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Project Code	
Project Type	

FINAL REPORT 2022

Applicants must read the *SAGIT Project Funding Guidelines* prior to completing this form. These guidelines can be downloaded from www.sagit.com.au

Final reports must be submitted by email to admin@sagit.com.au as a Microsoft Word document in the format shown **within two months** after the completion of the Project Term.

PROJECT CODE	TC119
PROJECT TITLE	(10 words maximum)
Increasing the reliability of lentil production on sandy soils	

PROJECT DURATION *These dates **must** be the same as those stated in the Funding Agreement.*	
Project start date	**1/04/2019**
Project end date	**30/06/2021**

PROJECT SUPERVISOR CONTACT DETAILS *(responsible for the overall project)*		
Title:	**First Name:**	**Surname:**
	Sam	Trengove
Organisation:	**Trengove Consulting**	

ADMINISTRATION CONTACT DETAILS *(responsible for all administrative matters relating to project)*		
Title:	**First Name:**	**Surname:**
	Sam	Trengove

PROJECT REPORT: *Please provide a clear description for each of the following:*

Executive Summary (200 words maximum)

A few paragraphs covering what was discovered, written in a manner that is easily understood and relevant to SA growers. A number of key dot points should be included which can be used in SAGIT communication programs.

This project has highlighted four key areas for improving lentil productivity on underperforming sands.

- Four key steps to improving lentil productivity on underperforming sandy soils are: soil amelioration, variety selection, herbicide choice and nutrient management.
- Ameliorating (e.g. deep ripping, spading, chicken litter application, etc.) soil constraints increased lentil grain yields up to 347%, with an average 0.31t/ha (85%) yield response to deep ripping.
- The highest yielding varieties on loamy soil types may not be the highest yielding on underperforming sandy soils. Lines with higher biomass production levels were found to perform relatively better on sandy soils than heavier textured types.
- Weed control methods on sandy soil types must be carefully planned to minimise yield loss due to the heightened risk of herbicide damage from soil residual herbicides. Currently, there are no suitable safe IBS herbicide strategies for managing high weed burden areas on sandy soils with high levels of weed control. New herbicides and/or novel herbicide tolerant crop options show promise for lentil production on sandy soils.
- Sandy soils with high soil pH (alkaline sites tested had pH CaCl2 0-10cm > 7.8) may be at greater risk of unacceptable crop damage from group B and group C herbicides used IBS when compared to sandy soils with lower soil pH.
- Nutrient requirements on sandy soil types can vary across locations and seasons. Application of molybdenum at 25g/ha on acidic sands pH $CaCl_2$ <6 (0-10cm) was shown to increase grain yields.
- Lentil growth and biomass, as measured by NDVI, was positively correlated with grain yield on sandy soils and suggest growers should employ management options to promote biomass production and avoid practices that supress biomass growth eg crop damage from herbicide application or early season insect attack.
- Lentil varieties with new novel traits such as tolerance to clopyralid and metribuzin herbicides can provide safe alternative weed control compared to traditional group B and C herbicides that are commonly used. The importance of this may become greater as resistance develops in species such as milk thistle, prickly lettuce and Indian hedge mustard.

Project objectives

A concise statement of the aims of the project in outcome terms should be provided.

This project aims to improve the reliability of lentil production in South Australia through the development of improved nutrition and weed control practices for growers. It will expand on knowledge gained in the previous project TC116, Increasing lentil productivity on dune swale soils, and address knowledge gaps identified in that project.

Five primary areas for investigation are:

1. Assess the agronomic and economic value of new novel herbicide traits under development in lentil breeding programs, including tolerance to metribuzin and clopyralid herbicides.
2. Continued investigation of best practice herbicide strategies for sandy soils; this will include assessment of crop safety, herbicide efficacy and yield loss associated with weed competition.
3. Understand the differences in herbicide activity and safety on alkaline sands compared with neutral and acidic sands.
4. Continued varietal evaluations on poorer performing sandy soils.
5. Lentil nutritional responses on acidic sandy soils, in particular responses to Molybdenum.

It was also originally proposed to investigate

6. Lentil response to liming and increased soil pH on acidic sandy soils

However, this area of research was covered in the GRDC soil acidity project 'New knowledge and practices to address topsoil and subsurface acidity under minimum tillage cropping systems of South Australia'. As such and through a project variation this research area was replaced with item 3 above, investigating herbicide safety on alkaline sands.

Overall Performance

A concise statement indicating the extent to which the project objectives were achieved, a list of personnel who participated in the Research Project including co-operators, and any difficulties encountered and the reasons for these difficulties.

All project objectives were achieved, as follows

1. *Assess the agronomic and economic value of new novel herbicide traits under development in lentil breeding programs, including tolerance to metribuzin and clopyralid.*
   This objective was achieved, with a total of four trials being implemented over two seasons at four different locations. Two trials were located on sandy soils in the northern YP region and two on clay loam soils in the central YP region. Each trial included four genotypes, the commercially available varieties of PBA Jumbo2 and PBA Hurricane XT (IMI tolerant) and two novel breeding lines from Global Grain Genetics (GGG)/Grains Innovation Australia (GIA), GIA1703L (clopyralid + IMI tolerant) and GIA2004L (metribuzin + IMI tolerant). Each variety/line was treated with a different strategy for incorporation by sowing (IBS) and post-emergent herbicide application in line with its herbicide tolerance profile. All trials were completed successfully and weed control, plant growth levels (NDVI) and grain yield were assessed. An additional metribuzin tolerance trial was held in 2019 and assessed weed control and crop tolerance to an IBS metribuzin herbicide application on a metribuzin tolerant line from GGG and PBA Hurricane XT.

2. *Continued investigation of best practice herbicide strategies on sandy soils; this will include assessment of crop safety, herbicide efficacy and yield loss associated with weed competition.*
   Herbicide tolerance trials were conducted using simazine, diuron, metribuzin and terbuthylazine (group C) and chlorsulfuron (group B) herbicides applied IBS and diflufenican (group F) and Intercept (group B) applied post emergent and selected combinations of these. These trials included repeated treatments from project TC116 and have resulted in the collection of a large dataset for lentil crop herbicide tolerance/safety and weed control efficacy of the four main species infesting lentil crops on sandy soils, over a range of seasons. The group G herbicide, Reflex was included in three trials in 2020, given its commercial release in lentil in 2021.

   In addition, a trial was conducted in 2019 to investigate metsulfuron (group B) as an alternative to chlorsulfuron applied IBS in PBA Hurricane XT lentils.

3. *Investigate differences in herbicide activity and safety on alkaline sand compared with neutral and acidic sands.*
   Herbicide tolerance trials were located on neutral/acidic sands around Bute whilst alkaline sandy sites were located north of Alford. These trials located on alkaline sands contained a subset of treatments from the larger treatment list described above, investigating group C and Intercept herbicide safety on these soils.

   A total of five herbicide tolerance trials were conducted over two years on both acidic and alkaline sands. The spread of sites across soils varying in pH allowed for a greater understanding of lentil herbicide crop tolerance and provided additional data over varying seasons and contrasting soil types to the existing dataset. The safety of group C herbicides applied IBS is dependent on herbicide characteristics that effect mobility in the soil and the interaction with rainfall events post seeding. Of the group C herbicides tested, a mixture of simazine and diuron generally had good crop safety and provided control of Indian hedge mustard (IHM) (88%), sow thistle (81%) and wild turnip (77%). Application of Intercept® post emergent provided the best control of medic, whilst diflufenican provided control of IHM and wild turnip. The use of these two herbicides post-emergent had minimal effect on grain yield when used after IBS applications of simazine and diuron. Chlorsulfuron applied IBS provided excellent medic control, but was very high risk for crop damage, particularly when used in combination with other herbicides.

4. *Continued varietal evaluations on poorer performing sandy soils.*
   Two variety trials were successfully conducted on sandy soils, with one in 2019 on an alkaline sand and one in 2020 on an acidic sand. This data complimented the TC116 variety evaluation dataset and confirmed a positive relationship between plant biomass at the flowering growth stage and grain yield in lentil in these environments. A comparison of NVT and PBA datasets from previous years on heavier textured loamy soils on the YP found that this relationship did not exist in lentil in these higher and more favorable growing environments. It is now thought that the highest yielding lentil varieties in sandy soil environments may have specific adaptation to these soil types. This finding was important, as varietal selection is key for optimising productivity on different soil types.

5. *Investigate lentil nutrition responses on acidic sandy soils, in particular responses to Molybdenum.*
   Two nutrition trials were conducted on acid sands north of Bute, with one in 2019 and one in 2020. Trials were designed to identify individual nutrient deficiencies, by having omission and addition treatments for phosphorus, sulfur, nitrogen, magnesium, molybdenum, manganese + copper, and chicken litter. No consistent nutrition deficiency symptoms or responses were observed across the trials.

   Two post emergent molybdenum (Mo) nutrition trials were implemented, with one in 2019 and one in 2020. These trials both demonstrated a clear Mo response in lentil, with visual leaf colour, plant biomass and grain yield responses observed in both seasons. Low rates of sodium molybdate (25g/ha, approx. $1/ha) were sufficient to overcome deficiency, producing yield responses of 150-200kg/ha. These trials were showcased on two Northern Sustainable Soils (NSS) spring crop walks and has since resulted in a high adoption of post-emergent molybdenum use amongst lentil growers with acidic sands.

Personnel who participated in the project

Trengove Consulting: Sam Trengove, Stuart Sherriff, Jordan Bruce and Nathan Jones
Global Grain Genetics: Larn McMurray
Participating growers: Nathan Hewett, Bruce Bros, Brad Simpson, Paul Jarrett, James Venning and Andrew Davey.

KEY PERFORMANCE INDICATORS (KPI)

*Please indicate whether KPIs were achieved. The KPIs **must** be the same as those stated in the Application for Funding and a brief explanation provided as to how they were achieved or why they were not achieved.*

KPI	Achieved	If not achieved, please state reason.
Identify sites that meet selection criteria for seven trials (2019). Implement trial treatments and sow trials including • Novel herbicide traits at two sites • Herbicide tolerance • Variety trial • Nutrition trial • Lime and soil pH	Yes ☒ No ☐	*A lime and soil pH trial was established as part of a GRDC funded trial, as discussed in project variation. As mentioned in the variation agreement an additional trial was established to investigate group C and B chemistry on alkaline sands at a site near Alford.*

5 trial sites were identified, and trials mentioned above established plus two additional trials to investigate differences between chlorsulfuron and metsulfuron tolerance and how high rates of metribuzin affect metribuzin tolerant lentils and conventional lentils.		
Implement in season treatments • Novel herbicide traits • Herbicide tolerance • Nutrition trial • Molybdenum nutrition trial *In season treatments were implemented on existing trials including herbicide and nutrition treatments.* *Veris pH mapping data was used to identify acid sandy soil types and a post emergent molybdenum trial was established. This created great interest amongst local growers.*	Yes ☒ No ☐	

In season assessments of trials;
• Novel herbicide traits at two sites
    ○ Plot emergence scores
    ○ Herbicide damage scores
    ○ Weed control counts
    ○ Greenseeker NDVI
• Herbicide tolerance
    ○ Plot emergence scores
    ○ Herbicide damage scores
    ○ Weed control counts
    ○ Greenseeker NDVI
• Variety trial
    ○ Plot emergence scores
    ○ Early vigor scores
    ○ Greenseeker NDVI
• Nutrition trial
    ○ Plot emergence scores
	Yes ☒
	No ☐	

◦ Early vigor scores ◦ Greenseeker NDVI ◦ Leaf nutrient analysis • Molybdenum trials ◦ Vigor scores ◦ Greenseeker NDVI ◦ Root nodulation assessments *In season measurements were conducted successfully, dates of measurements are included in the attached trial reports.*		
Harvest trials for yield. Process in season and yield data into trial reports and SAGIT progress report *All trials were successfully harvested and measurements have been analysed. Trial reports have been completed for all trials.* *Crop lower limit samples were taken from four treatments in the Main Herbicide Tolerance trial at Bute to determine differences in crop extracted moisture. The hypothesis was that the effect of herbicide injury on crop growth and yield would also be reflected in crop water use and soil moisture extraction.*	Yes ☒ No ☐	
Identify sites that meet selection criteria for six trials (2020). Implement trial treatments and sow trials including • Novel herbicide traits at two sites • Herbicide tolerance • Variety trial • Nutrition trial *5 trial sites were identified, and trials mentioned above established plus an additional site used for post-emergent molybdenum application.* *Additional treatments to investigate the new group G herbicide, Reflex were also included in the herbicide tolerance trials at Alford and Bute. An additional trial at the Arthurton site was implemented to*	Yes ☒ No ☐	

investigate the potential use of Reflex for control of group B resistant Indian hedge mustard. These trials and treatments were beyond the original scope of the project but allowed the project to assess the latest herbicide technologies and provided additional relevance to growers. *The lime and soil pH trial were established in 2019 as part of a GRDC funded project, as discussed in project variation and this site was sown to lentil. The results from these trials and another soil amelioration trial at Bute will be included in reporting.*		
Implement in season treatments • Novel herbicide traits • Herbicide tolerance • Nutrition trial • Molybdenum nutrition trial *In season treatments were implemented on existing trials including herbicide and nutrition treatments.* *Veris pH mapping data was used to identify acid sandy soil types and a post emergent molybdenum application trial was established.*	Yes ☒ No ☐	

In season assessments of trials;
• Novel herbicide traits at two sites
  ○ Plot emergence scores
  ○ Herbicide damage scores
  ○ Weed control counts
  ○ Greenseeker NDVI
• Herbicide tolerance
  ○ Plot emergence scores
  ○ Herbicide damage scores
  ○ Weed control counts
  ○ Greenseeker NDVI
• Variety trial
  ○ Plot emergence scores
  ○ Early vigor scores
	Yes ☒
	No ☐	

○ Greenseeker NDVI • Nutrition trial ○ Plot emergence scores ○ Early vigor scores ○ Greenseeker NDVI ○ Leaf nutrient analysis • Molybdenum trials ○ Vigor scores ○ Greenseeker NDVI ○ Root nodulation assessments • Lime and soil pH ○ Vigor scores ○ Greenseeker NDVI ○ Root nodulation assessments *In season measurements were conducted successfully, dates of measurements are included in the attached trial reports.*		
Harvest trials for yield. Process in season and yield data into trial reports and SAGIT progress report *All trials were successfully harvested and measurements have been analysed. Trial reports have been completed for all trials.*	Yes ☒ No ☐	
Submit final report	Yes ☒ No ☐	

TECHNICAL INFORMATION (Not to exceed **three** pages)

Provide sufficient data and short clear statements of outcomes.

During the 2019 and 2020 growing seasons a total of 21 lentil agronomy trials have been conducted by Trengove Consulting under the project TC119. A report summarising the results from these trials was submitted to GRDC for inclusion in the 2021 Adelaide GRDC Adviser update. A version of this paper including all treatments has been included as an attachment and summarises all work completed.

Individual trial reports have also been compiled and can be found in the attached documents.

Data from other soil amelioration trials on sandy soil assessing lentil response in SA have also been compiled during the duration of this project and key messages incorporating that data have also been included in this final report.

The key messages from the 21 trials in TC119 incorporating findings from other lentil trials across the broader region are;

- Four key steps to improving lentil productivity on underperforming sandy soils are: soil amelioration, variety selection, herbicide choice and nutrient management.

- Ameliorating (e.g. deep ripping, spading, application of chicken litter and clay) soil constraints increased lentil grain yields up to 347% and an average yield response of 0.31t/ha (85%) occurred due to deep ripping.
- The highest yielding lentil varieties on loamy soil types may not be the highest yielding varieties on underperforming sandy soils. This is due to a positive correlation between lentil biomass and grain yield on sandy soils that does not exist on the heavier textured and higher biomass producing loams.
- Herbicide choice in lentil on sandy soil types requires careful consideration due to the heightened risk of herbicide damage from soil residual herbicides on these light textured soils.
- Nutrient requirements on sandy soil types can vary across locations and seasons. Application of molybdenum on acidic sands were shown to increase grain yields in lentil across seasons.
- Lentil growth and biomass, as measured by NDVI, was positively correlated with grain yield on sandy soils.
- Lentil varieties with novel traits such as tolerance to clopyralid and metribuzin herbicides can provide safe alternative weed control compared to traditional group B and C herbicides that are commonly used. The importance of this may become greater as resistance develops in species such as sow thistle, prickly lettuce and Indian hedge mustard.

Amelioration
Compaction is a common physical constraint of crop growth on sandy soils in the northern YP region, it inhibits plant root exploration beyond compacted depths, where penetrometer resistance exceeding 2,500kPa indicates a severe limitation. Many sandy soils in SA exceed this level, often peaking at up to 4,000kPa with high resistance between 15-40cm soil depth. Deep ripping treatments in the northern YP and Mallee regions increased lentil yield by 0.31 t/ha (85%) on average.

Varieties
Across a range of lentil agronomy trials, treatments that increased crop growth on sandy soils of the northern Yorke Peninsula also increased lentil grain yield. This finding was supported by variety trials, where varieties with higher NDVI values at the flowering growth stage produced higher grain yield. This contrasts with results from trials conducted on more loamy soils of the YP where biomass was not correlated with grain yield. This finding suggests that the highest yielding variety on a heavier textured soil type may be different to the highest yielding variety on a sand hill within the same paddock.

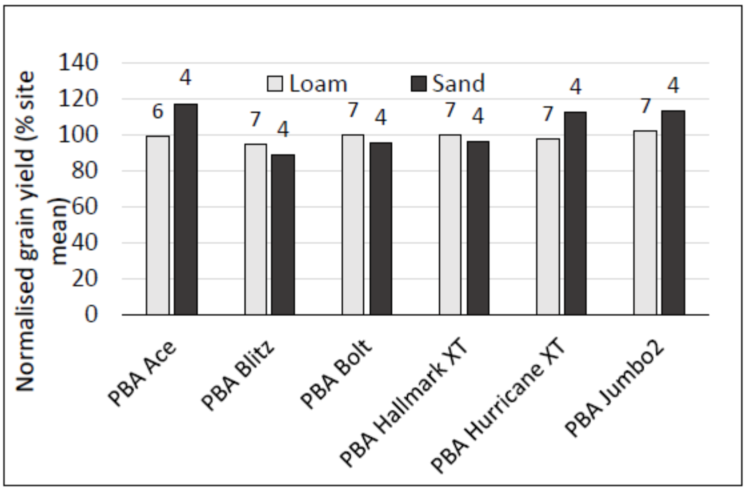

Figure 1. Average grain yield for selected commercial varieties as clustered by soil type for years 2017-2020 (Source: NVT Online, Willamulka NVT and Melton PBA yields used for loam cluster, sandy soil cluster yields from SAGIT TC116 and TC119 trials), number above bar shows number of variety comparisons.

Herbicides – herbicide tolerance and crop safety
Yield losses associated with herbicide damage in lentil trials on sandy soil types have ranged from 0 – 58% for individual products and up to 75% for herbicide combinations over 8 trials conducted in 2015 and from 2017 to 2020. Herbicide products applied individually generally

only showed low levels of crop damage and associated grain yield loss. In this series of trials, average yield loss for individually applied products was 9% when compared to the untreated control. However, when multiple products were applied, greater levels of crop damage were observed. This is particularly the case with the soil residual herbicide chlorsulfuron where the application of group C herbicides IBS in conjunction with this product increased yield loss to 50%. Similarly, the additional effect of Intercept® (applied post emergent) where chlorsulfuron residues were present significantly increased damage (median yield loss of 48%), whereas on its own, Intercept® did not reduce grain yield.

The new group G herbicide, Reflex (fomesafen), has recently been registered for IBS application in lentil for broadleaf weed control. Reflex was included in 2020 trials, although not originally included in the TC119 proposal. Reflex was included in herbicide tolerance trials at the acid sand site at Bute, the alkaline sand at Alford and in an additional trial near Arthurton, co-located with the novel traits trial. No yield loss was recorded as a result of the addition of Reflex at any site. Rates of Reflex tested ranged from 750-1000mL/ha on sandy soils and 1000-1500mL/ha on clay loam soils. Despite no yield loss being recorded, significant leaf mottling and reduced vigor was recorded at Alford on the alkaline sand. It is worth noting that no yield loss was associated with any herbicide treatment in any trial in 2020, which has not occurred in any other year of these herbicide tolerance trials. Given this result, further investigation of the use of Reflex in lentil on these soil types, particularly alkaline sands, will be important.

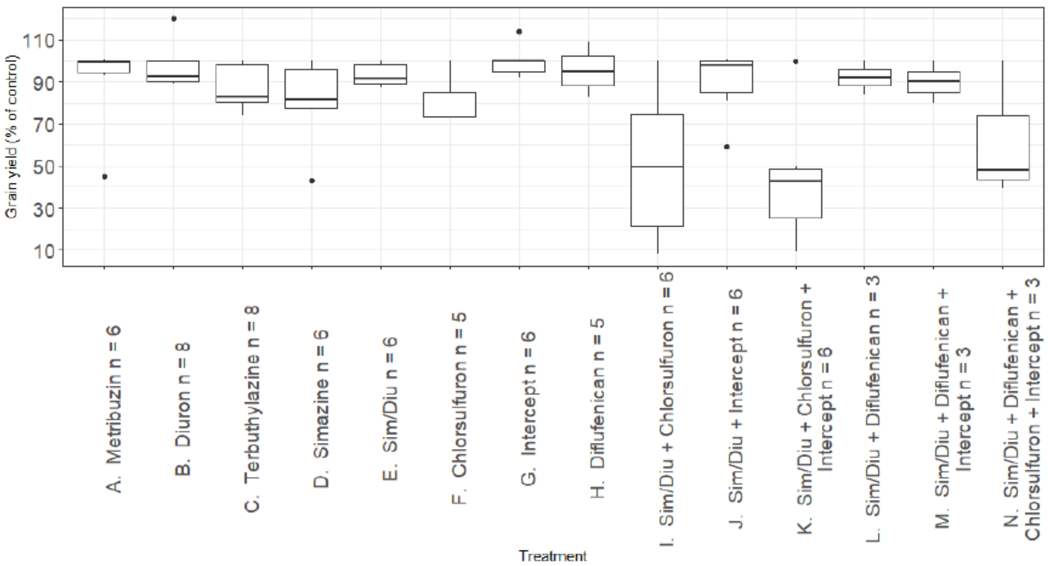

Figure 2. Grain yield presented as percent of control treatments for individual and product mixtures in the herbicide tolerance trials from projects TC116 and TC119 on sandy soils. All treatments applied IBS except for Intercept and Diflufenican, both applied POST. See table 2 for rates of products applied. ………..

Herbicides – weed control

Individual herbicides

- Metribuzin at the range of rates (150-180g/ha) applied IBS in the herbicide tolerance trials produced the lowest level of weed control of the group C herbicides across all weeds assessed (Indian Hedge Mustard (IHM), wild turnip (WT), sow thistle (ST), medic).
- Control of IHM with Intercept® applied POST at 500ml/ha was highly variable, and likely represents the presence of imidazolinone (IMI) herbicide resistance in some IHM populations across the region. Despite IMI resistance now reported in ST in the district, an average control of 79% was seen as a relatively good result.
- Post-emergent diflufenican (DFF) applied at 150ml/ha provided good control of the brassica weeds, IHM and WT.
- The group G herbicide Reflex applied IBS at 1L/ha provided excellent control of group B resistant IHM at Arthurton in 2020.

Herbicide combinations

- Combinations of herbicides improved weed control compared to the same herbicides applied alone.
- Group C herbicides applied IBS + DFF applied POST gave 100% control of IHM and WT and good control of medic (82%) and ST (94%).
- Group C herbicides applied IBS + Intercept® applied POST provided 85% or better weed control of all four weed species.
- Group C herbicides applied IBS + DFF applied POST + Intercept® applied POST averaged greater than 94% control of all four weed species.
- The combination of all four herbicides (group C + DFF+ Intercept® + chlorsulfuron) offered little value above that achieved with the combinations of a group C, DFF and Intercept®.

Table 1. Weed control of Indian hedge mustard (IHM) (Sisymbrium orientale), burr medic (Medicago polymorpha), common sow thistle (Sonchus oleraceus), and wild turnip (Brassica tournefortii) for different herbicide products and sequences in lentil herbicide tolerance trials from projects TC116 and TC119.

Herbicide product(s)	% weed control (# samples) range											
	IHM			Medic			Sow thistle			Wild turnip		
Metribuzin	58	(4)	29-82	28	(5)	0-76	45	(6)	16-69	62	(5)	50-83
Diuron	85	(4)	74-97	40	(5)	0-70	76	(6)	50-94	70	(5)	52-94
Terbuthylazine	92	(4)	83-100	63	(5)	36-82	81	(5)	61-96	85	(5)	78-100
Simazine	85	(3)	75-93	55	(4)	36-82	91	(5)	84-100	74	(4)	50-90
Simazine/diuron (sim/diu)	88	(4)	78-99	44	(5)	0-69	81	(6)	69-93	77	(5)	37-93
Chlorsulfuron	36	(2)	0-72	90	(2)	81-98	12	(3)	0-25	54	(2)	25-83
Intercept	59	(3)	0-91	56*	(4)	0-88	79	(5)	61-88	96	(4)	88-100
Diflufenican (DFF)	97	(2)	95-100	56	(2)	34-78	59	(3)	0-94	80	(2)	63-97
Sim/Diu/Chlorsulfuron	86	(2)	72-99	94	(2)	91-98	88	(3)	80-98	92	(2)	88-97
Sim/Diu + Intercept	85	(3)	62-97	86	(4)	71-94	92	(5)	63-100	87	(4)	74-100
Sim/Diu + DFF	100	(2)	100-100	82	(2)	74-90	94	(3)	88-100	100	(2)	100-100
Chlorsulfuron + Intercept	48	(2)	0-97	94	(2)	88-100	81	(3)	46-100	98	(2)	97-100
Sim/diu/chlorsulfuron + DFF	100	(2)	100-100	96	(2)	93-99	92	(3)	88-99	87	(2)	75-100
Sim/diu/chlorsulfuron + Intercept	85	(2)	74-97	93	(2)	87-100	97	(3)	90-100	100	(2)	100-100
Sim/Diu + DFF+ Intercept	99	(2)	99-100	94	(2)	92-96	95	(3)	84-100	100	(2)	100-100
Sim/diu/chlorsulfuron + DFF + Intercept	100	(2)	100-100	96	(2)	91-100	89	(3)	66-100	100	(2)	100-100

*in most cases surviving medic plants were severely stunted and not competitive

Table 2. The herbicide products and rates used alone (a). The herbicide products and rates used in a mixture or subsequent application (b).

(a)

Product name	Herbicide active constituent	Active constituent rate	Rates (#data)	Herbicide group
Chlorsulfuron	Chlorsulfuron	750g/kg	5g/ha (5)	B
Intercept	Imazamox + imazapyr	33g/L + 15g/L	500mL/ha (6)	B
Diuron	Diuron	900g/kg	550g/ha (2) 800g/ha (4) 825g/ha (2)	C
Metribuzin	Metribuzin	750g/kg	150g/ha (1) 180g/ha (4)	C
Simazine	Simazine	900g/kg	400g/ha (4) 500g/ha (1)	C
Diflufenican (DFF)	DFF	500g/L	80mL/ha (1) 150mL/ha (4)	F

(b)

Products	Rates (# data)
Simazine/diuron (sim/diu)	250/275g/ha (1) 260/200g/ha (1) 200/400g/ha (4)
Sim/diu + DFF	250/275g/ha + 150mL/ha (1) 200/400g/ha + 150mL/ha (2)
Sim/diu/chlorsulfuron	260/200/5g/ha (1) 250/275/5g/ha (1) 200/400/5g/ha (2)
Sim/diu + Intercept	250/275g/ha + 500mL/ha (1) 260/200g/ha + 500mL/ha (1) 200/400g/ha + 500mL/ha (4)
Sim/diu/chlorsulfuron + DFF + Intercept	250/275/5g/ha + 150mL/ha + 500mL/ha (1) 200/400/5g/ha + 150mL/ha + 500mL/ha (2)

The symbol “/” indicates herbicides applied together (i.e., mixed and applied IBS). The symbol “+” indicates the herbicide was applied in a separate application POST.

Treatments combining simazine with diuron applied IBS followed by either Intercept® or diflufenican applied post provided the best balance between crop safety and control of the four weed species assessed. However, these results highlight that there are narrow herbicide safety margins on these sandy soils and there are limited herbicide solutions that are both safe on the crop and provide high level weed control for a range of weeds. As such lentil production on sandy soils continues to be significantly constrained by herbicide usage and/or weed competition, as no current herbicide or herbicide combination can result in effective weed control without crop damage and the current safest application strategy results in insufficient weed control and potential loss from crop competition Therefore, future work on novel herbicide tolerances and/or new chemistries holds significant potential for lentil productivity improvements in these regions.

Nutrition

Lentil nutrition trials were run from 2017-2020 on both alkaline and acidic sands in the northern Yorke Peninsula region under projects TC116 and TC119. These trials included the addition and omission of a range of essential plant nutrients. While elevated levels of some nutrients were measured in tissue tests, no unique nutrition constraints were identified that led to improved yield, other than molybdenum on acidic sands.

Molybdenum on acidic sands

Post-emergent molybdenum application trials were conducted on slightly acidic sands in 2019 and 2020, soil pH values were 5.8 $CaCl_2$ and 5.9 $CaCl_2$ at 0-10cm, respectively. Nine treatments ranging from 0 – 400 g/ha sodium molybdate, applied over two timings, early July and mid-August were evaluated. In both seasons. Strong visual plant growth responses were observed within two weeks of treatment and resulted in increased NDVI values for all molybdenum treatments from 25-400g/ha sodium molybdate. This improvement in plant biomass resulted in increased grain yields of 43% and 21% for 2019 and 2020, respectively for all molybdenum treatments. In both seasons there was no benefit from increasing the rate of sodium molybdate above 25 g/ha and application timing did not affect grain yield. N fixation was measured in the 2020 trial. Application of sodium molybdate at 25g/ha increased N fixation by the crop from 16 kg N/ha to 37kg N/ha. This increase was primarily in response to the increased biomass, rather than an increase in the percent nitrogen derived from the atmosphere (%NDFA).

Biomass and yield

Across a suite of 21 trials on sandy soils of the northern Yorke Peninsula a consistent positive linear relationship between biomass at flowering (using Greenseeker NDVI as a biomass surrogate) and grain yield has been established. This is consistent with work by Lake and Sadras (2021) experimenting with 20 lentil lines varying in seed type and phenology across eight environments. They found yield correlated with biomass and crop growth rate in more stressful conditions, where yields were less than 1.07t/ha. However, they also found this relationship decoupled in more favourable conditions where yields exceeded 1.7t/ha. In these favourable conditions’ excessive vegetative growth can lead to self-shading, reduced pod and seed set, low harvest index and higher risk of disease and lodging (Lake and Sadras, 2021). The results generated from TC116 and TC119 suggest the physical and chemical constrained sandy soils of the northern YP are also plant biomass constrained and any treatment that can overcome some or all these constraints will result in an increase in both biomass and yield. However, it is also possible that this relationship may decouple on the heavier textured soils within the same paddocks where biomass is not a constraint to yield.

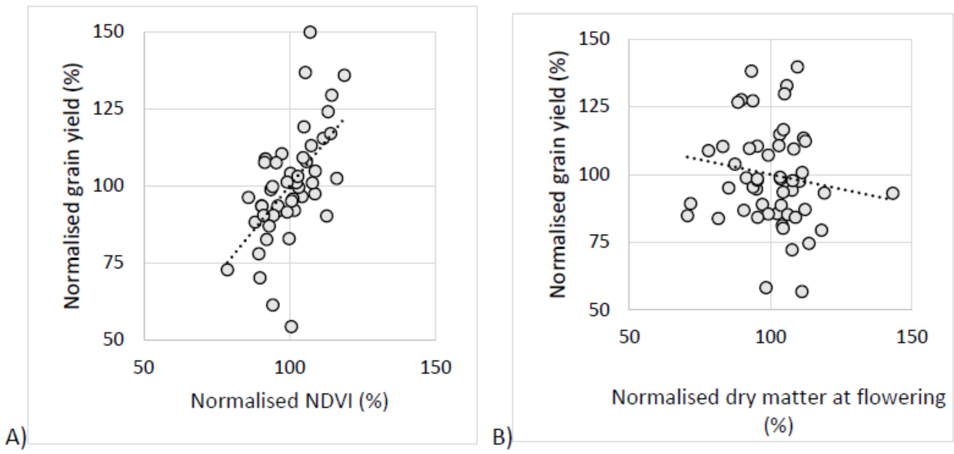

Figure 3. A) Normalised grain yield and NDVI at flowering from lentil variety trials located on sandhills of the northern Yorke Peninsula from projects TC116 and TC119 (y = 1.1674x - 16.642, R² = 0.329). B) Normalised grain yield and dry matter at flowering from PBA breeding program trials located on loamy soils near Melton, 2012-2014 (source: PBA) (y = 0.2176x + 121.82, R² = 0.0143).

Novel Herbicide Traits

Lentil varieties with novel herbicide tolerance to clopyralid (GIA1703L) and metribuzin (GIA2004L) were assessed against commercial varieties PBA Jumbo2 (conventional) and PBA Hurricane XT (IMI tolerant) in 2019 and 2020 trials. Herbicide product and rate used in these trials differed between varieties and was matched to the herbicide tolerance profile of each variety to optimise weed control and minimize off target crop damage (Table 2). Findings included:

- Rates of metribuzin applied to the metribuzin tolerant variety in this trial provided high level (>97%) of control of Indian hedge mustard, sow thistle, prickly lettuce and wild turnip (Table 2). Medic control averaged 60% and could potentially be higher if the higher metribuzin rates trialed in 2020 were also used in 2019. These weed control results were superior to those achieved when metribuzin was applied at lower rates (150-180g/ha IBS) in conventional and XT varieties (Table 1). Given there was no crop damage in the metribuzin tolerant line at these higher rates the findings suggest there is significant potential for this technology to improve lentil productivity on sandy soils.
- Clopyralid herbicide applied IBS with simazine and diuron to the clopyralid tolerant line controlled 84% of medic and 92% of sow thistle (Table 2). This was comparable to the control achieved with group B and C herbicides applied in PBA Hurricane XT.
- An economic benefit could not be demonstrated from improved weed control using varieties with novel herbicide traits at any trial site because of lower yields of tested novel trait lines and lack of yield loss due to weed competition in commercial varieties. Partial gross margins (PGM) were calculated for each novel trait treatment, which included differing herbicide costs and differing income from grain yield. PBA Jumbo 2 generated the highest yields and PGM at all four sites, despite its limited herbicide options. The clopyralid tolerant line was able to match the grain yield of PBA Jumbo 2 in 2020, but was 23-28% lower yielding in 2019.
- The metribuzin tolerant line available for evaluation was 23-41% lower yielding than PBA Jumbo 2 at all four sites. There is a fitness penalty (estimated at 20-30%, pers. comm. L. McMurray) associated with the metribuzin herbicide tolerance in lentil, similar to that which occurs in TT canola. Further breeding effort is required to develop lentil lines with more comparative yield to that achieved in conventional or XT varieties. However, given that this project has estimated that medic weed control efficacy can be as low as 30% and herbicide crop damage up to 75% with current available herbicide options on sandy soils there is significant scope for this technology to improve lentil productivity and system sustainability in these regions.
- In the absence of weed control, yield penalty due to weed competition ranged from 0-27%. This was dependent on weed density, variety and site. Literature reports yield losses of up to 87% from weed competition in lentil and it has not been uncommon for lentil growers on the YP to spray or slash out areas of their crop where weed competition has been high. However,

this provides an indication of potential yield loss when no effective herbicides are available, or herbicide resistance development has rendered some herbicides ineffective.

- Herbicide resistance management strategies advocate herbicides be mixed and rotated to delay the onset of resistance. This strategy relies on a range of effective herbicides being available to mix and rotate between. Mixing and rotating herbicides also has the potential for increasing herbicide damage of conventional varieties. Introduction of varieties with novel herbicide tolerance traits increases the ability to mix and rotate herbicides in lentil production, helping with resistance management.
- Differences between varieties observed in early crop vigour and canopy development affected crop competitiveness with weeds, this was particularly evident at Arthurton in 2020 where there was a high population of Indian hedge mustard. In terms of early vigour and competitiveness, it showed that the metribuzin tolerant line > PBA Jumbo 2, PBA Hurricane XT > clopyralid tolerant line.
- The clopyralid tolerant line yielded similarly to PBA Jumbo 2 at Bute (1.21t/ha) and Arthurton (4.24t/ha) in the absence of weeds in 2020. However, yield declined 27% at Arthurton in the presence of high-density Indian hedge mustard, whereas PBA Jumbo 2 declined by only 10%. These yield losses are related to each varieties competitive ability and suggest that further plant breeding effort could improve the agronomic suitability of these varieties.

Table 2: Weed control data for novel traits trials in seasons 2019 and 2020.

Variety	Location	Year	Herbicide & rate (g or mL/ha)	Medic	IHM	Sow Thistle	Let
Jumbo 2	Bute	2019	S200, D400	59	95	93	
Jumbo 2	Maitland	2019	S400, D400	19		87	7
Jumbo 2	Bute	2020	S200, D400			85	
Jumbo 2	Arthurton	2020	S400, D400, DFF 150		91		
Average weed control in Jumbo 2				39.0	93.0	88.3	75
Hurricane XT	Bute	2019	S150, D300, I500	79	64	85	
Hurricane XT	Maitland	2019	S300, D300, G10, I500	91		97	4
Hurricane XT	Bute	2020	S150, D300, I500			94	
Hurricane XT	Arthurton	2020	S300, D300, I500, DFF150		93		
Average weed control in Hurricane XT				85.0	78.5	92.0	42
Clopyralid	Bute	2019	S150, D300, C300	95	73	98	
Clopyralid	Maitland	2019	S300, D300, C300	73		87	8
Clopyralid	Bute	2020	S150, D300, C300			91	
Clopyralid	Arthurton	2020	S300, D300, C300, DFF150		94		
Average weed control in Clopyralid tolerant line				84.0	83.5	92.0	88
Metribuzin	Bute	2019	M200, M150	60	100	93	
Metribuzin	Maitland	2019	M250, M200	59		100	1
Metribuzin	Bute	2020	M200, M300			100	
Metribuzin	Arthurton	2020	M400, M400		96		
Average weed control in Metribuzin tolerant line				59.5	98.0	97.7	10

Herbicides: S = simazine 900g/kg IBS, D = diuron 900g/kg IBS, DFF = diflufenican post emergent, I = Intercept post emergent, G = chlorsulfuron 750g/kg IBS, C = clopyralid 300g/L IBS, M = metribuzin 750g/kg IBS or post emergent

CONCLUSIONS REACHED &/OR DISCOVERIES MADE (Not to exceed one page)

Please provide concise statement of any conclusions reached &/or discoveries made.

Amelioration: soil constraints such as compaction can reduce crop production on sandy soils. Results from trials conducted in the northern YP and Mallee regions show an average lentil response to deep ripping of 0.31 t/ha, or 85% yield increase.

Molybdenum on acidic sands:

The discovery of molybdenum deficiency on acidic sands in lentils has provided an opportunity to demonstrate a simple yet effective solution. Low rates of foliar molybdenum spray applications can overcome this deficiency at a low cost to growers.

Varieties: the highest yielding varieties on loamy soil types may not be the highest yielding on underperforming sandy soils. On sandy soils, any agronomic practice that increases lentil biomass should increase grain yield and this includes utilising varieties that produce higher levels of biomass as seen with PBA Ace.

Herbicide tolerance: lentil crops have a narrow safety margin when using herbicides IBS, particularly on sandy soils. Early season rainfall patterns and soil moisture levels at the time of IBS application play a significant role in the herbicide damage endured during the season. Soil texture and pH adds further complexity to the process of herbicide and rate selection, as group B, C and G herbicides are impacted by soil pH and sand content. Understanding the soil properties and assessing the weather conditions around the timing of application is critical for herbicide selection and rates. On average treatments combining simazine with diuron applied IBS followed by either Intercept® or diflufenican applied post provided the best balance between crop safety and control of the four weed species assessed on the sandy soils evaluated in this project. The new herbicide Reflex® was only preliminary evaluated in this project and offers promise, albeit with potential for crop damage on sandy soils observed in one trial.

Weed control: the rates of herbicides applied IBS for weed control in lentil is limited by the low herbicide tolerance level of the crop. Therefore, the choice of where to grow lentils is often limited, as achieving high levels of broadleaf weed control often comes with high levels of crop damage. If it is suspected that the weed burden on sandy soils going into a lentil crop is high, then crop selection may need to be revisited.

Novel traits: varieties with novel herbicide tolerance provided alternative options for controlling important weeds of lentil. These options may also provide improved herbicide resistance management options in lentil production. In economic terms, the clopyralid tolerant lines were competitive with PBA Jumbo 2 in certain lentil growing environments, however the metribuzin tolerant line incurred a significant yield drop and will require more breeding effort to bridge the yield gap with current commercial varieties if it is to become a mainstream variety. However, the metribuzin tolerant lentil offers significant potential to the sandy soil regions where current weed burden levels on these soils prohibit the growing of lentil due to the risk of weed 'blow outs'\ or high levels of crop damage.

INTELLECTUAL PROPERTY

Please provide concise statement of any intellectual property generated and potential for commercialisation.

none

APPLICATION / COMMUNICATION OF RESULTS

A concise statement describing activities undertaken to communicate the results of the project to the grains industry. This should include:

- *Main findings of the project in a dot point form suitable for use in communications to farmers;*
- *A statement of potential industry impact*
- *Publications and extension articles delivered as part of the project; and,*
- *Suggested path to market for the results including barriers to adoption.*

Note that SAGIT may directly extend information from Final reports to growers. If applicable, attach a list of published material.

Main findings

- Four key steps to improving lentil productivity on underperforming sandy soils are: soil amelioration, variety selection, herbicide choice and nutrient management.
- Ameliorating (e.g. deep ripping, spading, chicken litter application, etc.) soil constraints increased lentil grain yields up to 347%, with an average 0.31t/ha (85%) yield response to deep ripping.
- The highest yielding varieties on loamy soil types may not be the highest yielding on underperforming sandy soils. Lines with higher biomass production levels were found to perform relatively better on sandy soils than heavier textured types.
- Weed control methods on sandy soil types must be carefully planned to minimise yield loss due to the heightened risk of herbicide damage from soil residual herbicides. Currently, there are no suitable safe IBS herbicide strategies for managing high weed burden areas on sandy soils. New herbicides and/or novel herbicide tolerant crop options show promise for lentil production on sandy soils.
- Sandy soils with high soil pH (alkaline sites tested had pH CaCl2 0-10cm > 7.8) may be at greater risk of unacceptable crop damage from group B and group C herbicides used IBS when compared to sandy soils with lower soil pH.
- Nutrient requirements on sandy soil types can vary across locations and seasons. Application of molybdenum at 25g/ha on acidic sands pH $CaCl_2$ <6 (0-10cm) was shown to increase grain yields.
- Lentil growth and biomass, as measured by NDVI, was positively correlated with grain yield on sandy soils and suggest growers should employ management options to promote biomass production and avoid practices that supress biomass growth eg crop damage from herbicide application or early season insect attack.
- Lentil varieties with new novel traits such as tolerance to clopyralid and metribuzin herbicides can provide safe alternative weed control compared to traditional group B and C herbicides that are commonly used. The importance of this may become greater as resistance develops in species such as milk thistle, prickly lettuce and Indian hedge mustard.

Potential industry impact

Previous estimates of impact in this area have been calculated on 20% of lentils in the northern YP area being grown on sandy soil types relevant to this project, where that equates to 4,550ha.

Yield loss on sandy soils from the combined use of commonly used herbicides has been demonstrated to be up to 0.9t/ha, with an average 9% yield loss from commonly used herbicides applied individually. Yield loss up to 27% due to weed competition was also demonstrated. The benefits from these findings will depend on individual grower's current herbicide strategy and weed burdens. However, using a conservative estimate of 5% (75kg/ha) yield improvement through safer herbicide strategies and improved weed control equates to an additional 341t produced, or $273,000 at $800t.

Yield increases of 0.2t/ha have been observed in response to sodium molybdate application of 25g/ha (approx. $1/ha). It is estimated 25% of the sand producing lentils in the region is less than pH $CaCl_2$ 6.0. Therefore, an additional 227t, or $182,000 could be generated from growers adopting these results. An additional 21kg N/ha was also fixed, worth approx. $42/ha currently, or $47,775 to the region.

Based on grower and agronomist interest from around SA, there is potential for findings from TC119 to have relevance and impact on lentil production on sandy soils across many regions of the state, generating a much greater industry impact.

Activities
Results from this project have been communicated to industry and growers via a range of media. This includes

- Trial presentation at annual NSS field days. Trials presented include herbicide tolerance trials (2019), molybdenum nutrition trial (2019 & 2020), lentil nutrition trial (2020).
- Publication of trial results in farming systems group compendiums, including NSS and AirEP.
- Presentation of results at GRDC adviser updates in Adelaide, 2021. This presentation ranked equal top for content relevance at this event, based on GRDC audience survey responses. Paper attached.
- Presentation of results at GRDC grower updates in Woomelang and Yorketown, 2021. The Yorketown presentation was delivered online due to Covid restrictions.
- Article published in Ground Cover, January 2021.
- Several Twitter posts have generated a lot of interest.

Path to market and barriers to adoption
Extension and communication of results to date have seen practice change occurring already eg use of Mo, deep ripping and changes to IBS herbicide strategies. However, continued extension of the findings will provide reinforcement and continuity of learning for growers taking on new ideas. However, several barriers also exist

- Grower decision making must consider all soil types within a paddock. With respect to herbicide use in lentils, it is difficult to apply individual herbicides site specifically when they are often applied in tank mixtures with other herbicides. Therefore, most common practice is to apply them uniformly across all soil types across the paddock. In this scenario, the decision on herbicide use then needs to balance herbicide safety and efficacy across those soil types, which can lead to compromises.
- There is an ongoing challenge for lentil breeders to develop varieties that are well adapted to sandy soil types for growers to adopt.

POSSIBLE FUTURE WORK

Provide possible future directions for the research arising from the project including potential for further work and partnerships.

New group G (14) herbicide options for broadleaf weed control in pulses are becoming available with the registration of herbicides like Reflex (fomesafen) from Syngenta, Voraxor (saflufenacil and trifludimoxazin) from BASF and Terrain (flumioxazin) from Nufarm. Initial evaluation by Trengove Consulting in 2020 showed that herbicide safety of Reflex is likely to be soil type specific and its use in herbicide combinations needs evaluation. This work is being undertaken in the new SAGIT project TC121 Improving crop safety and broadleaf weed control with herbicides in lentil.

There is an opportunity through continued breeding effort, to target plant types that perform better on constrained sandy soils. These varieties broadly are those that produce high biomass at flowering and efficiently convert biomass into grain yield.

Further validation of varieties with novel herbicide tolerance traits, particularly in regions of paddocks with high weed burdens on sandy soils. These lines, with metribuzin tolerance, are potentially a solution to the issue of herbicide choice and rate selection on variable soils, as mentioned in barriers to adoption. Work could be done to model where the yield loss (due to variety yield) vs weed control and/or herbicide crop damage pays off across variable soils on a paddock scale.