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Final report on improving seed tuber quality and vigour via the use of cover crops

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ABSTRACT (FOR DISSEMINATION)	Cover crops are playing an increasingly important role in agricultural production, with the potential for much greater adoption and use in the future. The influence of cover crops on seed potato production was evaluated in the ECOBREED project. The cover crop trials were conducted in the UK and Slovenia with individual cover crop species, i.e. Black mustard, Oil radish, Lucerne, Black oats, Vetch and a mixture of all five. Four potato cultivars were grown over the cover crops in the following year. At both sites, yield and its characteristics were influenced by the choice of potato cultivar and cover crop. The use of cover crops affected plant health and tuber quality in terms of shape regularity and silver scurf infection.
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Executive summary

Cover crops are playing an increasingly important role in agricultural production with the potential for much greater future adoption and utilisation. In the past cover crops have generally been used to reduce soil erosion and nutrient loss and to provide a supply of nutrients particularly N to the following crop. However, in recent years a move towards more regenerative production systems has seen an increased use of cover crops to provide living roots in the soil profile throughout the season with the potential to increase soil health.

A cover crop trial was set up at Nafferton Farm, Northumberland, UK and in central Slovenia at Jablje, Kmetijski inštitut Slovenije in the 2020-21, 2021-23 and 2022-23 seasons. The cover crop was drilled one year before potato in August, ploughed in spring and planted with potato over the cover crop.

The cover crop trials were conducted with individual cover crop species, i.e. Black mustard (*Brassica juncea*), Oil radish (*Raphanus sativus*), Lucerne (*Medicago sativa*), Black oat (*Avena strigosa*) and Common vetch (*Vicia sativa*). As only a small amount of Sticky nightshade (*Solanum sisymbriifolium*) was received, this species was not included as originally planned. A sixth treatment was included, which was a mixture of the 5 individual species. Treatment number 7 was the control with no cover crops (except for the 2021-22 season at UNEW). Four different cultivars were used at both locations, i.e. Alouette, Carolus, Casablanca and Cara in the UK and Alouette, Carolus, KIS Kokra and KIS Tamar in the corresponding trial in Slovenia. Four rows of each variety were planted, with the inner two rows used for yield and tuber quality analysis.

Tuber yield, tuber number, dry matter content and tuber sizes <25mm, 25-45mm, 45-65mm, 65-85mm and >85mm were determined after harvest. Disease assessment in the field and of tubers was carried out according to the phenotypic descriptor list D3.1.

At both locations, yield and its characteristics were influenced by the choice of cultivar and cover crop in both years. The differences were significant in most cases, with the exception of the very dry year 2022 in Slovenia, when yields were very low. Most of the interactions were not significant, which means that there is no strong relationship between cultivar and cover crop. This means that a cover crop effect can be expected for most of the cultivars used by farmers.

For UNEW Rhizoctonia, scab and slug damage were more severe in the 2022-23 season in the UK, as Rhizoctonia symptoms tend to be more frequent and severe on cool, moist soils at temperatures of 16°C-23°C. Cultivar susceptibility to *Rhizoctonia solani* varies and was clearly evident in the 2021-22 season, but with much higher levels in 2022-23, no significant difference was observed between varieties. Good seed health is important in

minimising the risk of Rhizoctonia disease and therefore the use of tubers harvested from the previous season in these two cover crop trials may have contributed to the high levels of *Rhizoctonia solani* in both seasons.

Looking at the tuber quality traits observed in Slovenia, there were differences between cultivars in several traits, many of which are genetically determined and were expected (e.g. eye depth, disease resistance etc.). In 2021, when growing conditions were good, there were no differences in tuber quality between the different cover crop treatments. It seems that in the stressful conditions of 2022, the choice of cover crop influenced (improved) tuber quality at least in terms of shape regularity and Silver scurf infection.

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Introduction

Cover crops are playing an increasingly important role in agricultural production with the potential for much greater future adoption and utilisation. In the past cover crops have generally been used to reduce soil erosion and nutrient loss and to provide a supply of nutrients particularly N to the following crop (Harramoto & Gallandt 2005). However, in recent years a move towards more regenerative production systems has seen an increased use of cover crops to provide living roots in the soil profile throughout the season with the potential to increase soil health.

The potential to deliver a range of 'ecosystem services' (Díaz *et al.,* 2007) is likely to be of particular benefit in organic and low-input production systems via reduced weed contamination, increased vigour and health depending on the growth pattern, nutrient exchange and chemical composition of the species used. Cover crops have also been shown to aid in the suppression of weeds and increased nutrient supply (Harramoto & Gallandt 2005) thus increasing seed quality and vigour. Many cover crops are grown in mixtures using brassica, cereal and legume species with differing benefits provided by the individual species. For example, brassicas are used for their fast growth, biomass accumulation and ground coverage while cereals e.g. Black oat are used for their extensive rooting systems to aid nutrient uptake and minimise leaching losses while legumes provide the ability to fix atmospheric nitrogen.

For a number of years brassicas have been used as a cover crop due to their potential for soil biofumigation (Collins *et al*., 2006) which is particularly important in organic and low-input production systems where pesticide use is not allowed and/or restricted. There is also increasing evidence that cover crop species can be used to reduce pest and disease levels in potato. For biofumigation, crops like Indian mustard *(Brassica juncea*) and Oil radish (*Raphanus sativus*) with their rapid growth and ability to produce/release isothiocyanates have been well studied. Oilseed rape (*Brassica napus*) has also been shown to provide some control of early blight (*Alternaria solani*) (Runno-Paurson *et al*., 2019). There is also good evidence for the use of Sticky nightshade (*Solanum sisymbriifolium*) in the control of PCN (Timmermann *et al*., 2007). Alfalfa (*Medicago sativa*) has been shown to reduce *Rhizoctania solani* severity by 50% in potato (Snapp *et al.,* 2005). This study looked at the potential for individual cover crop species to improve the growth and reduce the pest and disease levels in 4 varieties of potato grown in Slovenia and the UK.

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Materials and methods

Cover crop trials were set up at Nafferton Farm, Northumberland, UK and in central Slovenia at Jablje, Kmetijski inštitut Slovenije in the 2020-21, 2021-23 and 2022-23 seasons.

A first set of cover crop trials was conducted with individual cover crop species, i.e. Black mustard (*Brassica juncea* - 10 kg/ha), Oil radish (*Raphanus sativus* - 15 kg/ha), Lucerne (*Medicago sativa* - 25 kg/ha), Black oat (*Avena strigosa* - 25 kg/ha) and Common vetch (*Vicia sativa* - 25 kg/ha). As only a small amount of Sticky nightshade (*Solanum sisymbriifolium*) was received, this species was not included as originally planned. A sixth treatment was included, which was a mixture of the 5 individual species based on 2 kg each of Black mustard and Oil radish together with 1 kg each of Lucerne, Black oat and Common vetch drilled at a seed rate of 15 kg/ha. Treatment number 7 was the control with no cover crops (except for the 2021-22 season at UNEW where no control treatment was planted).

At UNEW, the 6 treatments were drilled with a 3 m Horsch combination drill (after the land had been ploughed and pressed (to help retain moisture) approximately 3 weeks earlier with dimensions of 6 x 50 m for each plot/species. The land had been left fallow in the previous season and before that had been planted with the ECOBREED potato working collection (Task 3.1) to provide a high level of potato pest and disease pressure. A cover crop trial was sown in the first year on 11 August 2020 in a very dry dust-bowl at Nafferton Farm, Northumberland, UK, and despite good establishment the trial soon became over-grown with Charlock (*Sinapis alba*) and had to be destroyed before potatoes could be planted in spring 2021. As a result, replicated trials were carried out in the UK in both the 2021-22 and 2022-23 growing seasons.

The cover crop trial was ploughed in on 18 March 2022 with potatoes planted on the 14th of April. Tubers of 4 varieties i.e. Carolus, Casablanca, Alouette and Cara were sourced from the UK with Carolus and Alouette also being grown in the corresponding trial in Slovenia. Four rows of each cultivar were planted with the inner two rows only being used for yield and tuber quality analyses. Pest and disease assessments (early blight, late blight, Leaf roll and Virus Y) were carried out on 2, 11 and 18 August 2022 with the crop being flailed on 23rd August.

The cover crop/potato trial was harvested between 8-12 September with some interruptions due to rain. Tuber yields from the trial are presented in Table 1. Tuber yields were taken from the 2 middle rows based on a 4m plot length with 86.4cm between rows giving a harvested area of 6.91m^2. Tuber yield, tuber number, dry matter content and tuber <25mm, 25-45mm, 45-65mm, 65-85mm and >85mm were determined after

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harvest. Disease assessment in the field and of tubers was carried out according to the phenotypic descriptor list D3.1.

The second UK trial was planted on Wednesday 3rd August 2022 using the same design as in the previous season but with the inclusion of a control treatment (i.e. no cover crop). The crop was drilled into very dry conditions but rainfall in late August has meant that establishment was good. As a result, the remaining cover crop residues were ploughed into the ground on 28 March 2023 prior to the land being cultivated on 17th April with potatoes being planted on Tuesday, 18 April. The potato trial was harvested on the 7 September having been flailed in mid-August. Foliar disease assessment (early blight only) was carried out on 10/07, 27/07 and 09/08 in 2023.

At KIS, the 6 treatments were drilled with a 1.25 m Wintersteiger drill (after the land had been ploughed and pressed about 4 weeks earlier) with dimensions of 6.25 x 50 m for each plot/species. There was a four-year crop rotation: in previous year's wheat, maize, clover and potatoes were grown.

On 20 August 2020 the first cover crop trial was sown at KIS in IC Jablje. The establishment of cover crops in Slovenia was very good, so in 2021 the trial in Slovenia was ploughed in March and planted on 6 May over the cover crops with 4 potato varieties, i.e. Alouette, Carolus, KIS Tamar and KIS Kokra. Four rows of each variety were planted, with the inner two rows used only for yield and tuber quality analysis. Field disease assessments were carried out during the growing season. The trial was harvested on 26 October 2021.

On 10 August 2021, a second cover crop trial was sown at KIS in IC Jablje. The establishment of cover crops in Slovenia was again very good, so in 2022 the trial in Slovenia was ploughed in March and planted on 12 April over the cover crops with 4 of the same potato varieties as in the previous year. Four rows of each variety were planted, with the inner two rows used only for yield and tuber quality analysis. Field disease assessments were carried out during the growing season. The trial was harvested on 13 October 2022.

Statistical analysis was performed in each year separately, as no control treatment was used in the 2021-22 trial. At UNEW analysis of variance (ANOVA) was used to assess the effects and interactions between potato variety and cover crop species on the measured parameters in each season using the 'nlme' package in R (R Core Team, 2017). The normality of the residuals of all parameters was checked using the 'qqnorm' function in R. Means and standard errors of means for the main effects and the interaction effect tables were generated using the 'tapply' function in R. At KIS analysis of variance (ANOVA) was used to assess the effects and interactions between potato variety and cover crop

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species on measured parameters in each season using the Statgraphics program. Multiple range tests were used to differentiate between treatments.

Results

UNEW Season 2021-22

Cover crop establishment was very good in the autumn of 2021 particularly the brassica species (Black mustard and Oil radish) but the Black oat *Avena strigosa* showed low establishment. There were no symptoms of Virus Y at any of the assessment dates and for leaf roll virus only very low levels were detected and only in the cultivar Casablanca but with no effect of cover crop (data not presented). Following harvest tuber assessment showed no tuber irregularities with no tuber blight, scab or Rhizoctania evident on the tubers most likely due to the very dry conditions throughout the growing season and at harvest in 2022.

There were significant effects of potato cultivar (Table 1) on tuber yield ($p<0.05$), dry matter % ($p<0.001$), grading fraction 25-45 mm ($p<0.01$) and *Rhizoctonia solani* level ($p<0.001$). With respect to cover crop species there were significant effects on tuber yield ($P<0.001$), tuber DM% ($p<0.001$), grading fractions 25-45 mm ($p<0.001$) and 45-65mm (<0.05), early blight ($p<0.001$), late blight ($p<0.001$) and Rhizoctonia ($p<0.05$). There were no significant potato variety × cover crop species interaction in 2021-22. When averaged across all varieties and cover crop species, Cara and the species mixture produced the highest tuber yield. Conversely it was Cara and the species mixture which produced the lowest tuber dry matter %. Casablanca showed the highest susceptibility to early blight with Alouette and Carolus showing the highest susceptibility to late blight.

For each potato variety it was different cover crop species that produced the highest tuber yield i.e. Lucerne in Alouette, the species mix in Cara, Oil radish in Carolus and Black oat in Casablanca (Table 2). However Common vetch resulted in the lowest tuber yield in Cara, Carolus and Casablanca with Black mustard producing the lowest yield in Alouette. Rhizoctonia levels were highest in Carolus and lowest in Casablanca they were also highest following Common vetch and lowest following Black mustard. There was much greater consistency with respect to cover crop species on Rhizoctonia levels (Table 3) in that Black mustard produced the lowest Rhizoctonia levels in the varieties Cara, Carolus and Casablanca while the lowest levels in Alouette were following Oil radish. The highest Rhizoctonia levels in Alouette, Cara and Casablanca were following Common vetch while in Carolus it was following the cover crop species mixture.

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Table 1 Means of the effect of cover crop species and potato variety on the tuber yield, DM%, tuber grading, resistance to foliar disease and tuber disease levels at Nafferton Farm in 2021-22.

	Yield	DM	Tuber grading (mm)					EB*	LB*	Rhizoc**
	t/ha	%	<25	25-45	45-65	65-85	>85			
Cover crop (C)										
Lucerne	25.38	22.9	0	0.23	0.65	0.12	0	9.5	8.6	0.30
Black oat	24.31	22.8	0	0.23	0.72	0.04	0	9.4	8.7	0.46
Black mustard	23.00	23.5	0	0.25	0.70	0.04	0	9.6	8.5	0.14
Oil radish	24.11	23.1	0	0.24	0.70	0.06	0	8.5	8.5	0.35
Common vetch	21.27	23.0	0	0.29	0.65	0.06	0	9.3	8.3	0.64
Species mix	26.02	21.6	0	0.20	0.72	0.08	0	9.3	8.6	0.45
Variety (V)										
Alouette	21.85	22.9	0	0.31	0.63	0.06	0	9.5	7.9	0.36
Casablanca	20.92	22.8	0	0.24	0.73	0.03	0	8.9	8.7	0.26
Cara	30.12	21.8	0	0.18	0.71	0.11	0	9.7	9.7	0.44
Carolus	23.16	23.8	0	0.24	0.70	0.06	0	9.9	7.9	0.48
Anova										
Cover crop	*	***	NS	**	NS	NS	NS	NS	NS	***
Variety	***	***	NS	***	*	NS	NS	***	***	*
C × V	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

*Resistance to Early blight (EB) and Late blight (LB) was assessed on a 1-10 scale where 1 = plants completely blighted (occasionally parts of stem not affected), 5= 50% of leaves infected and 10= occasional necrotic spots.
**Rhizoctonia levels are presented as a proportion of total tuber weight

Table 2 Tuber yields (t/ha) ± SE of the cover crop trial at Nafferton Farm in the UK in the 2021-22 season.

Cover crop species	Alouette	Cara	Carolus	Casablanca
Lucerne	24.01 ± 5.05	31.60 ± 2.81	24.85 ± 2.43	21.08 ± 1.25
Oil radish	21.26 ± 1.40	28.88 ± 0.88	24.89 ± 1.03	21.43 ± 1.89
Black mustard	20.23 ± 1.05	28.00 ± 2.08	24.27 ± 1.06	19.47 ± 1.33
Common vetch	20.66 ± 0.13	27.00 ± 1.14	19.65 ± 1.31	17.78 ± 0.93
Black oat	23.75 ± 0.98	29.14 ± 0.63	21.21 ± 1.74	23.12 ± 1.60
Species mix	21.17 ± 4.04	36.12 ± 2.81	24.11 ± 2.86	22.67 ± 0.12

When averaged across all cover crop treatments the highest tuber yield was in Cara (30.12 t/ha) and the lowest in Casablanca (20.92 t/ha). When averaged across all four varieties the tuber yield following the cover crop mixture was highest at 26.02 t/ha followed by Lucerne (25.38 t/ha) and the lowest following Vetch (21.27 t/ha). For the varieties Cara, Carolus and Casablanca the lowest tuber yield was following Vetch but for the variety Alouette it was after Black mustard which was only 0.43 t/ha lower than Vetch (Table 2). For Alouette the highest tuber yield occurred following Lucerne while for Cara it was after

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the mixture of cover crop species while for Carolus and Casablanca it was following Oil radish and Black oat respectively.

Table 3 Proportion of tubers infected with *Rhizoctonia solani* ± SE as influenced by potato variety and cover crop species at Nafferton Farm, UK in the 2021-22 season.

Cover crop species	Alouette	Cara	Carolus	Casablanca
Lucerne	0.46 ± 0.12	0.26 ± 0.15	0.39 ± 0.19	0.07 ± 0.04
Oil radish	0.16 ± 0.08	0.25 ± 0.20	0.61 ± 0.13	0.29 ± 0.17
Black mustard	0.06 ± 0.03	0.10 ± 0.01	0.28 ± 0.10	0.12 ± 0.02
Vetch	0.60 ± 0.06	0.88 ± 0.06	0.56 ± 0.15	0.52 ± 0.17
Black oat	0.53 ± 0.23	0.65 ± 0.06	0.35 ±0.03	0.30 ± 0.08
Species mix	0.38 ± 0.03	0.50 ± 0.13	0.67 ± 0.11	0.23 ± 0.10

UNEW Season 2022-23

In the following season despite being drilled in very dry conditions following a warm and dry summer at Nafferton, cover crop establishment was good and with rain occurring in September followed by mild and good growing conditions a high level of crop biomass was achieved (Fig 1). Rapid growth in the autumn due to mild weather conditions meant that in December/January the Oil radish, Black mustard and Black oat species were at stem extension. Two very cold periods of weather for about 12 days in mid-December 2022 and then again for about 10 days in mid-January 2023 resulted in senescence of the Oil radish, Black mustard and Black oat species together with a large amount of crop biomass in the species mixture treatment. This had not occurred in the previous season and was likely due to the early cover crop development into the more sensitive stem extension phase then combined with a prolonged period of freezing temperature and snowfall resulting in senescence. This was not the case for the Common vetch and Lucerne which were at a much earlier stage of their crop development cycle. The wet summer in the UK from the beginning of July resulted in high levels of tuber scab, *Rhizoctonia solani* and slug damage with 52 out of the 84 plots showing slug damage of harvested tubers (data not presented).

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Fig 1 Cover crops established in the early autumn of 2022 at Nafferton Farm in the UK.

Tuber yields were lower in 2022-23 but again Cara produced the highest yield but this time it was the Oil radish cover crop that produced the highest tuber yield being 12.52 t/ha higher than the control (Table 4). There were significant effects of potato variety on tuber yield ($p<0.001$), tuber DM% ($p<0.001$), grading fractions 25-45 mm ($p<0.001$), 65-85 mm ($p<0.001$), >85mm ($p<0.001$) and scab ($p<0.001$). With respect to cover crop species there were significant effects on tuber yield ($p<0.001$), grading fraction 25-45mm ($p<0.001$), 65-85 mm ($p<0.001$) and tuber scab ($p<0.05$). Although Rhizoctonia levels were higher in 2022-23 than the previous season there was no significant effect of potato variety or cover crop species. There were significant potato variety × cover crop species interactions on the grading fractions 25-45 mm ($P<0.001$), 45-65mm ($p<0.05$) and 65-85 mm ($P<0.05$).

No tuber scab had been reported following the very dry 2022 growing season but in 2023 scab levels were high with Carolus having 49% of tubers infected and Casablanca the lowest at 26%. The highest tuber scab levels occurred following Common vetch and the species mixture (45% of tubers infected) and the lowest following the control treatment (24% of tubers infected).

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There was greater consistency in the effect of cover crop species in the 2022-23 season whereby Oil radish resulted in the highest tuber yield and Black oat the lowest tuber yield in all potato varieties (Table 5). The highest proportion of tubers affected by scab (Table 6) was following Common vetch for Cara and Casablanca, following the species mixture for Alouette and following Black oat and the species mixture for Carolus. The lowest proportion of tubers affected by scab occurred for Alouette following Common vetch, for Cara following Oil radish and the control (no cover crop), for Carolus following Black mustard and for Casablanca following Oil radish.

Table 4 Means of the effect of cover crop species and potato variety on the tuber yield, DM%, tuber grading and tuber disease levels at Nafferton Farm in 2022-23.

	Yield	DM	Tuber grading (mm)					Scab**	Rhizoc***
	t/ha	%	<25	25-45	45-65	65-85	>85		
Cover crop (C)									
Lucerne	15.04	21.6	0	0.27	0.68	0.05	0	0.43	0.99
Black oat	10.57	21.9	0	0.38	0.58	0.03	0	0.37	0.92
Black mustard	23.79	21.9	0	0.19	0.68	0.13	0	0.37	0.96
Oil radish	29.23	21.8	0	0.16	0.70	0.13	0	0.27	0.99
Common vetch	15.91	21.7	0	0.25	0.67	0.08	0	0.45	0.95
Species mix	23.32	22.2	0	0.18	0.61	0.19	0.01	0.45	0.99
Control	16.71	21.8	0	0.19	0.70	0.10	0	0.24	0.99
Variety (V)									
Alouette	16.34	22.0	0	0.33	0.65	0.02	0	0.41	0.96
Casablanca	19.70	21.5	0	0.26	0.69	0.05	0	0.26	0.99
Cara	23.82	22.0	0	0.12	0.61	0.25	0.02	0.31	0.97
Carolus	17.03	21.8	0	0.22	0.69	0.09	0	0.49	0.97
Anova									
Cover crop	***	NS	NS	***	NS	**	NS	*	NS
Variety	***	***	NS	***	NS	***	***	***	NS
C × V	NS	NS	NS	**	*	*	NS	NS	NS

* Early blight (EB) and Late blight (LB) were assessed on a 1-10 scale Scale of 1-10 where 1 = plants completely blighted (occasionally parts of stem not affected), 5= 50% of leaves infected and 10= no symptoms, occasional necrotic spots.
** Scab levels are presented as a proportion of tuber number
*** *Rhizoctonia solani* levels are presented as a proportion of tuber weight

Table 5 Tuber yields (t/ha) ±SE of the cover crop trial at Nafferton Farm in the UK in the 2022-23 season.

Cover crop species	Alouette	Cara	Carolus	Casablanca
Lucerne	13.23 ± 0.62	18.74 ± 1.62	14.41 ± 3.67	13.77 ± 0.68
Oil radish	22.76 ±0.66	34.76 ± 1.35	30.30 ± 1.40	29.10 ± 2.53
Mustard	18.75 ± 0.74	32.17 ± 1.87	21.55 ± 2.25	22.70 ± 0.97
Common vetch	15.44 ± 1.48	17.54 ± 6.26	11.62 ± 4.78	19.05 ± 1.99
Black oat	9.62 ± 1.88	12.12 ± 4.48	7.28 ± 3.64	13.26 ± 1.42
Species mix	20.30 ± 0.86	31.6 ± 0.50	18.40 ± 4.05	22.99 ± 1.46
Control	14.30 ± 2.68	19.81 ± 3.73	15.67 ± 4.77	17.07 ± 1.88

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Table 6 Proportion of tubers infected by scab in response to potato variety and cover crop species at Nafferton Farm, UK in the 2022-23 season.

Cover crop species	Alouette	Cara	Carolus	Casablanca
Lucerne	0.45 ± 0.14	0.50 ± 0.08	0.48 ± 0.14	0.29 ± 0.11
Oil radish	0.39 ± 0.12	0.11 ± 0.05	0.40 ± 0.06	0.17 ± 0.13
Mustard	0.41 ± 0.01	0.37 ± 0.11	0.19 ± 0.14	0.21 ± 0.11
Common vetch	0.28 ± 0.01	0.55 ± 0.04	0.61 ± 0.13	0.37 ± 0.18
Black oat	0.36 ± 0.15	0.29 ± 0.11	0.59 ± 0.09	0.25 ± 0.09
Species mix	0.67 ± 0.15	0.24 ± 0.05	0.58 ± 0.04	0.32 ± 0.04
Control	0.34 ± 0.17	0.12 ± 0.05	0.27 ± 0.12	0.22 ± 0.12

KIS Season 2020-21

Very good cover crop emergence and development was achieved in the 2020 (Fig 2). The crops were clean, healthy and without weeds.

Fig. 2. Cover crop trial established at KIS at Jablje farm taken on 29 September 2020.

Year 2021 was very wet in May, delaying emergence until the end of May, and very dry and hot in June. Soils compacted by the rain in May and high temperatures affected leaf growth, which was rather small by the end of June. The weather in July and August is crucial for late potato crops. In 2021 they were without any major stresses, with enough rain and not too high temperatures, so the plants were able to produce good yields.

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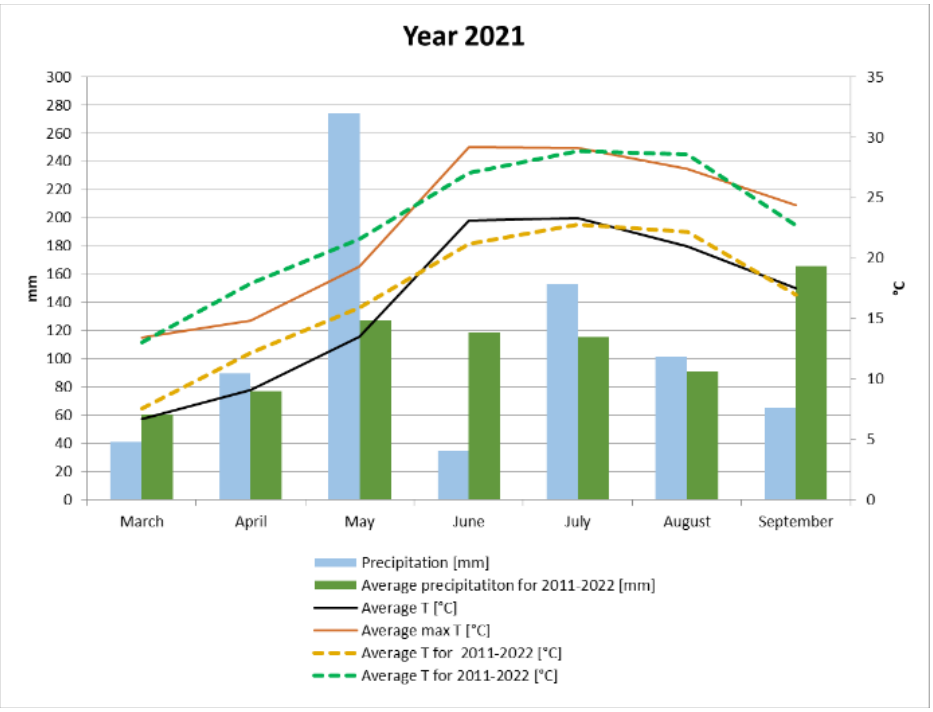

Fig. 3. Weather conditions at Domžale (close to Jablje trial site) in 2021.

Yield

Tuber yields and yield characteristics of cultivars from the 2020-21 season in Slovenia are shown in Table 7. The yields are rather high due to good weather in 2021. The highest yields were achieved by the two Slovenian cvs. KIS Tamar (45.43 t/ha) and KIS Kokra (39.71 t/ha), which also had the largest tubers. They had significantly better yields than cvs. Alouette and Carolus (Table 9). The differences in yields after cover crops were also statistically significant, with the highest average yields after Lucerne (43.39 t/ha), followed by the mixture of species, and the lowest after Oil radish and in the control without cover crops (Tables 8 and 10). There were no significant differences in tuber number between cultivars and between different cover crops. There was a positive interaction between cultivar and cover crop on yield, meaning that the effect of cover crops on yield was cultivar dependent.

Table 7. Tuber yields (t/ha), number of tubers per plant and tuber sizes of cultivars at KIS in the 2020-21 season.

Cultivar	Yield t/ha	No. of tubers	<25	25-45	45-65	65-85	>85
Alouette	32.38	16.7	0.01	0.62	0.37	0.00	0.00
Carolus	30.37	15.9	0.01	0.62	0.37	0.00	0.00
KIS Kokra	39.70	13.8	0.00	0.27	0.71	0.02	0.00
KIS Tamar	45.43	14.8	0.00	0.21	0.75	0.04	0.00

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Table 8. Tuber yields (t/ha), number of tubers per plant and tuber sizes following different cover crop species at KIS in the 2020-21 season.

Cover crop	Yield t/ha	No. of tubers	<25	25-45	45-65	65-85	>85
Black mustard	33.99	14.4	0.01	0.45	0.54	0.01	0.00
Oil radish	29.31	12.3	0.00	0.33	0.41	0.01	0.00
Lucerne	43.19	16.5	0.00	0.35	0.60	0.04	0.00
Black oat	36.46	14.6	0.00	0.41	0.58	0.01	0.00
Common vetch	35.86	16.2	0.00	0.45	0.53	0.01	0.00
Species mix	38.50	15.4	0.01	0.44	0.54	0.01	0.00
Control	33.60	13.5	0.01	0.42	0.56	0.02	0.00

Table 9 Multiple range tests for yield in 2021 by cultivar.
Method: 95,0 percent LSD

Cultivar	*Count*	*LS Mean*	*LS Sigma*	*Homogeneous Groups*
Carolus	21	30.3657	1.96472	X
Alouette	21	32.3848	1.96472	X
KIS Kokra	21	39.5962	1.96472	X
KIS Tamar	21	41.0305	1.96472	X

Table 10 Multiple range tests for yield in 2021 by cover crop.
Method: 95,0 percent LSD

Cover crop	*Count*	*LS Mean*	*LS Sigma*	*Homogeneous Groups*
Oil radish	12	29.31	2.599	X
Control	12	33.60	2.599	XX
Black mustard	12	33.99	2.599	XX
Common vetch	12	35.86	2.599	XXX
Black oat	12	36.46	2.599	XXX
Species mix	12	38.5	2.599	XX
Lucerne	12	43,19	2.599	X

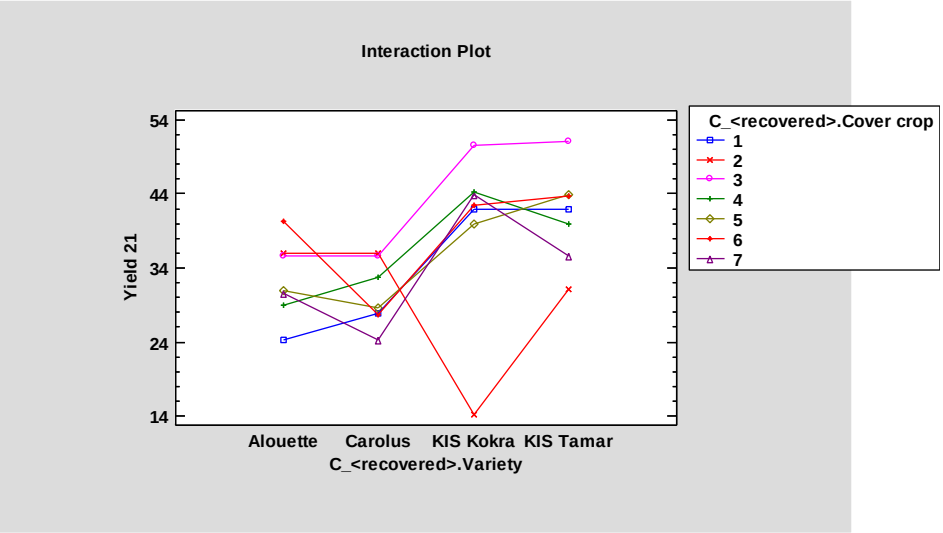

Fig. 4. Interaction plot of yield between cultivar and cover crop in 2021.

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Tuber quality assessment

In December 2021, tubers from the 2020-21 season cover crop trial were analysed at KIS. A total of 14 quality parameters described in D3.1 (10 of which are listed in Tables 11 and 12) were evaluated. Hollow heart, black heart, internal heat necrosis and vascular discolouration were not observed, so these data are not included in the report. Traits were scored from 1 to 9, with 9 being the best, and diseases were scored as 1.

There were no significant differences in tuber quality between cultivars (Table 11). Alouette had good shape regularity, the shallowest eyes, good uniformity, intermediate skin finish, but was more susceptible to secondary growth, with almost no Rhizoctonia and Common scab observed. It was the worst for Silver scurf. Carolus had poor uniformity and skin finish but had the most secondary growth and severe Common scab infection. KIS Tamar was among the best for almost all quality parameters, while KIS Kokra was the worst for uniformity of shape and depth of eyes, with additional problems of some cracks on tubers, most likely caused by Rhizoctonia.

Table 11. Tuber quality characteristics of cultivars at KIS in the 2020-21 season.

	1-9	1-9	1-9	1-9	%	%	No.	1-6	1-5	1-5
Cultivar	**Regularity shape**	**Depth of eyes**	**Uniformity**	**Skin finish**	**Mechanical damage**	**Secondary growth**	**Cracks**	**Rhizoctonia**	**Silver scurf**	**Common scab**
Alouette	7.7	8.5	7.5	5.1	0.0	0.4	0.0	0.1	4.5	0.0
Carolus	5.9	7.3	7.1	3.9	0.0	0.8	0.0	1.2	1.5	4.5
KIS Kokra	5.2	5.5	6.9	5.5	0.0	0.1	3.0	1.7	2.4	1.9
KIS Tamar	8.0	8.4	7.2	7.4	0.1	0.1	0.0	0.8	2.1	0.8

There were also no significant differences in tuber quality between the cover crops used, but there was an improvement in quality compared to the control treatment. Control has more secondary growth, cracking and Rhizoctonia and the tubers were less regular and uniform. Black mustard trial had the best shape regularity and uniformity, while Lucerne and Black mustard trials had the best skin quality. Black mustard trial also had the lowest number of cracks, followed by Common vetch. Infestation with Common scab was lower after Lucerne, Oil radish and Black mustard (Table 12).

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Table 12. Tuber quality characteristics of cover crops at KIS in the 2020-21 season.

	1-9	1-9	1-9	1-9	%	%	No.	1-6	1-5	1-5
Cover crop	Regularity shape	Depth of eyes	Uniformity	Skin finish	Mechanical damage	Secondary growth	Cracks	Rhizoctonia	Silver scurf	Common scab
Black mustard	7.1	7.6	7.6	5.8	0.0	0.3	0.5	1.0	3.1	1.5
Oil radish	6.7	7.3	7.1	5.7	0.0	0.3	0.9	1.0	2.5	1.5
Lucerne	6.8	7.2	7.1	6.1	0.0	0.3	0.9	0.8	2.8	1.4
Black oat	6.8	7.5	7.2	5.5	0.0	0.3	1.3	0.8	2.3	1.8
Common vetch	6.8	7.6	7.1	5.6	0.0	0.4	0.6	0.8	2.6	1.7
Species mix	6.5	7.1	7.3	5.2	0.1	0.2	1.1	1.1	2.7	1.9
Control	5.8	7.1	6.8	5.3	0.2	0.7	1.5	1.5	2.9	1.8

KIS Season 2021-22

The year 2022 was very dry from winter onwards, with well below average rainfall for the first eight months of the year, with the exception of April (which was just in time for planting and emergence). In the trial area, we faced extremely dry conditions that affected potato yield. Heavy rain came in September, when it was too late for the potato crop development (Fig 5).

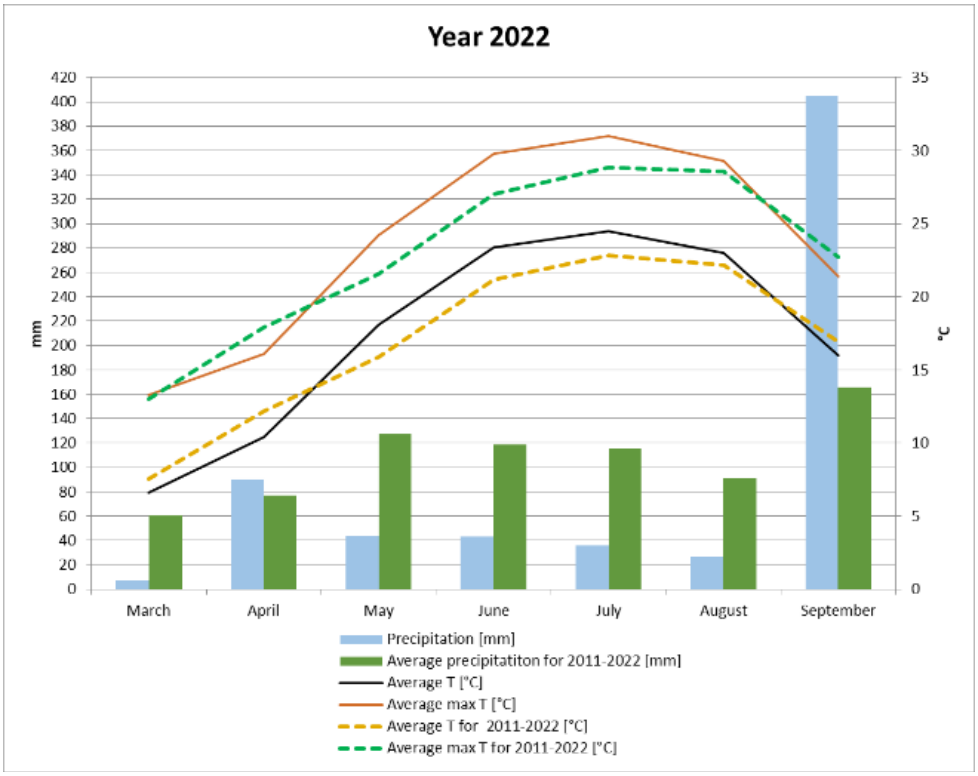

Fig. 5. The weather conditions at Domžale (close to Jablje trial site) in 2022.

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Yield

The average tuber yields and other yield characteristics for each variety and cover crop from the 2021-22 season in Slovenia are presented in Tables 13 and 14.

Table 13. Tuber yields (t/ha), number of tubers per plant and tuber sizes of cultivars at KIS in the 2021-22 season.

Cultivar	Yield t/ha	No. of tubers	<25	25-45	45-65	65-85	>85	Dry matter %
Alouette	15.96	7.96	0.01	0.58	0.40	0.00	0.00	23.49
Carolus	16.25	10.30	0.02	0.74	0.24	0.00	0.00	23.47
KIS Kokra	14.77	8.18	0.01	0.54	0.44	0.00	0.00	25.54
KIS Tamar	14.79	7.11	0.02	0.45	0.51	0.02	0.00	24.35

Table 14. Tuber yields (t/ha), number of tubers per plant and tuber sizes of cover crops at KIS in the 2021-22 season.

Cover crop	Yield t/ha	No. of tubers	<25	25-45	45-65	65-85	>85	Dry matter %
Black mustard	11.43	7.19	0.02	0.71	0.28	0.00	0.00	24.50
Oil radish	18.09	8.52	0.01	0.46	0.51	0.02	0.00	24.07
Lucerne	12.50	8.33	0.02	0.71	0.26	0.01	0.00	22.85
Black oat	18.35	8.72	0.01	0.46	0.53	0.01	0.00	24.43
Common vetch	18.01	9.28	0.01	0.54	0.44	0.01	0.00	24.48
Species mix	14.96	8.38	0.01	0.64	0.34	0.00	0.00	24.41
Control	14.94	7.87	0.01	0.50	0.48	0.01	0.00	25.26

There were no significant differences between the cultivars tested, while there were significant differences in yield between the cover crops (Tables 15 and 16). The significantly higher yields were achieved after Black oats, Oil radish and Common vetch.

Table 15 Multiple range tests for yield in 2022 by cover crop.
Method: 95,0 percent LSD

Cover crop	*Count*	*LS Mean*	*LS Sigma*	*Homogeneous Groups*
Black mustard	12	11.43	1.0040	X
Lucerne	12	12.5	1.0040	XX
Control	12	14.937	1.0040	X
Species mix	12	14.963	1.0040	X
Common vetch	12	18.007	1.0040	X
Oil radish	12	18.093	1.0040	X
Black oat	12	18.35	1.0040	X

Dry matter content is highly dependent on variety and weather conditions. In 2022 the dry matter content was very high due to the dry growing conditions and low yields. There were significant differences in dry matter content between the cultivars tested and

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between the cover crops, but there was no interaction between them. The highest dry matter content was obtained with cv. KIS Kokra, followed by KIS Tamar (Table 16). Cover crops also influenced the dry matter content, with the highest being achieved by the control, followed by Black mustard and Common vetch (Table 17).

Table 16. Multiple range tests for dry matter in 2022 by Cultivar
Method: 95,0 percent LSD

Cultivar	*Count*	*LS Mean*	*LS Sigma*	*Homogeneous Groups*
Carolus	21	23.4714	0.209923	X
Alouette	20	23.4929	0.217291	X
KIS Tamar	21	24.3476	0.209923	X
KIS Kokra	21	25.8333	0.209923	X

Table 17. Multiple range tests for dry matter in 2022 by Cover crop
Method: 95,0 percent LSD

Cover crop	*Count*	*LS Mean*	*LS Sigma*	*Homogeneous Groups*
Lucerne	12	22.85	0.2777	X
Oil radish	12	24.0667	0.2777	X
Species mixture	12	24.4083	0.2777	X
Black oat	12	24.433	0.2777	X
Common vetch	12	24.4833	0.2777	XX
Black mustard	12	24.5	0.2777	XX
Control	11	25.2625	0.2945	X

Tuber quality assessment

In December 2022, tubers from the 2021-22 season cover crop trial at KIS were analysed. A total of 14 quality parameters described in D3.1 and 10 of them listed (Table 18) were evaluated. Hollow heart, black heart, internal heat necrosis and vascular discolouration were not observed in 2022. Traits were scored from 1 to 9, with 9 being the best score, while for diseases a score of 1 was the best score. There were large differences between the cultivars, which was to be expected as resistance is genetically determined and depends on the genes in a particular genotype. Alouette had good shape regularity, the shallowest eyes, good uniformity, skin finish, but was more susceptible to secondary growth, with almost no Rhizoctonia and Common scab observed, but was the worst for Silver scurf infection. Carolus had good uniformity and skin finish but had the most Common scab. KIS Tamar was among the best for almost all quality parameters, while KIS Kokra was the worst for uniformity and eye depth, with additional problems of some cracks on tubers, most likely caused by Rhizoctonia (Table 18).

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Table 18. Tuber quality characteristics of cultivars at KIS in the 2021-22 season.

	1-9	1-9	1-9	1-9	%	%	No.	1-6	1-5	1-5
Cultivar	**Regularity shape**	**Depth of eyes**	**Uniformity**	**Skin finish**	**Mechanical damage**	**Secondary growth**	**Cracks**	**Rhizoctonia**	**Silver scurf**	**Common scab**
Alouette	7.9	8.0	7.5	7.0	0.2	0.2	0.0	0.0	3.3	0.0
Carolus	7.5	8.0	6.7	6.9	0.2	0.6	0.0	0.1	0.6	1.1
KIS Kokra	5.9	6.1	6.2	5.8	0.2	0.6	0.1	0.8	0.6	0.1
KIS Tamar	6.1	7.8	5.8	6.4	0.2	1.9	0.6	0.2	1.6	0.2

For the tuber quality of the crop following certain cover crops in 2022, there were differences in several tested traits (Table 19). Eye depth is a highly heritable trait, so we did not expect large differences. Oil radish scored best for shape regularity, the control was the most uniform (at low yield) and the species mix gave the best skin finish. Oil radish and Common vetch had the least secondary growth. Species mix was most affected by Rhizoctonia, control by Silver scurf and Common scab by Black oat. Only some of the differences were significant and are shown in Tables 21 and 26.

Table 19. Tuber quality characteristics of cover crops at KIS in the 2021-22 season.

	1-9	1-9	1-9	1-9	%	%	No.	1-6	1-5	1-5
Cover crop	**Regularity shape**	**Depth of eyes**	**Uniformity**	**Skin finish**	**Mechanical damage**	**Secondary growth**	**Cracks**	**Rhizoctonia**	**Silver scurf**	**Common scab**
Black mustard	6.7	7.3	6.3	6.1	0.0	1.1	0.4	0.3	1.5	0.2
Oil radish	7.2	7.4	6.4	6.5	0.0	0.4	0.0	0.3	1.7	0.5
Lucerne	6.0	7.3	6.6	6.1	0.8	1.1	0.4	0.0	0.9	0.3
Black oat	7.1	7.5	6.7	6.6	0.0	1.3	0.3	0.3	2.0	0.6
Common vetch	6.7	7.3	6.3	6.7	0.0	0.4	0.0	0.3	1.2	0.2
Species mix	7.0	7.4	6.6	6.9	0.8	0.8	0.2	0.5	1.7	0.2
Control	7.0	7.4	6.8	6.3	0.0	0.8	0.0	0.0	2.3	0.3

The significant difference between cultivars in regularity of shape is seen in Table 20. The cultivar Alouette had the best regularity of shape, followed by Carolus and KIS Tamar.

Table 20. Multiple range tests for regularity of shape by cultivar.
Method: 95,0 percent LSD

Cultivar	*Count*	*LS Mean*	*LS Sigma*	*Homogeneous Groups*
KIS Kokra	21	5.667	0.1259	X
KIS Tamar	21	6.143	0.1259	X
Carolus	21	7.476	0.1259	X
Alouette	21	7.904	0.1259	X

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The best regularity of shape was achieved after Oil radish, followed by Black oats, the control and mixture. The worst regularity of shape was found after Lucerne (Table 21), which could be caused by intensive growth due to more nitrogen in the soil.

Table 21. Multiple range tests for regularity of shape by cover crop.
Method: 95,0 percent LSD

Cover crop	*Count*	*LS Mean*	*LS Sigma*	*Homogeneous Groups*
Lucerne	12	6.0	0.1667	X
Black mustard	12	6.667	0.167	X
Common vetch	12	6.667	0.167	X
Species mix	12	7.0	0.167	XX
Control	12	7.0	0.167	XX
Black oat	12	7.083	0.167	XX
Oil radish	12	7.167	0.167	X

Eye depth is a highly heritable trait, so we expected the differences between cultivars. The results confirm their descriptions (Table 22).

Table 22. Multiple range tests for deepness of eyes by cultivar.
Method: 95,0 percent LSD

Cultivar	*Count*	*LS Mean*	*LS Sigma*	*Homogeneous Groups*
KIS Kokra	21	5.857	0.079	X
KIS Tamar	21	7.762	0.079	X
Carolus	21	7.952	0.079	XX
Alouette	21	8.0	0.079	X

There were significant differences between cultivars for uniformity, Rhizoctonia and Common scab (Tables 23 to 25). The cultivar Alouette was significantly better for uniformity than the Slovenian cultivars KIS Kokra and KIS Tamar, while Carolus had better uniformity only compared to KIS Tamar. In terms of Rhizoctonia infection, KIS Kokra was much more infected than the others, which is in line with previous results. The cultivar Carolus had the worst Common scab score, to the extent that the tubers were not marketable.

Table 23. Multiple range tests for uniformity of tubers by cultivar.
Method: 95,0 percent LSD

Cultivar	*Count*	*LS Mean*	*LS Sigma*	*Homogeneous Groups*
KIS Tamar	21	5.762	0.222	X
KIS Kokra	21	6.143	0.222	XX
Carolus	21	6.714	0.222	X
Aouette	21	7.524	0.222	X

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Table 24. Multiple range tests for Rhizoctonia by cultivar.
Method: 95,0 percent LSD

Cultivar	*Count*	*LS Mean*	*LS Sigma*	*Homogeneous Groups*
Alouette	21	0	0.126	X
Carolus	21	0.095	0.126	X
KIS Tamar	21	0.190	0.126	X
KIS Kokra	21	0.762	0.126	X

Table 25. Multiple range tests for Common scab by cultivar.
Method: 95,0 percent LSD

Cultivar	*Count*	*LS Mean*	*LS Sigma*	*Homogeneous Groups*
Alouette	21	0	0.119	X
KIS Kokra	21	0	0.119	X
KIS Tamar	21	0.190	0.119	X
Carolus	21	1.095	0.119	X

The significant differences in Silver scurf infection in cover crops can be seen in Table 26. The lowest Silver scurf infection was found after Lucerne and the highest infection in the control plot. Besides Lucerne, Black mustard and Common vetch gave significantly less infected tubers compared to the control.

Table 26. Multiple range tests for silver scurf by cover crop.
Method: 95,0 percent LSD

Cover crop	*Count*	*LS Mean*	*LS Sigma*	*Homogeneous Groups*
Lucerne	12	0.916667	0.267	X
Common vetch	12	1.16667	0.267	X
Black mustard	12	1.5	0.267	XX
Oil radish	12	1.66667	0.267	XXX
Species mix	12	1.66667	0.267	XXX
Black oat	12	2.0	0,267	XX
Control	12	2.33333	0.267	X

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Discussion

At both locations, yield and its characteristics were influenced by the choice of cultivar and cover crop in both years. The differences were significant in most cases, with the exception of the very dry 2022 in Slovenia, when yields were very low. Most of the interactions were not significant, which means that there is no strong relationship between cultivar and cover crop. This means that a cover crop effect can be expected for most of the cultivars used by farmers.

For UNEW Rhizoctonia, scab and slug damage were more severe in the 2022-23 season in the UK, as Rhizoctonia symptoms tend to be more frequent and severe on cool, moist soils at temperatures of 16°C-23°C. Cultivar susceptibility to *R. solani* varies and was clearly evident in the 2021-22 season, but with much higher levels in 2022-23, no significant difference was observed between varieties. Good seed health is important in minimising the risk of Rhizoctonia disease and therefore the use of tubers harvested from the previous season in these two cover crop trials may have contributed to the high levels of *Rhizoctonia solani* in both seasons. The use of clean, certified seed is recommended and seed samples should be washed and inspected for signs of visible black scurf. Microscopic fungal growth that isn't visible to the naked eye may also be present, so laboratory testing could have helped detect seed infection.

Looking at the tuber quality traits observed in Slovenia, there were differences between cultivars in a number of traits, many of which are genetically determined and were expected (e.g. eye depth, disease resistance etc). In 2021, when growing conditions were good, there were no differences in tuber quality between the different cover crop treatments. It seems that in the stressful conditions of 2022, the choice of cover crop (sown in the previous year) influenced (improved) tuber quality at least in terms of shape regularity and Silver scurf infection.

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