disease.

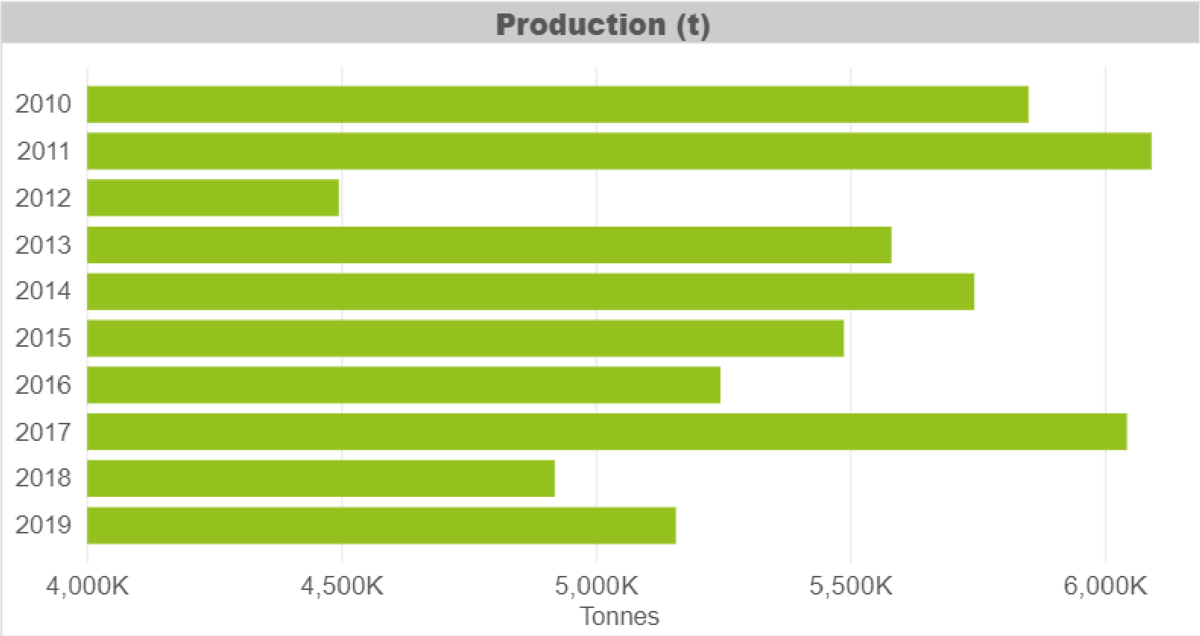

Figure 1. UK potato production (t), 2010 to 2019. (AHDB, 2020)

The potato cyst nematodes (PCN) (*Globodera pallida* and *G. rostochiensis*) are significant pests of potatoes across the world and of high economic importance within the UK potato industry, causing substantial yield reductions. The most recent UK surveys to determine the extent of their presence was Dybal *et al.* (2019) and Minnis *et al.* (2002). Minnis *et* al. (2002) reported that 64% of samples taken contained PCN, with 67% of those containing *G. pallida*, 8% *G. rostochiensis* and 25% containing both species. The survey by Dybal (2019) reported that 48% of samples taken contained PCN, with 89% containing *G. pallida*, 5% *G. rostochiensis* and only 6% containing both species. The latest survey therefore shows a substantial shift in population to *G. pallida* which, of the two PCN species, is the more difficult to control primarily because there is a significant lack of commercial potato cultivars with full resistance to this species. Currently, of the varieties listed in the AHDB variety database which score >=5 for *G. pallida* resistance (AHDB, 2020a), only Innovator is a top ten variety and 4 are listed in the top 50, based on planted area. Consequently, for both organic and non-organic producers the only other cultural control options for PCN management are limited to long crop rotations, seven years minimum between potato crops and/or the use of biofumigation crops which have efficacy of between 49-65% (Back *et al*., 2019). For many years however, there has been the potential to use a commercially available PCN trap crop *Solanum sisymbriifolium*, also known as sticky nightshade and currently only sold as 'Decyst ™' from 'Produce Solutions'. A PCN trap-crop' is a crop, normally a

Solanaceae, which can stimulate hatch of PCN, attract them into the roots and, as the crop is fully resistant to both species, prevent multiplication, thus effectively reducing the PCN soil population. The potential for the crop to reduce PCN populations has been shown to exceed 75% by Scholte (2000); Scholte and Vos (2000); Timmermans (2005); Timmermans *et al.* (2006); Timmermans *et al* (2007); Timmermans, Vos and Stomph (2009) and between 50-99% in glasshouse experiments (Dandurand and Knudsen, 2016; Dandurand *et al.*, 2019). Similarly, there is also growing evidence of its potential for use as a trap crop for reducing populations of *Meloidgyne* spp. (Dias *et al*, 2012), of which we are becoming more aware of in the UK. Although the crop has been grown commercially in the UK for approximately 20 years there has been both anecdotal farmer and scientific evidence (Timmermans, 2005) of poor establishment and growth. Ongoing PCN work at Harper Adams University also identified that planting depth and crop nutrition were factors influencing crop establishment (Grove, Unpublished). Unfortunately, the best crop establishment is seen from planting in late-May or early June, which can only be achieved in few commercial arable rotations. Consequently, growers have been reluctant to invest the time and money to use this crop to help control PCN as it entails loss of a commercial 'cash' crop.

Alternatives to *S. sisymbriifolium* to act as a trap crop for PCN in the UK has seen little research but there has been some work carried out. Ellis *et al.* (2016) investigated the alternative *Solanaceae* plants of black nightshade (*Solanum nigrum*), sticky nightshade (*Solanum sisymbriifolium*), thorn-apple (*Datura stramonium*), woody nightshade (*Solanum dulcamara*) and garden huckleberry (*Solanum melanocerasum*), grown in 5 litre pots. They concluded that garden huckleberry and black nightshade were the most effective at controlling PCN, although the establishment of black nightshade was unreliable. Similarly, trap crop candidates have emerged through research conducted for the AHDB and a PhD project in Kenya. Species such as *S. scabrum*, *S. villosum* and *S. melanocerasum* appear to have strong potential for trap cropping in GB potatoes, with *S. scabrum* demonstrated the ability to suppress PCN populations by >80% (Chitambo *et al*., 2018). *S. scabrum* is considered multipurpose as its produces broad leaves that are edible, nutritious and regarded as a delicacy in Kenya (Abukutsa-Onyango and Karimi, 2007**;** Kirigia *et al*, 2019). The fruits are not edible however, due to alkaloid content, but are used as natural source of ink or dye (Kamga et al., 2013) As a member of the *Solanum* genus and closely related to *S. nigrum*, *S. scabrum* should grow well under UK conditions.

Based on these observations and research reports a group of growers known as the 'Shropshire Growers Discussion Group' wished to investigate several aspects of the establishment of *S. sisymbriifolium* and the potential of *S. scabrum* as an alternative PCN trap crop.

For these 2020 trials the emphasis was not on PCN control as the cost of sample analysis would be prohibitive within the funding available and therefore detrimental to organizing sufficient trials from which to make 'establishment' decisions. The PCN counts were therefore kept to a minimum and the trials focused on 'late' and 'very late' planting, sowing depth, crop establishment and crop growth.

Materials and methods

Trial sites and trial design:
North Shropshire: Caynton (sandy loam), Tibberton (Loamy sand) and Lilyhurst (Clay loam)
Lancashire: Ormskirk (Sandy loam)
Standard Randomised Complete Block (RCB) with three replicates of all treatments. All trials used the same trial design.

Equipment:
Caynton, Tibberton and Lilyhurst: Lemken solitaire with 125mm spacing (Figure 2)
Ormskirk: Vaderstaad rapid with 125mm spacings (Figure 3).

Figure 2. Planting equipment at Caynton, Lilyhurst and Tibberton. Lemken Solitaire 9.

Figure 3. Planting with a Vaderstad rapid at Ormskirk, 8th July 2020

Plot size:
4m wide x 8m long. 4m wide turning areas between blocks which were over-drilled with either *S. sisymbriifolium* or *S. scabrum*, figures 4 and 5. Surrounds were left unplanted except for the site at Caynton where the whole field was planted with a commercial crop of *S. sisymbriifolium* using the same seed batch.

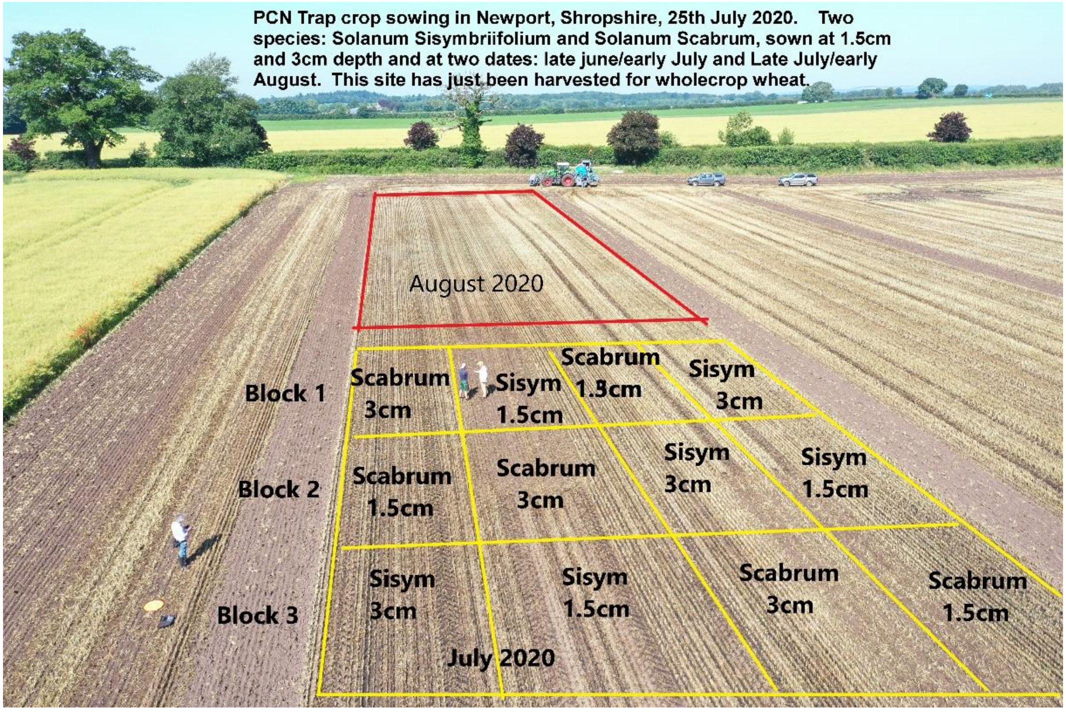

Figure 4. Trial layout at Caynton which was replicated at other sites.

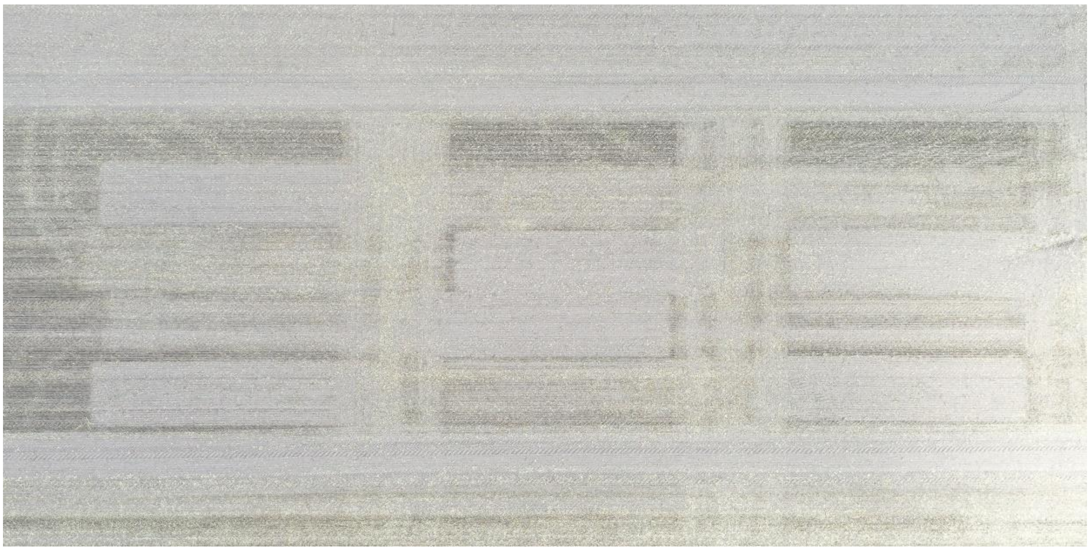

Figure 5. Aerial image of Caynton site, after planting on 25th June 2020, showing 4m turning area between plots.

Planting dates and previous crops

Planting was achieved as early as possible when previous crops had been removed, table 1.

Table 1. Planting dates and previous crops for the four trial sites involved in the Innovative Farmers trap crop trials 2020.

Site	Planting date 1	Planting date 2	Previous crop	County
Caynton	25th June 2020	28th July 2020	Forage rye	N. Shropshire
Lilyhurst	28th June 2020	28th July 2020	Unplanted area within potatoes	N. Shropshire
Ormskirk	8th July 2020	7th August 2020	Cauliflowers	Lancashire
Tibberton	N/A	28th July 2020	Carrots	N. Shropshire

Agronomy and Management

Seed

Certified seed was supplied by Produce solutions, Market Drayton, Shropshire, UK:
Solanum sisymbriifolium (mixed with lentils) as DeCyst™ applied at a rate of 20 kg/ha
Solanum scabrum (mixed with lentils) applied at 20 kg/ha.

Cultivations

Caynton: Lemken solitaire with power harrow/drill combination into stubble
Lilyhurst: Lemken solitaire with power harrow/drill combination into unplanted soil as prepared for potato planting in April
Tibberton: Lemken solitaire with power harrow/drill combination into cultivated land after carrots
Ormskirk: Vaderstad rapid into cultivated soil post cauliflowers.

Crop nutrition

All sites and trials, except Caynton, received 50 kg/N ha as Ammonium nitrate (Extran) within 2 weeks of planting. Caynton received digestate two days before planting.

Weed management

The trials were sponsored by Innovative farmers, part of the Soil Association and so herbicides were not included. However, there are no herbicides specifically recommended for either *S. sisymbriifolium* or *S. scabrum* in the UK/EU.

Irrigation

There were no applications of irrigation to any of the trials

PCN populations

The effect of the trap crops on underlying PCN populations were not a significant part of these trials as the focus was to determine if the crops could be grown outside of their normal recommended planting times. However, six soil samples were taken from the Caynton date 1 site to quantify any existing PCN presence and any changes within that population. The samples were analysed by the Nematology Group at Harper Adams University, Shropshire.

Emergence and ground cover assessments

The emergence counts were done by counting emerged plants at either side of a metre cane in the centre of the plot and at 2m and 5m from the start of the plot. These counts were then converted to counts per m^{-2} for analysis.

Ground cover was measured in the centre line of the plot, at 2m and 5m from the start of the plot, to prevent bias of area selection. The ground cover was captured using the phone app 'Canopy Cover' which uses Red Green Blue light to determine the green leaf area of the canopy. The data collected is logged along with the co-ordinates of the observation. At 114DAP the pre-determined spot ground cover estimates were deemed less useful as it was obvious that the establishment and growth of each species of crop was substantially different. At this point aerial imagery was utilised to capture whole plot images taken at 15m AGL using a DJI Mavic 2 Pro with a 20MP Hasselblad camera. Images were cropped to each individual plot and non-crop green material (weeds) were converted to black/brown before being analysed using the 'Easy leaf area' and 'Canopy cover' software from the University of California. The pixels within each image are individually analysed for RGB and then a composite image is produced which segregates the 'green area' and converts it to Ground cover percentage.

Observations

Plants were quite slow to emerge at all sites. Weeds are one of the biggest problems once they start to come through as the trap crops provided no shading during their early growth. Weed management probably needs to be considered along the lines of sugar beet management.

Statistics

All of the main data collected which included data for all plots within a trial, i.e., emergence and ground cover, were analysed as RCB factorial 2 x 2 design. The results are presented as non-significant (N/S) when probability values were $P>0.05$. Where results were significant the actual P values are given to show the level of significance. Analysis was done with a combination of R version 4.0.3. (R foundation, 2020) and modified Excel worksheets.

Results

PCN populations (Caynton date 1 trial)

The underlying PCN population at Caynton was shown to vary from 5 to 13.5 eggs/g soil, table 2. There is no statistical analysis as they were not part of the randomised design of the experiment. The final counts Pf will be done early in 2021 so that the full effect of the growing crop will be known.

Table 2. PCN population counts at Caynton Date 1 trial.

	Pi (eggs/g)	Pf (eggs/g)
Wade 1	4.25	Post Winter
Wade 2	9	Post Winter
Wade 3	8	Post Winter
Wade 4	5	Post Winter
Wade 5	4.25	Post Winter
Wade 6	13.5	Post Winter

Emergence

Caynton date 1 (Sown 25th June 2020)

Plant emergence was patchy but had achieved approximately 50% emergence 22DAP based on final plant emergence m^{-2} at 36DAP. Even though the plant counts were quite low, table 3, there was statistically greater (*P = 0.01*) number of *Solanum sisymbriifolium* compared to *S. scabrum*. There were no effects of the planting depths and no interactions between species and depth.

Table 3. Plant emergence (m^{-2}) at Caynton 36DAP.

36DAP	*Species*			
	Sisym	Scabrum	Mean depth	
1.5cm	12.5	5.5	**9**	**N/S**
3cm	11	3.97	**7.48**	
Mean species	**11.75**	**4.73**		**0.01**
			Interaction	**N/S**

No further emergence counts were done at Caynton as the emerged plants were becoming quite large and therefore the assessment was switched to ground cover percentage to better capture growth progression.

Lilyhurst date 1 (Sown 28th June 2020)

No emergence had occurred by July 21st, 22DAP, figure 6.

At 35DAP there were no statistical differences (*P>0.05*) of plant emergence between species or planting depths and no interactions, table 4, but the counts were very variable between plots. It was obvious from the soil that block 1 had been substantially wetter post planting than blocks 2 and 3, figure 7.

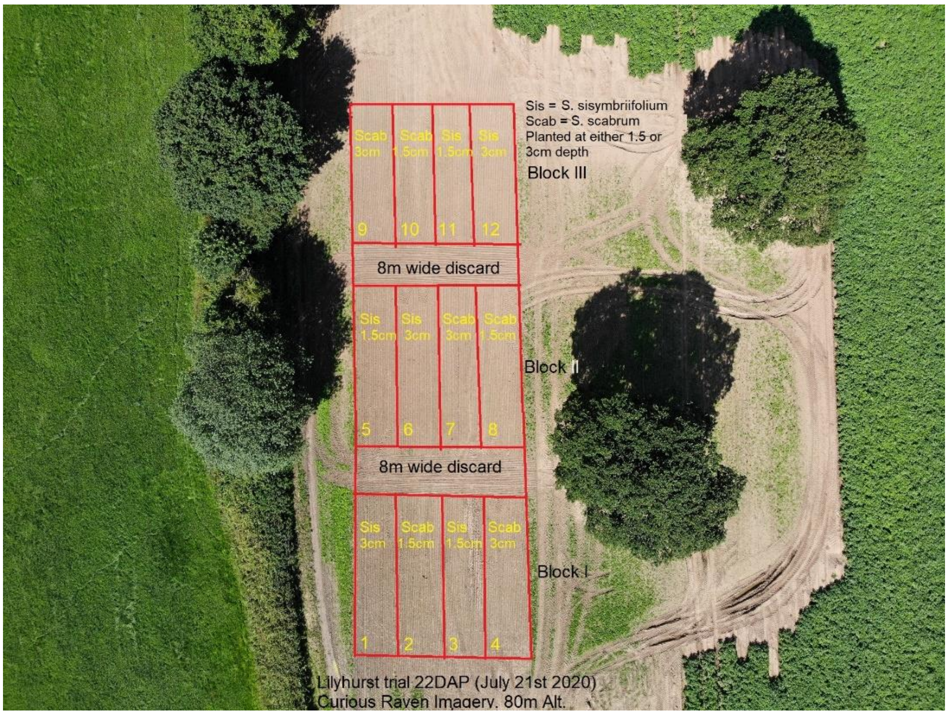

Figure 6. Lilyhurst trial date 1 layout with no trap crop growth, 21st July.

Table 4. Date 1: Emergence plants m^{-2} at Lilyhurst 35DAP

35DAP	*Species*			
	Sisym	Scabrum	Mean depth	
1.5cm	15	15.5	**15.25**	**N/S**
3cm	10.5	14	**12.25**	
Mean species	**12.75**	**14.75**		**N/S**
			Interaction	**N/S**

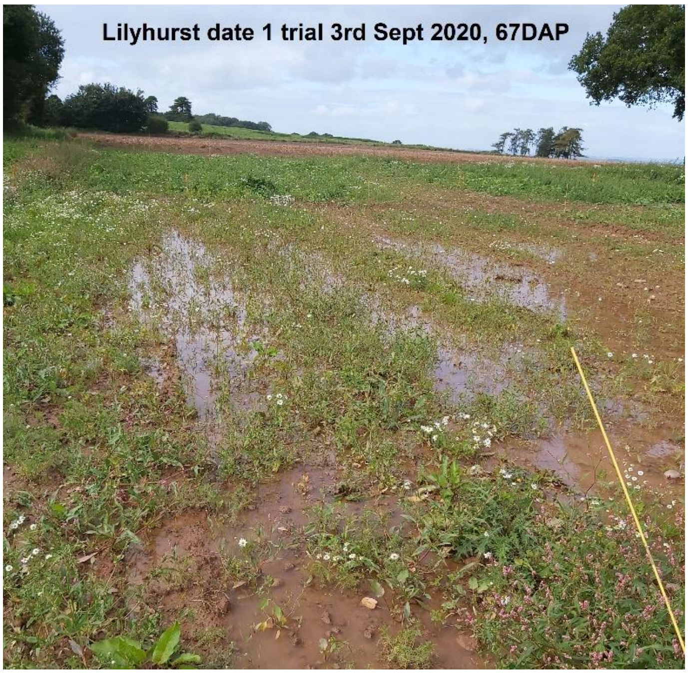

Figure 7. Lilyhurst date 1 trial on 3rd September, 67DAP.

By the 3rd September half of the date 1 trial was saturated after a very wet period, figure 7, very few trap crop plants survived. On the date 2 trial there was virtually no emergence, odd plants. Weed growth was substantial in both trials at this point and the trial was terminated as no useful assessment could be done.

Ormskirk date 1 (8th July 2020)
Plants did not emerge sufficiently to enable emergence counts to be done. Sporadic emergence was noted by 8 weeks after planting but not sufficient numbers to enable plot counts with meaning.

Tibberton date 1
It was not possible to plant at or near this date as the carrot crop was still awaiting harvest.

Caynton date 2 (28th July 2020)
Emergence was monitored for 8 weeks following planting, but it was patchy and could not be meaningfully analysed. The plots did have some ground cover, this was measured and will be reported in ground cover results.

Lilyhurst date 2 (28th July 2020)
Emergence was monitored until termination of the experiment 37DAP but there was virtually no emergence, odd plants. Weed growth was substantial in this trial and the trial was terminated as no useful assessment could be done.

Ormskirk date 2 (7th August 2020)
There was very patchy emergence on this trial and therefore no meaningful counts could be made.

Tibberton Date 2 (28th July 2020)
The emergence at this trial was very slow and extremely patchy. The weed growth, groundsel, was extensive and made it almost impossible to spot the slow growing trap crops. However, an assessment was achieved at 66DAP (1st October). There was a significantly greater emergence in the *S. scabrum* plots but depth had no effect and there was no interaction between depth and species, table 6.

Table 6. Plant emergence m^{-2} at Tibberton (date 2) 66DAP

66DAP	*Species*			
	Sisym	Scabrum		
1.5cm	3.5	6	4.75	**N/S**
3cm	3.5	6.5	5	
	3.5	6.25		**0.04**
			Interaction	**N/S**

Ground cover

Continual ground cover assessment was only possible for the Caynton date 1 trial as it produced good crops which also prevented weed growth for much of the time. The analysed data is shown in tables 7 and 8, and also in figure 9.

Although both species were slow to emerge and produce ground cover there were some statistical differences: *S. sisymbriifolium* produced greater (*P<0.05*) percentage ground cover at 43, 55, 69DAP and both crops achieved 50% GC by 83DAP.

Table 7. Ground cover (%) results for Caynton Date 1 (43 to 83DAP)
Statistically significant results (*P < 0.05*) in bold and italic

		Ground cover %			
DAP		S. sisym	S. scabrum	Mean depth	Signif.
43	1.5cm	4.6	2.57	**3.58**	**N/S**
	3cm	3.27	1.9	**2.58**	
Species mean		***3.93***	***2.23***		***0.03***
				Interaction	**N/S**
49	1.5cm	12.53	5.63	**9.08**	**N/S**
	3cm	7.9	6.9	**7.4**	
Species mean		**10.2**	**6.3**		**N/S**
				Interaction	**N/S**
55	1.5cm	32.62	12.45	**22.53**	**N/S**
	3cm	23.28	17.72	**20.5**	
Species mean		***27.95***	***15.08***		***0.01***
					N/S
62	1.5cm	40.92	24.07	**32.49**	**N/S**
	3cm	26.08	23.95	**25.07**	
Species mean		**33.5**	**24**		**N/S**
				Interaction	**N/S**
69	1.5cm	45.97	25.18	**35.58**	**N/S**
	3cm	39.08	22.58	**30.83**	
Species mean		***42.53***	***23.88***		***0.01***
				Interaction	**N/S**
76	1.5cm	45.4	32.05	**38.73**	**N/S**
	3cm	38.42	31.15	**34.78**	
Species mean		**41.9**	**31.6**		**N/S**
				Interaction	**N/S**
83	1.5cm	54.37	54.5	**54.43**	**N/S**
	3cm	47.13	43.77	**45.45**	
Species mean		**50.75**	**49.13**		**N/S**
				Interaction	**N/S**

At 97DAP the assessment method changed from spot measurement at the pre-designated spots to a whole plot score using aerial images and this showed that although the *S. scabrum* was growing well in patches it was lower on an overall plot score than the *S. sisymbriifolium*. At 115DAP and thereafter, the aerial images were used to collect ground cover images as previously described, table 8.

Table 8. Ground cover (%) results for Caynton Date 1 (97 to 152DAP) (Statistically significant results ($P < 0.05$) in bold and italic)

		Ground cover %			
DAP		S. sisym	S. scabrum	Depth means	Signif.
97	1.5cm	58.33	35.67	**47**	**N/S**
	3cm	41.67	28.33	**35**	
	Species mean	***50***	***32***		***0.02***
				Interaction	**N/S**
115	1.5cm	77.33	63.33	**70.83**	**N/S**
	3cm	70	51.66	**60.83**	
	Species mean	**74.17**	**57.5**		**N/S**
				Interaction	**N/S**
115	1.5cm	80.42	74.16	**77.29**	**N/S**
Aerial	3cm	71.72	67.39	**69.55**	
	Species mean	**76.07**	**70.78**		**N/S**
				Interaction	**N/S**
127	1.5cm	78.52	65.7	**72.11**	**N/S**
Aerial	3cm	70.43	62.76	**66.6**	
	Species mean	**74.48**	**64.23**		**N/S**
				Interaction	**N/S**
135	1.5cm	69.52	63.34	**66.43**	**N/S**
Aerial	3cm	69.23	57.23	**63.23**	
	Species mean	**69.38**	**60.29**		**N/S**
				Interaction	**N/S**
142	1.5cm	70.1	37.98	**54.04**	**N/S**
Aerial	3cm	67.07	32.07	**49.57**	
	Species mean	***68.58***	***35.03***		***0.01***
				Interaction	**N/S**
154	1.5cm	66.67	23	**44.83**	**N/S**
Aerial	3cm	64.33	21	**42.67**	
	Species mean	***65.5***	***22***		***< 0.00***
				Interaction	**N/S**

At 97DAP the whole plot ground cover % was significantly better ($P=0.02$) for *S. sisymbriifolium* (50%) compared to *S scabrum* (32%). There was no significant effect of depth even though the data suggests that the 1.5cm depth was better.

There were no other significant effects until 142DAP when the *S scabrum* had significantly less (*P=0.01*) ground cover than *S. sisymbriifolium*. This was most likely because *S. scabrum* had started to lose substantial ground cover as the first hard frosts had occurred in mid-October. At 154DAP the *S. sisymbriifolium* still had significantly greater (*P < 0.01*) ground cover and remained green. During the whole of the assessments, although the growth at the 1.5cm sowing depth appeared to be better, there were never any statistically significant effects at the *P< 0.05* level.

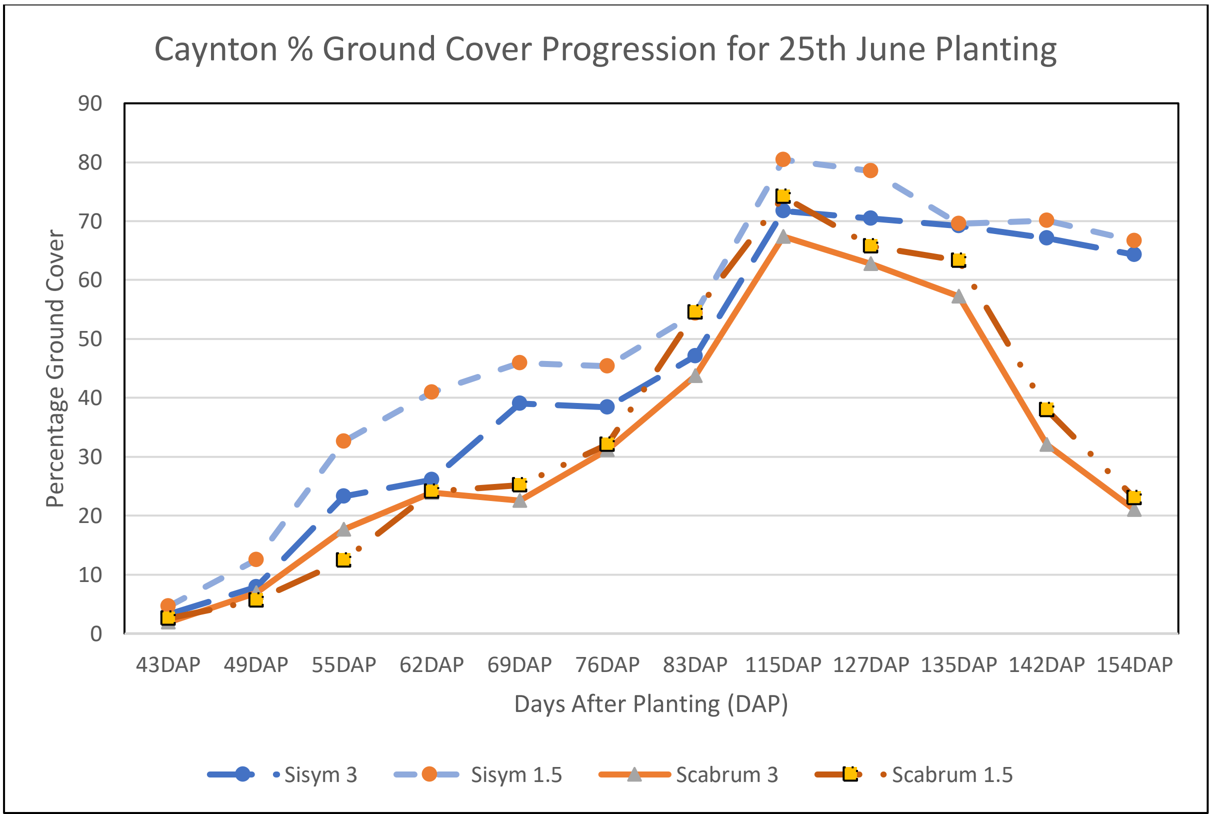

Figure 9. Ground cover (%) progression for Caynton date 1 (25th June 2020)

Caynton ground cover Date 2 (sown 28th July 2020)

By 17DAP the plants had started to emerge and were producing patchy but early ground cover. At 21DAP the *S. Sisymbriifolium* had significantly greater (*P=0.047*) ground cover than *S. scabrum* which continued for 27, 34 andl 44DAP. At 34DAP there was also a depth and species interaction, P=0.01, whereby *S. sisymbriifolium* had greater ground cover from the 1.5cm sowing depth in contrast to *S. scabrum* which showed greater ground cover from the 3cm sowing depth. By 65DAP the percentage ground cover for *S. sisymbriifolium* and *S scabrum* sown at 3cm were significantly (*P=0.016*) greater than when sown at 1.5cm. This trend at the final assessment at 92DAP, table 9 and figure 10. The development of the grown cover achieved from the date 2 planting was substantially slower than for the date 1 planting, probably reflecting the reduction in solar radiation.

Table 9. Ground cover (%) results for Caynton Date 2
(Statistically significant results (*P < 0.05*) in bold and italic)

		Ground cover %			
DAP		S sisym	S. scabrum	Depth	Signif.
17	1.5cm	0.8	0.1	**0.45**	**N/S**
	3cm	0.17	0.1	**0.13**	
Species mean		**0.48**	**0.1**		**N/S**
				Interaction	**N/S**
23	1.5cm	0.62	0.3	**0.46**	**N/S**
	3cm	0.6	0.38	**0.49**	
Species mean		**0.61**	**0.34**		**0.047**
				Interaction	**N/S**
30	1.5cm	1.82	0.77	**1.29**	**N/S**
	3cm	1.42	1.5	**1.46**	
Species mean		**1.62**	**1.13**		**0.03**
				Interaction	**0.01**
37	1.5cm	3.17	1.8	**2.48**	**N/S**
	3cm	3.33	2.18	**2.76**	
Species mean		**3.25**	**1.99**		**0.01**
				Interaction	**N/S**
44	1.5cm	4.73	2.3	**3.52**	**N/S**
	3cm	4.53	4.07	**4.3**	
Species mean		**4.63**	**3.18**		**0.029**
				Interaction	**N/S**
51	1.5cm	12.2	6.066667	9.133333	**N/S**
	3cm	9.9	9.9	9.9	
Species mean		11.05	7.983333		**N/S**
				Interaction	**N/S**
65	1.5cm	13.3	6.33	**9.83**	**0.016**
	3cm	20	20.67	**20.33**	
Species mean		**16.67**	**13.5**		**N/S**
				Interaction	**N/S**
92	1.5cm	15.66	10	12.83	0.018
	3cm	26.67	31.67	29.17	
Species mean		**21.17**	**20.83**		**N/S**
				Interaction	**N/S**

Aerial images of the trials at three dates are shown in figures, 11, 12, 13 and 14.

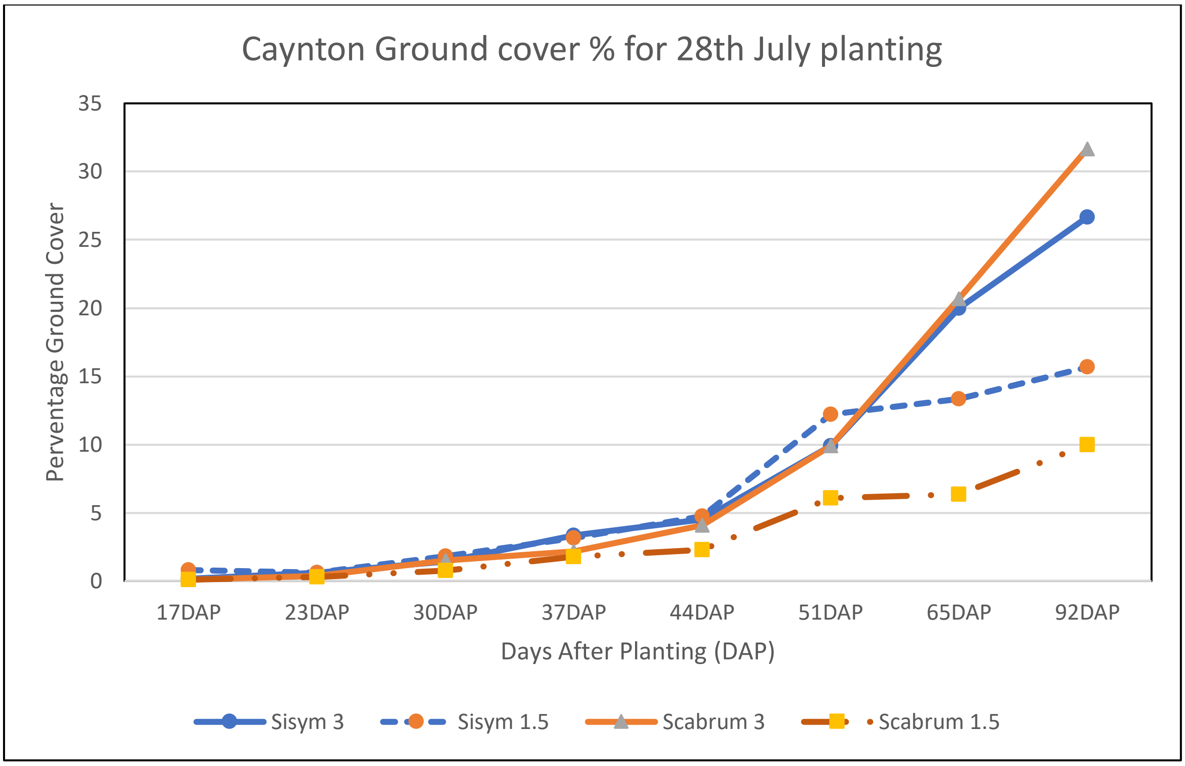

Figure 10. Caynton date 2 ground cover (%) progression.

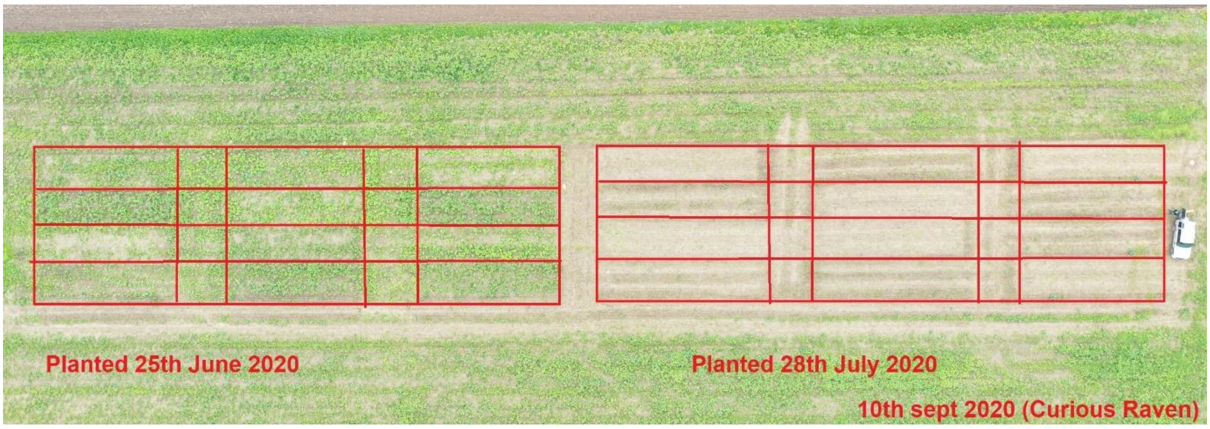

Figure 11. Comparison of ground cover between date 1 and date planting at Caynton on the 10th September (77DAP and 44DAP respectively)

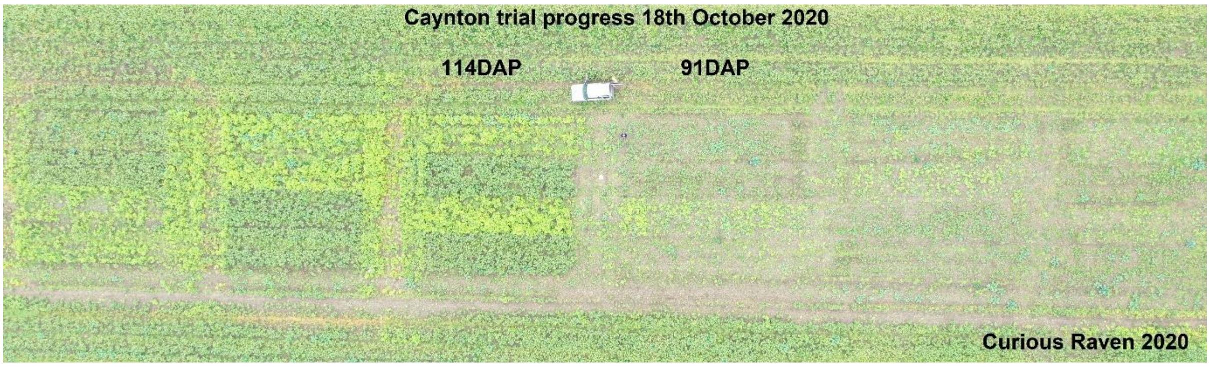

Figure 12. Comparison of ground cover between date 1 and date planting at Caynton on the 18th October 2020 (114DAP and 91DAP respectively)

Figure 13. Comparison of ground cover between date 1 and date planting at Caynton on the 18th October 2020 (114DAP and 91DAP respectively)

Figure 14. Comparison of ground cover between date 1 and date planting at Caynton on the 12th December 2020 (170DAP and 137DAP respectively)

Dry matter and plant count for (Caynton Date 1 trial)
Plants of both species were excavated to inspect roots, figure 15. Plants of *S. sisymbriifolium* were taken on the 8th October (104DAP) from two 1m^{-2} quadrats, from within representative areas within plots. Plants were cut at ground level, taken to the laboratory, weighed for fresh-weight, dried in a force draught oven at 60°C for 48 hours to obtain dry-weight. Plants counts on 26th November were 12.7 m^{-2} when planted at 1.5cm and 10.7 m^{-2} when planted at 3cm.

Sample 1 = 315.1 g/dry matter m^{-2} (total from 11 plants)
Sample 2 = 157.4 g/dry matter m^{-2} (total from 9 plants)
Giving a mean plant dry matter of 236.3 g/ dry matter m^{-2}

Figure 15. Root differences between *S. sisymbriifolium* and *S. scabrum*, 105DAP

Temperature, rainfall and Solar radiation information

The average temperatures, solar radiation and rainfall recorded at Harper Adams University weather station, figures 16, 17, 18 and 19, should be fair representations of those experienced at both the Cayton and Tibberton sites (1500 and 1800m away respectively) and give an indication of those experienced at the Lilyhurst site (7.8km away). The data for Ormskirk was provided by the grower taken from a dedicated Sencrop weather station and so is therefore is a very good indication of the air temperatures and rainfall experienced at the site, figures 16 and 19.

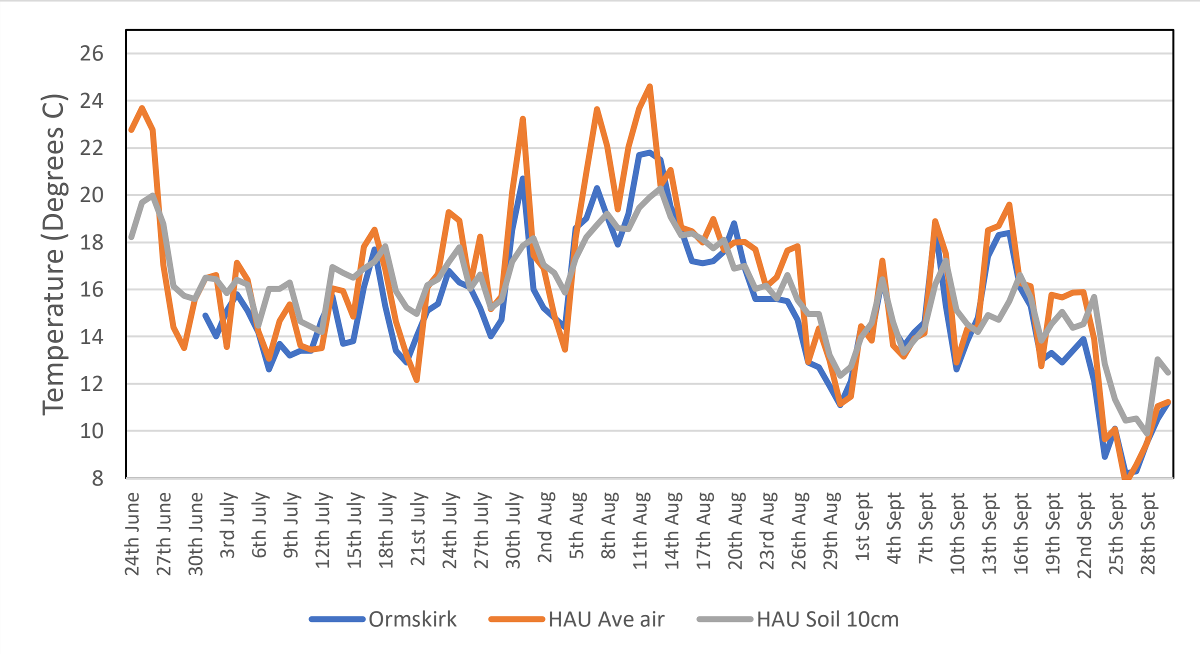

Figure 16. Average air temperature (°C) HAU and Ormskirk, average soil temperature at 10cm HAU.

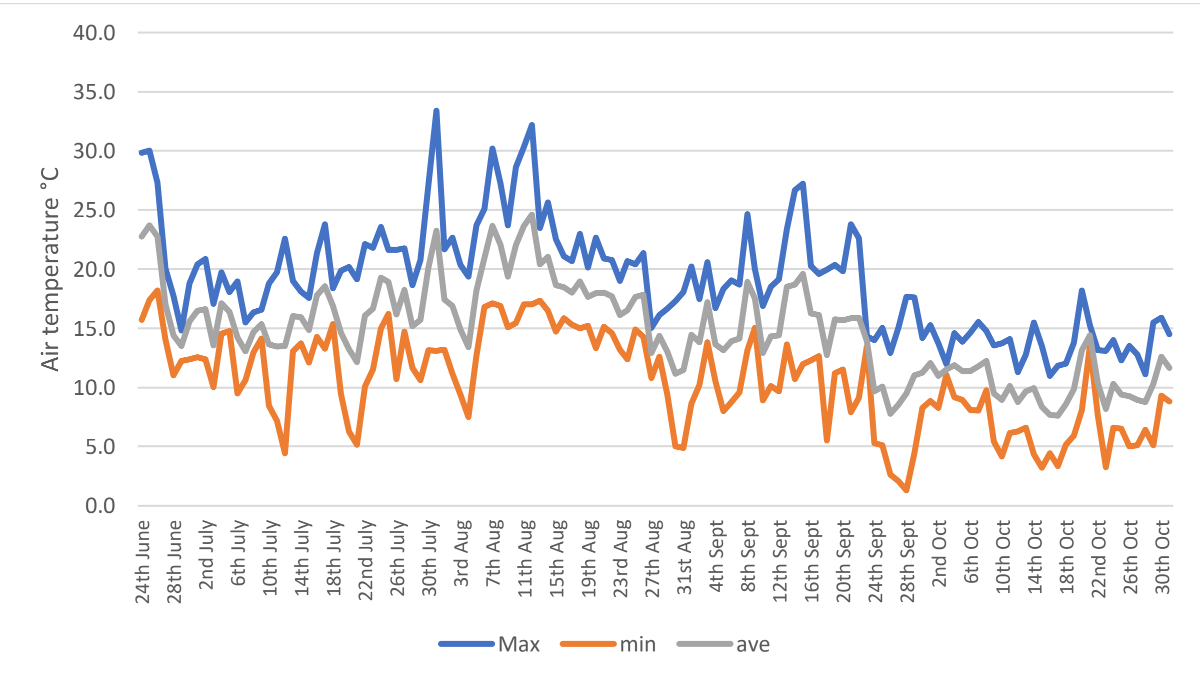

Figure 17. Average, min and max air temperature (°C) recorded at HAU.

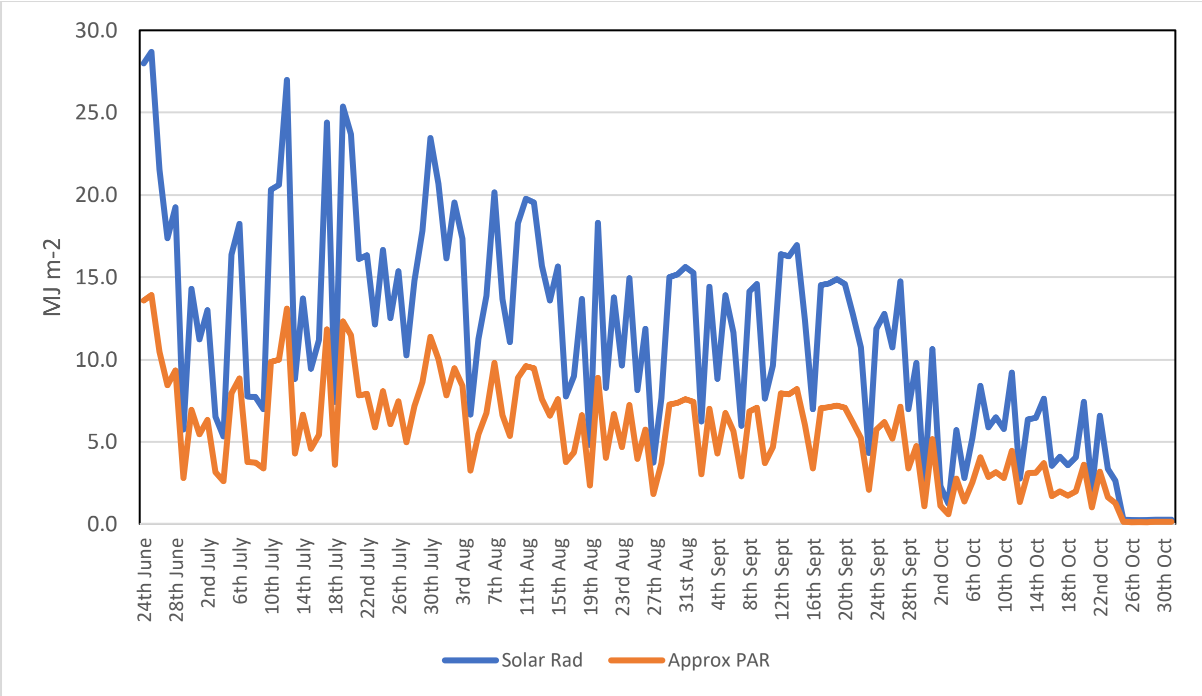

Figure 18. Solar radiation recorded at HAU and calculated PAR.

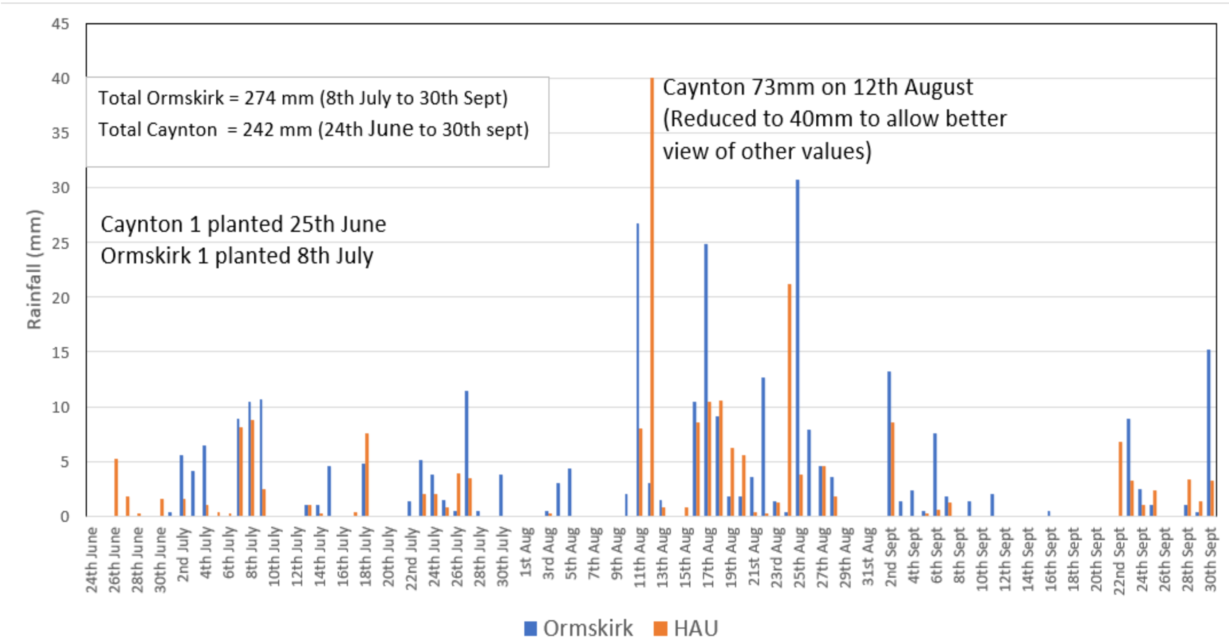

Figure 19. Rainfall (mm) recorded at HAU weather station and Ormskirk grower Sencrop data

Discussion

Solanum sisymbriifolium is a PCN trap crop that when grown in the UK has suffered from poor establishment when placed at a 'convenient' sowing time of post-harvest, mid to late July. The seed is available commercially from only one main supplier in the UK currently, 'Produce solutions', where it is sold as DeCyst™. The optimum sowing times recommended are given as mid-May to the end of June for irrigated crops and during May when no irrigation is to be used (Produce solutions, 2017). Seed is sown at 0.5-1cm depth and the seedbed should be consolidated. Branston (2011), a former supplier, suggest sowing at 3-4kg/ha to achieve 30 plants m^{-2}, sown at 1cm followed by rolling, at an ideal soil temperature above 10°C when plants should take 12-14 days to emerge but between 6-8 weeks to achieve good ground cover. As these timings for sowing conflict with times when conventional crops are still growing during the main part of the UK growing season, the crop is seldom grown. The actual requirements for growing the crop in Europe on a field-scale were published in several influential papers produced by Timmermans (2005), Timmermans (2007) and Timmermans, Vos and Stomph (2009) based on work at three sites in Holland coupled with 'crop modelling'. This work suggested a base temperature of 9°C and optimum planting can achieve emergence within just 10 days when planted in Mid/late June. Work on planting depth and nitrogen rates was also done at Harper Adams University by Grove (unpublished) which suggested that the crop grew better when planted at 2-3cm than when surface sown, and much better with increasing rates of nitrogen application.

In order to prevent readers from being misled regarding planting times when growing both *S. sisymbriifolium* and *S. scabrum*, the terms 'late' and 'very late' are used to differentiate them from the recommended planting times.

For these Innovative farmers trials there were three main questions which were proposed:

Question 1: Can *S. sisymbriifolium* and *S. scabrum* be grown effectively when sown 'late' in June or 'very-late' in July?

Question 2: Do *S. sisymbriifolium* or *S scabrum* need to be sown deeper than the recommended depth?

Question 3: Does *S. scabrum* show growth potential in Shropshire & Ormskirk?

Emergence and establishment

The planting of the 'late' crops in these trials was achieved on 25th June at Caynton and 28th June at Lilyhurst in Shropshire. Emergence at both Caynton and Lilyhurst was observed to be slow and patchy. However, Caynton and Lilyhurst had achieved the 12 plants m^{-2}, which was later classed as the established and the final plant counts. For Caynton this was achieved at 22DAP and for Lilyhust 35DAP. Determining the effect of temperatures on potential emergence (germination) the diurnal air temperatures, measured at 2m above the soil surface, were 30°C and 16°C on the 25th June reducing to 18°C to 11°C on the 28th June and 23°C and

4.4°C on the 10th July. As the biological processes such as germination are a product of physical time and temperature combined, ‘thermal time’ (Buchan, 2011), it is not just the attainment of specific temperatures but the accumulated thermal time which is required to trigger or sustain germination. Within these trials, the recorded daily temperatures at HAU, used for all three Shropshire sites, are above the suggested base temperature for *S sisymbriifolium* of 9°C (Timmermans, 2005). Although there are four growth models described by Timmermans (2005) the ‘linear thermal time model’ was used here: germination rate (d^{-1}) = 0.0093T + -0.078, and from this it is possible to calculate that the Caynton site should have reached full emergence by 14 days, so the recorded 22DAP is slower. Similarly, for the Lilyhurst site, with slightly later planting, it would have been expected to reach full emergence by 16DAP rather than the 35DAP recorded. Using the calculations and weather for Ormskirk full emergence would also have been expected at around 16 DAP, where in fact there was no visible emergence recorded for many weeks, and even then it was patchy. Further calculation using Accumulated day degrees demonstrate that at all three sites the date 1 plantings attained 150 Day degrees by 22-24 DAP, values not dissimilar to those of Timmermans (2005) for 50% emergence. The poor emergence/establishment at Lilyhurst and Ormskirk can however be related directly to excessive rainfall at these sites as Timmermans *et al.* (2007) suggests that large amounts of rain and waterlogging early post planting are detrimental to establishment and growth of the crop. For Ormskirk after planting on July 8th there followed 2 consecutive days of 10mm rainfall. Whereas at the Lilyhurst site HAU rainfall suggests 73mm of rain on the 12th August (45DAP) even the established plants died off on the wetter area of the trial. Although the work by Timmermans (2005) is without doubt the most crop specific, the varying germination requirements given for some *Solanum* relatives may provide an insight into possible. Del Monte and Tarquis (1997) report a base temperature requirement for germination for *S. nigrum* and *S. physalifolium* of between 7.5 and 10°C but notes that maximum germination occurs between 20 - 30°C. Kamgari (2009) suggests germination temperatures for *Solanum nigrum* between 18 - 34°C, but with an optimum between 26 - 30°. Whilst the work by Finch-Savage and Leubner-Metzger (2006) proposes little germination below 20°C and an optimum range of 28-33°C. It is possible therefore that further work is required to determine the difference between ‘base’ temperature and temperature at which 50% will germinate effectively. Beyond the germination temperature it is possible to utilise ‘accumulated day degrees’ (ADD) requirements to quantify germination and growth potential based on positive mean temperatures above the base of 9°C (Timmermans, 2005). For these trials there were no days where ADD did not contribute positively to germination from 24th June until mid-September, so the trap crops were growing in a positive temperature environment. Soil temperature at 10cm was recorded at HAU of 20°C reducing to 12°C over that period, soil temperature does not vary substantially on a daily basis unlike air temperature as there is always a lag due to physical soil heat retention. However, as the seeds are sown close to the soil surface and the near surface soil temperature and the air temperature are more closely related (Tsilingiridis and Papakostas, 2014) than at 10cm depth. Consequently, the seed temperature may have been nearer to the grass minimum temperature, measured at 50mm above the soil surface. These temperatures were 14/15°C, at planting, averaged only 10.1°C in July and recorded only 18 positive values greater than the base temp. Additionally, the accumulated degree days of only 45.8 is significantly lower than would be required. Similarly, this would also have been relevant for the crops planted in early July in Ormskirk as those temperatures were similar to those in Caynton. Work by Ellis *et al* (2016) does show that planting at 10°C in late-May, into rising temperatures, gives rise to modest (40%) emergence but they were growing into rising temperatures rather than static or falling temperatures. It should be noted at this point that before the main trials began, the seed was grown in pots within an unheated glasshouse and produced between 50-80% emergence, showing that the seed itself was viable. Subsequently as the germination process can be influenced by many other factors, it is possible that factors not measured within the field trials may have contributed to low emergence rates. Plausibly, as the seed itself is not grown within the UK it could have been influenced by the growing conditions of the 'seed' which may have predisposed it to different/greater temperature requirements for germination. In such cases it is often suggested that seed may benefit from either stratification or priming processes. Timmermans (2005) however, suggests that unless the seed is sown very close to the surface there is no evidence of diurnal temperature requirements (stratification) for germination of *S. sisymbriifolium*.

For the 'very late' crops planted in Shropshire the temperatures fluctuated from 18/12°C on the 28thJuly, to 33/13°C on the 31st July (3 days post sowing) and then fluctuated around 25/18° for approximately 16 days, suggesting that temperature should not have been an issue, but all emergence was sparse. The crop planted at Ormskirk on the 7th August also failed to grow beyond a few isolated plants despite having average temperature of 15.9°C, range of 12-22°C, until 24th September when it fell below 9°C. Notably, there were two significant rain events shortly after the Ormskirk planting, 27mm on 11th August and 25mm on the 17th August, both of which would have been detrimental to germination by reducing the soil temperature substantially below the recorded air temperature. As Schneider and Gupta (1985) and Al-Darby and Lowery (1987) acknowledge that when soil moisture is near field capacity, seed bed temperature then becomes the most critical environmental factor affecting emergence of crops such as maize, a plant with similar germination requirements.

Ground cover

The ground cover progression throughout the growth of the crop was only captured at the Caynton date 1 site as either no ground cover was achieved or weed ingress prevented the isolation of ground cover values at the other sites. The early growth was slow, taking until 80DAP to reach 50% ground cover. At 115DAP (18th October) maximum ground cover of 80% was achieved by *S. simybriifolium* and 74% for *S. scabrum*, both planted at 1.5cm depth. When planted at 3cm depth the *S. simybriifolium* attained a maximum of 71% and *S. scabrum* 76%. Throughout the trial the shallower sown plots always produced greater ground cover suggesting that sowing beyond 1.5cm was detrimental to growth. It was apparent from ground cover assessments and visual observations that the *S. scabrum* plots were not uniformly established but where they were uniform the crop exhibited a much denser canopy than that of the S. sisymbriifolium. As the trial continued the *S. scabrum* became affected by frost which reduced its ground cover to c. 21% by 154DAP and zero by 170DAP (12th December). The *S. sisymbriifolium* retained 65% ground cover at 154DAP and was still largely unaffected by 170DAP. This is similar to the work by Ellis et al (2016) which showed that in their investigations up to 30% of the *S. simybriifolium* still remained alive on 14 January 2014, whereas <5% of *S. nigram* and no *S. dulcamara* or *Datura stramonium* survived the winter, which demonstrates the hardiness of *S. Sisymbriifolium* once established. The requirement or benefit of the trap crop remaining alive remains to be quantified on the PCN population throughout the colder Autumn and Winter period and it may be beneficial to growers if the trap crop can either be incorporated as green manures or dies off quickly in November.

The actual potential for this crop to be an effective trap-crop is linked to its ability to accumulate 700g/m^2 above ground dry matter, which then corresponds to a proportionate root system and effective PCN hatch (Timmermans, 2005). In relation to growth in the UK, Timmermans *et al.* (2009) suggest that the time for the crop to attain the 700gm^2 dry matter varies with average environmental conditions. In the south, roughly the Midlands and southern UK, the time was given as 79-93 days to achieve the goal, with a latest planting date of late June/Early July (Julian days 166-186). North of the Midlands the latest sowing date was the beginning of June as 93-127 days were required to reach the 700g figure (Timmermans *et al.*, 2009). Within our trials the dry matter accumulation was examined only for *S. sisymbriifolium*, and not *S. scabrum*, as there is a known dry matter requirement for good PCN control with the former. Plants were removed from plots on 8th October, 105DAP or 12 weeks after 50% emergence, which corresponded quite well to the target of 700g dm m^{-2} at 14WAP provided by Timmermans (2005). At 105DAP the ground cover recorded from the plots were almost at a peak, so little extra growth was achieved after that time, making it a suitable representation. The mean dry matter achieved in our trial was only 236g, range 157 – 315 g dry matter m^{-2} which is much lower than the suggested biomass required for effective PCN control. To achieve 700g m^{-2} Tmmermans (2007) suggested that approx. 420 MJ m^{-2} PAR were required, figure 20, and this achieved 1.67g dry matter per MJ PAR. As, the solar radiation (MJ/m^{-2}/day) obtained from the HAU weather station uses total solar radiation in MJ m^{-2} a conversion to PAR is required for comparisons to be made. Unfortunately, there is no simple way to convert MJ/m^{-2} to mu mol photons / m^{-2} / s (PAR) but an approximation can be achieved by multiplying total solar radiation by 0.486, as PAR is approximately 0.45-50 of total radiation (Campbell and Norman, 1998). For the biomass measurement date of 8th October 2020, taken from the date of 50% emergence (17th July 2020) approximately 511 MJ m^{-2} PAR were received but only 0.46g dry matter MJ m^{-2} were achieved. It is therefore proposed that either insufficient ground cover, leaf area and or plant density had been achieved at the Caynton date 1 site, to fully maximise the incoming available solar radiation, and therefore further work is required to achieve the biomass target.

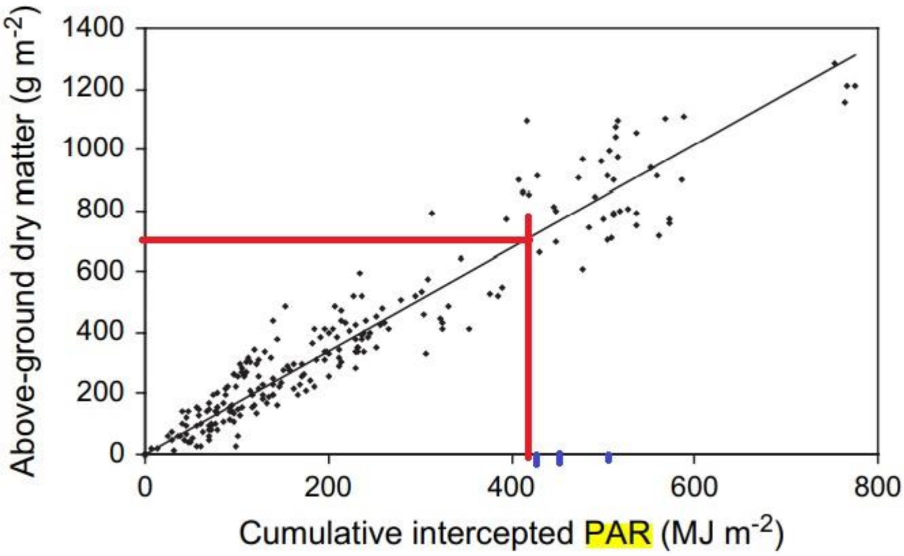

Figure 20. Above ground dry matter (g m^2) and cumulative intercepted PAR (Modified from Timmermans et al, 2007)

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Agronomy of the crops

One area which could influence the attainment of greater crop density and biomass is the agronomy of the crops. A key difference between the agronomy of our trials and those done by Timmermans et al (2007) is the application of nutrients. Both 'Produce solutions' and Branston recommendations are for 50 kg N ha at planting whereas Timmermans (2007) included 44 kg P ha and 54 kg K ha at sowing time, then 100 kg N ha (as calcium ammonium nitrate) 3 weeks after emergence and another 50 kg N ha 7 weeks after emergence, substantially greater than our applications. The nutrient applications at Tibberton and Lilyhurst were 50 kg N/ha at planting whilst the better growing crops at Caynton had received digestate which, although not analysed, would easily provide greater than 50kg/N ha, dependent on source material (Makádi *et al.*, 2012). With respect of *S. scabrum,* Abukutsa-Onyango and Karimi (2007) investigated a range of N from zero to 100 kg/N ha and found that an application of 40kg/N ha was adequate for good growth in Kenya. As the *S. scabrum* lacked uniformity it is difficult to postulate on the need for greater than the 50 kg N/ha applied.

Irrigation was not applied at any of the trials sites but based on the results of Timmermans (2005) the crop survives well at a wide range of soil water potential and does not necessarily need it. However, if irrigation is available, and the season is dry, it would be prudent to apply appropriate quantities to maintain growth.

The seed rate of 20kg/ha (3kg *S. sisymbriifolium* ha) used in our trials, equates to approximately 138 seeds m^{-2}, which agrees with Timmermans *et al.* (2007) who states that a seed rate of 100 seeds m^{-2} is generally sufficient, with c. 70%

emergence, whereas above 150 plants m^{-2} leads to crop lodging. The attained plant counts in our trials of c. 11-13 plants m^{-2} is substantially lower than the 70 m^{-2} suggested by Timmermans *et al.* (2007) or the 30 m^{-2} suggested by Branston (2011). This would have substantially reduced the potential for our crop to achieve the ground cover and leaf area required to achieve the 700g d.m. m^{-2} for good PCN control.

The depth of planting data from the Caynton date 1 trial suggests that the 1.5cm gave better emergence than the 3cm depth. Whereas in the date 2 experiment the 3cm depth appears to have been better for the 'very late' planted crop, even though of little relevance now. Arguably this may not be unexpected as the deeper planting may have placed seed into a warmer environment which also experiences a smaller diurnal change. Significantly in the work reported by Timmermans (2005) the sowing depths used were 2-4cm and at only one point was it hypothesized that a variation in the rate of emergence that was seen may have resulted from variable planting depth or surface compaction. In relation to depth of planting, Zhou et al. (2005) studied the relationship of depth and emergence in *S. nigrum* and concluded that the maximum emergence at planting depths of 2 cm or less and decreased with increased seeding depth until 8 cm where no emergence occurred.

Conclusions:

Question 1: Can *S. sisymbriifolium* and *S. scabrum* be grown effectively when sown 'late' in June or 'very-late' in July?

Question 2: Do *S. sisymbriifolium* or *S scabrum* need to be sown deeper than the recommended depth?

Question 3: Does *S. scabrum* show growth potential in Shropshire & Ormskirk?

1. Planting at Ormskirk at the late or very late timings does not appear to be viable especially with the rainfall patterns experienced.
   Planting in North Shropshire at the late June, 'late' timing, shows some potential on the sandy loam soils but weed control and soil moisture can be significantly influential especially on the clay loam soils.
   Planting at the Very late timing in North Shropshire does not produce a suitable crop and is therefore not viable.
2. Planting deeper than the recommended planting depth shows no benefit at the 'late' timing but some benefit for the 'very late' timing'.
3. *Solanum scabrum* shows good growth potential in North Shropshire but could not be established at Ormskirk.

Suggested Further work

Although there are many areas which need further investigation for a greater scientific understanding of the use of trap crops, e.g. the period over which the plant species continue to release exudates and any accompanying hatch response from PCN, there are specific areas which can be assessed by additional trials operating in the same methodology as those described in this report.   The areas suggested are therefore:

- Planting of both *Solanum sisymbriifolium* and *S. scabrum* at mid-May and mid-June timings to compare growth and PCN population management under UK conditions.
- Priming of seed to aid germination and emergence
- Precision drilling of pure seed and potential of 'primed' seed to aid reduce seed rates but produce better emergence may be beneficial
- Adjusting the fertiliser rates and timing
- Inter row cultivation for weed control and possible herbicide use.
- PCN population monitoring per plot (Pi and Pf)
- Three sites (2x Shrosphire and 1 Ormskirk)

The assessments suggested are:

- PCN population densities at planting and mid-September
- Plant emergence
- Percentage ground cover (x8) using aerial images and software analysis
- Biomass production, fresh and dryweight m^2 sample per plot, preferably at 100% ground cover.
- Root inspection and weight, 2 plants per plot, all plots.

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Appendix 1: Shropshire Growers Log

Shropshire Growers Innovative Farmers Progress Log		
Date	**Action**	**Notes**
February 2020	Shropshire Grower's discussion group meeting at Harper Adams University	
March 2020	Formulation of idea's and confirmation of interested growers	
April 8th 2020	Soil Association/Innovative Farmers Skype meeting.	
April/May 2020	Application forms completed and submitted. Four growers confirmed interest and desire to be part of the work.	
May/June 2020	Application reviewed, accepted and funding instigated.	
June 2020	Plan to drill two trap crop species *Solanum sisymbriifolium* and *Solanum scabrum* drilled at both 1.5cm and 3cm depths (approx.) and at two dates, early July and early august.	
25th June 2020	First trial site planted at ME Furniss, Shropshire. The field was wholecrop rye, harvested one week before. Lemken solitaire with power harrow. Plot sizes 4m drill width and 15m long with 8m guards (mainly for turning equipment. Plots drilled as a replicated and randomised experiment/trial. Two species: *Solanum sisymbriifolium* and *Solanum scabrum d*rilled at both 1.5cm and 3cm depths (approximately).	Sandy loam soil. 50kgN/ha applied to field as slurry in previous week. Hot dry day, 27°C, soil temperatures at drill depth 25°C. Aerial images and video captured using Mavic Pro 2 (IGG)
27th June 2020	Seed delivered to AM Webster, Ormskirk. Trial will be planted using contractor drill as the seed is very small. Field is currently in cabbages and will be planted shortly.	
29th June 2020	Second trial site planted at T & N Belcher, Shropshire. Planted in unplanted area within a potato field. Same equipment used: Lemken solitaire with power harrow. Plot sizes 4m drill width and 15m long with 8m guards (mainly for turning equipment. Plots drilled as a replicated and randomised experiment/trial. Two species: *Solanum sisymbriifolium* and *Solanum scabrum d*rilled at both 1.5cm and 3cm depths (approximately).	Clay loam soil. Cool day, 14°C, soil temperatures at drilling 13°C.
8th July 2020	1st of the two trials sown at Andrew Websters farm in Ormskirk, Lancashire, using a vaderstaad drill.	Soil type Sandy Loam. 18mm rainfall shortly after sowing.

10th July 2020	Solanum sisymbriifolium just starting to emerge at Caynton Manor, Plots 1, 3, 6 and 11. No S Scabrum showing as yet (2 weeks after sowing)	
17th July 2020 (21DAP)	3 weeks after planting for Caynton trial. Very limited emergence still but all three plots of Sisymbriifolium planted at 3cm have some emergence. Remaining plots of Sisym (1.5cm) and Scabrum at both depths very limited. Not possible to quantify effectively as yet.  Sisym on headlands showing depth possible to come up from, range 4 – 4 cm.	
21st July 2020 (22DAP Lilyhurst)	3 weeks after planting for lilyhurst trial. Very little emergence, just a few from 3cm sisym planted at 3cm.	
21st July 2020 (25 DAP Cayton)	Emergence improving on Sisym plots. Few Scabrum plants now emerging.	
28th July 2020	Second sowing of Caynton (32 days after 1st sowing) and Lilyhurst (29 days after 1st sowing). Sowing at Tibberton on sandy loam. **Caynton emergence in every plot and species (32DAP), Sisym best but Scabrum coming through**. Lilyhust emergence is still patchy but Scabrum in greatest numbers. This site is more exposed than caynton and heavier soil.	Soil temperatures ranging from 14-16°C, air temps around 18°C.
1st August 2020	36DAP Mean emergence counts plants per 2m row at Caynton: Sisym at 3cm 3.7; Sisym at 1.5cm 4.2; Scabrum at 3cm 1.7; Scabrum at 1.5cm 1.8	

<table>
<tr><td>3rd Aug 2020</td><td>Emergence assessed at Lilyhurst

<table>
<tr><td colspan="3">Plants emerged in 2m row 1st sowing</td></tr>
<tr><td></td><td>Caynton 36DAP</td><td>Lilyhust 35DAP</td></tr>
<tr><td>Sisym 3cm</td><td>3.7</td><td>3.5</td></tr>
<tr><td>Sisym 1.5cm</td><td>4.2</td><td>5.0</td></tr>
<tr><td>Scab 3cm</td><td>1.7</td><td>4.7</td></tr>
<tr><td>Scab 1.5cm</td><td>1.8</td><td>5.2</td></tr>
<tr><td></td><td>Sandy loam</td><td>Clay loam</td></tr>
</table></td><td></td></tr>
<tr><td>5th August 2020</td><td>Emergence very limited and only Scabrum at Ormskirk (28DAP), no sisymbriifolium found.
Second sowing planned for 6/7th August.</td><td></td></tr>
<tr><td>7th August 2020</td><td>2nd sowing completed at ormskirk.
Followed by 30mm rain on 10th August.</td><td></td></tr>
<tr><td>8th August 2020</td><td>Caynton ground cover assessment at 43DAP of first sowing date: Images taken with Canopy cover app, non-crop green material removed with photo software and then analysed using Easy Leaf Area software.
<table>
<tr><td colspan="2">GC Mean 43DAP</td></tr>
<tr><td>Sisym 3cm</td><td>3.291088</td></tr>
<tr><td>Sisym 1.5cm</td><td>4.468179</td></tr>
<tr><td>Scabrum 3cm</td><td>1.862044</td></tr>
<tr><td>Scabrum 1.5cm</td><td>2.220158</td></tr>
</table>
Both the Sisym and Scabrum are ahead at the 1.5cm planting depth. There is a statistical difference (P=0.04) but it is a small trial so treat with extreme caution.

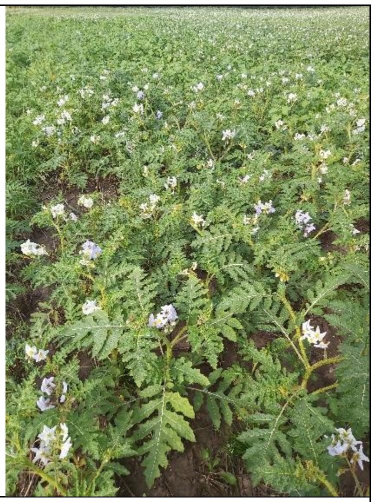
2nd sowing date (11DAP) is showing some early emergence, very limited.

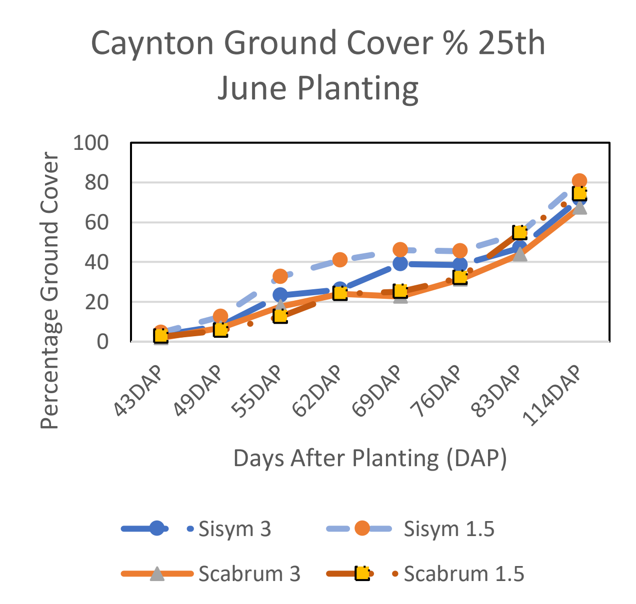
Results circulated grower group.</td><td>

Sisym planted at 1.5cm depth (image 43DAP)</td></tr>
<tr><td>8th August 2020</td><td>Tibberton showing no emergence (11DAP).

Lilyhurst emergence from 1st date is progressing but weeds now becoming problematic. 2nd sowing no emergence at 11DAP.
Results circulated grower group.</td><td></td></tr>
</table>

14th August 2020	Trial assessment carried out at Caynton, Tibberton and Lilyhurst sites, planting date 1 and 2 where emerged. Ground cover percentages using Canopy cover app and aerial imaging for site. Results circulated grower group.	
20th August 2020	Trial assessment carried out at Caynton date 1 (55DAP) and date 2 (23DAP), Lilyhurst date 1 (51DAP) and date 2 (23DAP), Tibberton (23DAP). Ground cover percentages using Canopy cover app and aerial imaging for site. Results circulated grower group.	
27th August 2020	Trial assessment carried out at Caynton date 1 (62DAP) and date 2 (30DAP), Lilyhurst date 1 (58DAP) and date 2 (30DAP), Tibberton (30DAP). Ground cover percentages using Canopy cover app and aerial imaging for site. Lilyhurst block 1 flooded. Clay loam site with poor drainage in parts of trial. Excessive rain had occurred. Results circulated grower group.	
3rd Septembe r 2020	Trial assessment carried out at Caynton date 1 (69DAP) and date 2 (37DAP), Lilyhurst date 1 (65DAP) and date 2 (37DAP), Tibberton (37DAP). Overall the S. scabrum plots tend have a more inconsistent establishment. Results circulated grower group.	
10th Septembe r 2020	Trial assessment carried out at Caynton date 1 (76DAP) and date 2 (43DAP), Lilyhurst date 1 (72DAP) and Tibberton (43DAP). Virtually no emergence on second sowing at Lilyhurst (43DAP) and so 2nd planting date trial terminated.	

17th Septembe r 2020	Trial assessment carried out at Caynton date 1 (83DAP) and date 2 (50DAP), Lilyhurst date 1 (79DAP) and Tibberton (50DAP). All canes removed from Lilyhurst and trial concluded ready for grower to plant wheat.	
1st October 2020	Final trial assessments carried out by IGG. Caynton 97and 64 DAP (planting dates 1 and 2), Image.  Tibberton at 64DAP Ground cover on a whole plot basis, including aerial images of all plots was carried out for Caynton. The Tibberton site had significant weed cover and very little trap crop establishment making the ground cover assessment difficult and ambiguous.	
8th October 2020 Caynton date 1 = 104DAP	Final field and group meeting Met in two groups to enable max 6 people together, 10.00 and 11.00. Two growers attended, Andrew Webster and Neil Furniss, plus Andrew Wade (OptiGro co-ordinator) Anne Stone (AHDB Co-ordinator), Matthew Back (HAU), Ivan Grove (Curious Raven), and Produce solutions team James Lee, Richard Griffith, William Wats + trainee. Caynton trials for both planting dates were discussed and then a visit to the Tibberton site, planting date 2 only.	Four plants from each of the most advanced plots for *S. sisymbriifolium* and *S. scabrum* were excavated and root systems compared. These will be weighed to determine root weight/mass. Two m^2 blocks of *S. sisymbriifolium* plants were taken from the most advanced plots so that they could be

	 Significant discussions were held regarding the development of the plants when planted at different dates. The earliest planting date, 28th June, had good growth whereas the later planting, 27th July, had poor establishment and had produced very little ground cover. It was suggested that the late June date was probably the latest safe sowing date to achieve sufficient ground cover and thus PCN control in North Shropshire. The Caynton site will be sampled for PCN and analysed at HAU. Although the trial is completed it will continue to be monitored to determine if further growth does occur.	weighed, oven dried and reweighed for dry matter production.  Image (M Back with Sisym plant)
18th Oct 2020	Trial inspection and ariel images for analysis	
30th oct 2020	Trial inspection and ariel images for analysis	
7th Nov 2020	Trial inspection and ariel images for analysis. Significant (first) frost, -3°C, on 3rd Nov, lasted until mid-morning and has affected the Scabrum but not the Sisym	
14th Nov 2020	Trial inspection and ariel images for analysis	
12th Dec. 2020	Trial inspection and aerial images.	
	Final results and report to be written and circulated.	