
# SA Industrial Hemp Trials

Update Report – January 2022

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Information current as of 1 January 2022





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- Rachel Burton, Carolyn Schultz, Shi Fang Khor, Jakob Schulz, Caitlin Fryar and Callum Fryar

Hurd and fibre analyses were undertaken by staff from CSIRO, including:

- Stuart Gordon and Josh Blood

Contents

# Executive summary

The key findings in the report are:

- Over four seasons the trials have clearly shown that industrial hemp can grow very successfully in South Australia.
- Some of the key practices which help achieve good production include:
    - Planting in free draining soil;
    - Using good quality irrigation water (<1500 parts per million (ppm or mg/L) / <2700 electrical conductivity units (EC));
    - Achieving a high plant density (>50 plants/$m^2$) assists in controlling weeds through early canopy closure.
- Performance of different varieties varies between the Murraylands (Loxton trial site) and the Limestone Coast (Kybybolite and Maaoupe trial sites), and between different times of sowing.
- Short season varieties appear to be well suited to growing in the Limestone Coast region.

This update report includes full results from trials carried out during the 2017/18 and 2018/19 growing seasons, as well as preliminary results from trials carried out during the 2019/20 and 2020/21 growing seasons.

A final report will be published once laboratory analyses are completed on 2019/20 and 2020/21 seed samples

This work is continuing under the AgriFutures Australia Industrial Hemp Variety Trials (IHVT) program. Results of the ongoing IHVT trials will be published under a separate title.

# Background

The passing of the Industrial Hemp Act by the SA Parliament in April 2017 to legalise the production of industrial hemp crops within South Australia, and the agreement by state and federal governments to allow the sale of hemp products as food in November 2017, created the need for a solid research footing to support the development of a hemp growing industry within South Australia.

Experience in Victoria suggested that the prime market for industrial hemp is in grain production, especially given the legalisation of hemp seed and hemp seed oil as food products. The bast fibre and hurd from the crop is of relatively low value, and facilities and expertise to extract them are currently scarce and scattered. As a result it is not likely to be economical to grow hemp primarily for fibre and hurd in the short term, rather fibre and hurd production is expected to be a by-product of grain production.

Previous South Australian hemp growing research carried out in 1995 (Potter and Hannay, 1996) gave variable results, but clearly indicated that production under rain-fed conditions in the mid-north and on Yorke Peninsula was not viable. Irrigated production at Kybybolite in the Limestone Coast proved successful, however the focus was on fibre production, and no seed was allowed to set. No further research has been carried out in South Australia since that time.

With the legalisation of hemp growing in other states over recent years, variety breeding and selection has occurred elsewhere in Australia, as well as across the world, providing a wider range of varieties worthy of evaluation under South Australian growing conditions.

A total of 11 industrial hemp cultivation licenses were issued under the new South Australian legislation during the first half of 2018. Nine of these licensees planted commercial crops in 2018/19, with a total crop area of approximately 160 ha. By October 2020 a total of 18 cultivation licences and 2 processing licences had been issued, indicating a cautious but steady uptake of this new crop.

The SARDI industrial hemp research trial program commenced in 2017/18, with the aim to evaluate industrial hemp production in two regions of South Australia (Murraylands and Limestone Coast), and to trial promising varieties and different sowing times. The trials are ongoing, and this report summarises results from the trials carried out in the 2017/18, 2018/19, 2019/20 and 2020/21 growing seasons.

# Project scope

The focus of this project is on the cultivation of industrial hemp in South Australia, specifically on production of hemp grain. Development of processing and markets is outside the scope of this project. However, it was important that the grain, fibre and hurd produced in this trial was assessed as to its suitability for a range of uses.

As a result, the broader project comprises multiple components:

- SARDI is conducting trials comparing varieties and times of sowing;
- SARDI and the University of Adelaide are assessing the quality of the grain produced;
- CSIRO is assessing the yield and quality of the bast fibre and hurd produced.

This report covers agronomic and yield results from the SARDI field trials over four seasons (2017/18, 2018/19, 2019/20 & 2020/21), as well as results from laboratory analysis of the grain grown in the SARDI field trials (2017/18 & 2018/19), and CSIRO's analyses of the fibre and hurd fractions produced in the field trials (2017/18).

# Materials and methods – 2017/18

The first season of industrial hemp field trials were established at two SARDI Research Centres, at Loxton and Kybybolite. These sites represent different climatic conditions in terms of rainfall, temperature and humidity, and also vary in terms of soil type and chemistry and irrigation water quality. Some parameters of the two sites are detailed in Table 1.

Five varieties were selected through initial pre-screening of 20 varieties readily sourced within Australia, for a range of factors contributing to the food value of hemp grain (Schultz et al., 2020). The varieties selected for planting at the field trial sites are summarised in Table 2, along with some details about their characteristics.

*Table 1 Details of trial site parameters – 2017/18*

| **Site parameters** | | | | | |
|---|---|---|---|---|---|
| **Site** | Latitude | January ave daily max temp | January ave daily min temp | Soil type | Irrigation water salinity |
| **Loxton** | -34.4º | 32ºC | 15ºC | Sandy loam | ~300 mg/L (540 EC) |
| **Kybybolite** | -36.9º | 30ºC | 12ºC | Clay | ~2000 mg/L (3600 EC) |

*Table 2 Varieties chosen for field trials – 2017/18*

| **Variety characteristics** | | | | | |
|---|---|---|---|---|---|
| **Variety** | Origin | Season | Type | Primary use | Reported THC |
| **ECO_16AH** | Australia | Late | Dioecious | Grain/Fibre | 0.27 |
| **Ferimon 12** | France | Mid | Monoecious | Grain | 0.03 |
| **ECO_50GC** | Australia | Early | Dioecious | Grain | 0.03 |
| **Frog One** | Australia | Late | Dioecious | Grain/Fibre | <0.30 |
| **Han NE** | China | Mid-late | Dioecious | Grain/Fibre | <0.30 |

*Table 3 Sowing dates for time of sowing (ToS) treatments at each trial site – 2017/18*

| **Trial sowing dates** | | | | | |
|---|---|---|---|---|---|
| **Site** | ToS 1 | ToS 2 | ToS 3 | ToS 4 | ToS 5 |
| **Loxton** | 20/10/17 | 10/11/17 | 30/11/17 | 20/12/17 | 15/01/18 |
| **Kybybolite** | 23/10/17 | 07/11/17 | 29/11/17 | 18/12/17 | 11/01/18 |

All varieties were subjected to the same five “Time of Sowing” (ToS) treatments. Due to the logistics associated with two geographically separated trial sites, the ToS treatments were applied to the two sites within a few days of each other, as detailed in Table 3.

Each combination of variety by ToS was replicated four times at each trial site. In order to minimize the potential for mature plantings to impact on younger plantings, each ToS was planted as a contiguous block, with varieties randomized within the block. Further, the first ToS treatment was planted at the southernmost edge of the trial site, with subsequent plantings being always to the north of the last planting, to avoid shading of new plantings by larger plants from previous ToS treatments.

The Loxton trial site was irrigated using overhead sprinklers on 2.5 m tall risers, spaced at 10 x 12 m. Irrigation at the Kybybolite trial site was applied using a travelling irrigator. Irrigation scheduling was determined by the manager at each site, in response to rainfall and climatic conditions.

Fertiliser applications were also managed by the local site managers, according to soil conditions at the trial sites. The timing and amount of major nutrients applied to each trial site are summarized in Table 4. In summary, both sites received similar amounts of Nitrogen, but differed in the amount of Phosphorous applied. Kybybolite also received an application of Potassium, whilst Loxton received Sulphur.

*Table 4 Type, amount and timing of fertiliser applications – 2017/18*

| **Fertiliser applications** | | | | |
|---|---|---|---|---|
| **Site** | **Timing** | N (kg/ha) | P (kg/ha) | K (kg/ha) |
| **Loxton** | **At sowing** | 18 | 25 | |
| | **Post emergence** | 100 | | 20 |
| | Total Applied | 118 | 25 | 20 |
| **Kybybolite** | **At sowing** | 25 | 29 | |
| | **Post emergence** | 100 | | |
| | Total Applied | 125 | 29 | 0 |

Crop growth stage was monitored twice per week from planting to harvest, using the decimal code of Mediavilla et al. (1998), to accurately compare the development of different treatments. Average plant height was measured weekly during the same period, to plot the vertical growth of the crop.

Sampling for THC testing was carried out at 50% female flowering. Eight flower heads were collected across each variety by ToS treatment at Loxton (excluding the fifth ToS treatment), and from the first four ToS treatments of the variety ECO_16AH at Kybybolite. The samples were dried and forwarded to the Southern Cross University’s Analytical Research Laboratory for grinding and THC testing.

Harvest was carried out manually, on a small subplot within each trial plot. All plants within the subplots were cut off at ground level and placed into bags, which were dried at 50°C for a number of days. The material was then weighed to determine total dry matter production per subplot, before the grain was threshed, cleaned and weighed to determine grain yield. Stem material was also weighed following threshing, to differentiate grain, stem and ‘other’ dry matter components. Subplot weights were multiplied up according to the area of the subplots to standardised yield per hectare figures.

Samples of the grain from each treatment plot were provided to Professor Rachel Burton from the University of Adelaide's School of Agriculture, Food & Wine. The University team conducted grain quality assessments on the samples, including assessment of:

- 1000 grain weight (estimated by 100 grain weight x 10);
- Heart to hull ratio;
- % of filled grain;
- Protein content;
- Fat content and profile.

Samples of stem material from each treatment plot in the first three times of sowing were provided to Stuart Gordon from CSIRO's Crop Improvement for Novel Plant Products Program. The CSIRO team evaluated relative yield of bast fibre and hurd from each sample and tested the strength of the fibres extracted.

Fibre strength was measured as breaking tenacity and reported in centi-Newtons per tex (cN/tex). For each field trial treatment, 25 separate samples were tested. The measurements reported here were conducted on fibres extracted from stems by hand, without the assistance of water retting. The method of retting can have an impact on fibre strength via cleavage of glycosidic linkages in the pectic and cellulosic polymer materials making up the stem, but for this comparison a consistent methodology is reported in order to highlight differences due to the field treatments, not the method of extraction.

Most data were subjected to two-way analysis of variance (ANOVA, SigmaPlot 14.0 statistical package; Systat Software Inc., San Jose, California, USA) to compare variety and time of sowing at each location. Pairwise multiple comparisons were used to differentiate treatments at $P<0.050$.

Full three-way ANOVA (location x variety x time of sowing) was not possible on most data sets due to missing data. Due to poor germination, waterlogging and salt burn issues discussed below, some individual plots at both trial sites produced were bare, and therefore no measurements were possible. These missing values precluded the use of three way ANOVA on any of the basic data sets.

The exception to this was the data for grain protein and lipids, where only one sample from each of two time of sowing treatments were analysed, leaving no missing data. These data were analysed using three-way ANOVA with pairwise multiple comparisons at $P<0.050$.

# Materials and methods – 2018/19

In the initial season of trials (2017/18), the trial site at Kybybolite proved to be unsuitable for hemp growing, due primarily to the high salinity of the groundwater used for irrigation (~2,000 mg/L). As a result, a new trial site was established for the 2018/19 trials, at Maaoupe, along with the continuation of trials at Loxton. Table 5 details some information about the two sites.

Of the five varieties trialled in 2017/18, two were retained for further testing in 2018/19 (Ferimon 12 and Han NE). Another four varieties were selected to be included, bringing the total number of varieties in the 2018/19 trials to six. The varieties selected for planting at the field trial sites are summarised in Table 6, along with some details about their characteristics.

*Table 5 Details of trial site parameters – 2018/19*

| **Site parameters** | | | | | |
|---|---|---|---|---|---|
| **Site** | Latitude | January ave daily max temp | January ave daily min temp | Soil type | Irrigation water salinity |
| **Loxton** | -34.4° | 32°C | 15°C | Sandy loam | ~300 mg/L (540 EC) |
| **Maaoupe** | -37.3° | 28°C | 12°C | Clay loam | ~750 mg/L (1350 EC) |

*Table 6 Varieties chosen for field trials – 2018/19*

| **Variety characteristics** | | | | | |
|---|---|---|---|---|---|
| **Variety** | Origin | Season | Type | Primary use | Reported THC |
| **ECO_AMB17** | Australia | Early-Mid | Dioecious | Grain/Fibre | 0.09 |
| **ECO_EX18** | Australia | Early | Dioecious | Grain | <0.30 |
| **ECO_MR17** | Australia | Late | Dioecious | Grain/Fibre | 0.06 |
| **Ferimon 12** | France | Mid | Monoecious | Grain | 0.03 |
| **Han NE** | China | Mid-late | Dioecious | Grain/Fibre | <0.30 |
| **Midlands S** | Canada | Early-Mid | Dioecious | Grain | <0.10 |

*Table 7 Sowing dates for time of sowing (ToS) treatments at each trial site – 2018/19*

| **Trial sowing dates** | | | | |
|---|---|---|---|---|
| **Site** | ToS 1 | ToS 2 | ToS 3 | ToS 4 |
| **Loxton** | 29/10/18 | 16/11/18 | 03/12/18 | 20/12/18 |
| **Maaoupe** | 26/10/18 | 19/11/18 | 06/12/18 | 20/12/18 |

In 2018/19 the number of “Time of Sowing” (ToS) treatments was reduced from five (in 2017/18) to four, by removing the mid-January ToS treatment. Due to the logistics associated with two geographically separated trial sites, the ToS treatments were applied to the two sites within a few days of each other, as detailed in Table 7.

Each combination of variety by ToS was replicated four times. In order to minimize the potential for mature plantings to impact on younger plantings, each ToS was planted as a contiguous block, with varieties randomized within the block. Further, the first ToS treatment was planted at the southernmost edge of each trial site, with subsequent plantings being always to the north of the last planting, to avoid shading of new plantings by larger plants from previous ToS treatments.

Both trial sites were irrigated using overhead sprinklers on 2.5 m tall risers, spaced at 10 x 12 m. Irrigation scheduling was determined by the manager at each site, in response to rainfall and climatic conditions.

Fertiliser applications were also managed by the local site managers, according to soil conditions at the trial sites. The timing and amount of major nutrients (N, P, K & S) applied to each trial site are summarized in Table 8.

*Table 8 Type, amount and timing of fertiliser applications - 2018/19*

| **Fertiliser applications** | | | | | |
|---|---|---|---|---|---|
| **Site** | **Timing** | ToS 1 | ToS 2 | ToS 3 | ToS 4 |
| **Loxton** | **At sowing** | 0-56-0-4 | 0-28-0-2 | 25-28-0-2 | 25-28-0-2 |
| | **Post emergence** | 50-0-50-0 | 50-0-50-0 | 42-0-50-0 | 42-0-50-0 |
| | **Total Applied** | 50-56-50-4 | 50-28-50-2 | 67-28-50-2 | 67-28-50-2 |
| **Maaoupe** | **At sowing** | 25-18-0-14 | 25-18-0-14 | 25-18-0-14 | 25-18-0-14 |
| | **Post emergence** | 46-0-0-0 | 46-0-0-0 | 46-0-0-0 | 46-0-0-0 |
| | **Total Applied** | 71-18-0-14 | 71-18-0-14 | 71-18-0-14 | 71-18-0-14 |

Phosphorous was applied at sowing to both sites. At Loxton where the soil was naturally lacking in P, extra P was applied at ToS 1, but due to equipment limitations an additional machinery pass was required to apply the additional P. The soil disturbance from this additional machinery pass impacted the sowing of the Hemp seeds, so later sowings received the standard rate.

The use of Triple Super at Loxton in the first two ToS treatments meant that these treatments did not receive N at sowing, but Triple Super could not be procured for the last two ToS treatments, so DAP was used instead. As a result all treatments received N at sowing except for ToS 1 & 2 at Loxton. All treatments received similar amounts of N as follow-up application, with the inclusion of K at Loxton but not Maaoupe. No nutrient deficiency symptoms were noted at either site.

Crop growth stage monitoring, sampling for THC testing, harvest and yield determination were carried out as described above for the 2017/18 season.

Samples of the grain from each treatment plot were again provided to Professor Rachel Burton from the University of Adelaide’s School of Agriculture, Food & Wine. Grain weights were measured on three technical replicates for each trial plot, based on samples of 100 grains counted using a Contador Pfeuffer seed counter. The resultant weights were multiplied to convert to standard 1,000 grain weights.

Heart to hull ratio was measured on ToS 3 only, and only the heaviest three replicates were analysed (based on average 1,000 grain weight). Each sample was made up of 25 grains selected from amongst the larger, dark coloured grain, to get a better estimate of the ratio for the “best” grain possible from each variety. The 25 grains were weighed, then heart and hull fractions manually separated and weighed. Further analyses of grain will be undertaken by the University of Adelaide, including analysis of grain fill and maturity, and the levels of lipids and protein. Results of these analyses will be reported in an update to this report.

Samples of stem material from each treatment plot were again provided to Stuart Gordon from CSIRO’s Crop Improvement for Novel Plant Products Program in June 2019. This material will be analysed for yield of fibre and hurd, and the breaking strength of fibre bundles. Results from his analyses will be included in a future update report.

Data were subjected to two-way analysis of variance (ANOVA) to compare variety and time of sowing at each location. Pairwise multiple comparisons were used to differentiate treatments at $P<0.05$.

Full three-way ANOVA (location x variety x time of sowing) was not possible on most data sets due to missing data. These missing values precluded the use of three-way ANOVA on any of the basic data sets.

# Materials and methods – 2019/20

The success of the 2018/19 trials at Maaoupe saw this site reused again in 2019/20, in addition to the continuation of trials at Loxton. Details of the two sites can be found in Table 5 in the previous section.

Of the varieties trialled in 2018/19, two were retained as standard varieties for comparing all other varieties to, one at each trial site (Ferimon 12 at Maaoupe and Han NE at Loxton). Another five varieties were selected to be trialed at both sites, bringing the total number of varieties in the 2019/20 trials to seven, with six being planted at each site (5 new and one standard). The varieties selected for planting at the field trial sites are summarised in Table 9, along with some details about their characteristics.

*Table 9 Varieties chosen for field trials – 2019/20*

| **Variety characteristics** | | | | | |
|---|---|---|---|---|---|
| **Variety** | Origin | Season | Type | Primary use | Reported THC |
| **Anka** | Canada | Mid-late | Monoecious | Grain/Fibre | <0.30 |
| **CFX-2** | Canada | Early | Monoecious | Grain | “Low” |
| **Earlina** | France | Early-Mid | Monoecious | Grain | 0.12 |
| **FINOLA** | Finland | Early | Dioecious | Grain | 0.15 |
| **Han FNQ** | China | Mid-late | Dioecious | Grain/Fibre | <0.30 |
| **Ferimon 12*** | France | Mid | Monoecious | Grain | 0.03 |
| **Han NE**** | China | Mid-late | Dioecious | Grain/Fibre | <0.30 |

*Ferimon 12 planted only at Maaoupe
**Han NE planted only at Loxton

*Table 10 Sowing dates for time of sowing (ToS) treatments at each trial site – 2019/20*

| **Trial sowing dates** | | |
|---|---|---|
| **Site** | ToS 1 | ToS 2 |
| **Loxton** | 2/12/19 | 19/12/19 |
| **Maaoupe** | 29/11/19 | 17/12/19 |

In 2019/20 only two “Time of Sowing” (ToS) treatments were applied, based on the relatively poor performance of the earliest sowing times in previous seasons. Delays in delivery of seed for some varieties saw the first sowing delayed from the planned timing of mid-November until the very end of November, and Han-FNQ seed had still not arrived on this Maaoupe sowing date, and was not sown in the first ToS treatment. As previously, the ToS treatments were applied to the two sites within a few days of each other, as detailed in Table 10.

Each combination of variety by ToS was replicated four times. In order to minimize the potential for mature plantings to impact on younger plantings, each ToS was planted as a contiguous block, with varieties randomized within the block. Further, the first ToS treatment was planted at the southernmost edge of each trial site, with subsequent plantings being always to the north of the last planting, to avoid shading of new plantings by larger plants from previous ToS treatments.

Both trial sites were irrigated using overhead sprinklers on 2.5 m tall risers. Irrigation scheduling was determined by the manager at each site, in response to rainfall and climatic conditions.

Soil tests were carried out prior to sowing at both sites, across both ToS areas. Results are displayed in Table 11, and indicate good levels of all the major nutrients. A legume crop was grown through the winter at Loxton, which fixed a good amount of Nitrogen in the soil, and fertility is naturally high at Maaoupe.

*Table 11 Soil test results - 2019/20*

| **Soil Test Results (mg/kg)** | | | | | |
|---|---|---|---|---|---|
| **Site** | **Sample** | **N** | **P** | **K** | **S** |
| **Loxton** | **ToS 1 0-15 cm** | 17.8 | 34 | 280 | 3.2 |
| | **ToS 1 15-30 cm** | 15.8 | 21 | 245 | 3.4 |
| | **ToS 1 30-60 cm** | 8.0 | 15 | 209 | 2.8 |
| | **ToS 1 0-15 cm** | 10.9 | 36 | 339 | 2.4 |
| | **ToS 1 15-30 cm** | 10.7 | 28 | 328 | 3.2 |
| | **ToS 1 30-60 cm** | 10.6 | 16 | 275 | 4.3 |
| **Maaoupe** | **ToS 1 0-15 cm** | 5.0 | 29 | 787 | 3.8 |
| | **ToS 1 15-30 cm** | 6.0 | 12 | 519 | 5.9 |
| | **ToS 1 30-60 cm** | 5.0 | 7 | 298 | 4.6 |
| | **ToS 1 0-15 cm** | 15.0 | 32 | 693 | 4.1 |
| | **ToS 1 15-30 cm** | 8.0 | 13 | 490 | 9.7 |
| | **ToS 1 30-60 cm** | 17.0 | 8 | 272 | 6.7 |

Fertiliser applications were managed by the local site managers, according to soil conditions at the trial sites. The timing and amount of major nutrients (N, P, K & S) applied to each trial site are summarized in Table 12. Nitrogen was not applied at Loxton as the soil levels were deemed sufficient, and no indications of Nitrogen deficit were noted during the growing season. The only fertilizer applied at Maaoupe was 140 kg/ha of DAP at sowing, as nutrient levels were deemed adequate, and weed issues later in the season made topdressing difficult.

Crop growth stage monitoring, sampling for THC testing, harvest and yield determination were carried out in a similar fashion as described above for the 2017/18 season.

Grain and stem material analyses will be carried out, and results added to this report at a later date.

Data were subjected to two-way analysis of variance (ANOVA) to compare variety and time of sowing at each location. Pairwise multiple comparisons were used to differentiate treatments at $P<0.05$.

Full three-way ANOVA (location x variety x time of sowing) was not possible on most data sets due to missing data. These missing values precluded the use of three-way ANOVA on any of the basic data sets.

*Table 12 Type, amount and timing of fertiliser applications - 2019/20*

| **Fertiliser applications (units/Ha)** | | | |
|---|---|---|---|
| **Site** | **Timing** | ToS 1 | ToS 2 |
| **Loxton** | **At sowing** | 0-45-0-14 | 0-45-0-14 |
| | **Post emergence** | 0-0-50-0 | 0-0-50-0 |
| | | 0-45-50-14 | 0-45-50-14 |
| **Maaoupe** | **At sowing** | 25-28-0-0 | 25-28-0-0 |
| | **Post emergence** | 0-0-0-0 | 0-0-0-0 |
| | | 25-28-0-0 | 25-28-0-0 |

# Materials and methods – 2020/21

Restricted funding in 2020/21 resulted in the suspension of research at Loxton, with available resources focused at the Maaoupe site, in recognition of the greater development of the industry in the Limestone Coast region relative to the Murraylands . Details of the Maaoupe site can be found in Table 5.

Ferimon 12 was retained as the standard variety, and five new varieties were selected for comparison against this standard. The varieties selected for planting at the field trial site are summarised in Table 13, along with some details about their characteristics.

*Table 13 Varieties chosen for field trials – 2020/21*

| Variety characteristics | | | | | |
|---|---|---|---|---|---|
| **Variety** | Origin | Season | Type | Primary use | Reported THC |
| **Canda** | Canada | Mid-late | Monoecious | Grain/Fibre | <0.30 |
| **Felina 32** | France | Mid | Monoecious | Grain/Fibre | <0.12 |
| **Ferimon 12*** | France | Mid | Monoecious | Grain | 0.03 |
| **Joey** | Canada | Mid-late | Monoecious | Grain/Fibre | <0.30 |
| **Katani** | Canada | Mid | Dioecious | Grain | <0.30 |
| **X-59** | Canada | Mid | Dioecious | Grain/Fibre | “v. low” |

*Table 14 Sowing dates for time of sowing (ToS) treatments – 2020/21*

| Trial sowing dates | | |
|---|---|---|
| **Site** | ToS 1 | ToS 2 |
| **Maaoupe** | 10/11/20 | 23/12/20 |

As was the case in 2019/20, only two “Time of Sowing” (ToS) treatments were applied, based on the relatively poor performance of the earlier and later sowing times in previous seasons (Table 14). The second sowing was delayed due to other obligations with the team undertaking the sowing, resulting in a longer than ideal gap between the two sowings.

As in previous seasons, each combination of variety by ToS was replicated four times, each ToS was planted as a contiguous block with varieties randomized within the block, and the first ToS treatment was planted at the southernmost edge of each trial site, with subsequent plantings being always to the north of the last planting, to avoid shading of new plantings by larger plants from previous ToS treatments.

The trial site was irrigated using overhead sprinklers on 2.5 m tall risers. Irrigation scheduling was determined by the manager at the site, in response to rainfall and climatic conditions.

Soil tests were not carried out prior to sowing. Fertility is naturally high at Maaoupe and the trial site was alongside the site from the previous season.

*Table 15 Type, amount and timing of fertiliser applications - 2020/21*

| Fertiliser applications (units/Ha) | | | |
|---|---|---|---|
| **Site** | **Timing** | ToS 1 | ToS 2 |
| **Maaoupe** | **At sowing** | 25-28-0-0 | 25-28-0-0 |
| | **Post emergence** | 0-0-0-0 | 0-0-0-0 |
| | **Total Applied** | 25-28-0-0 | 25-28-0-0 |

Fertiliser applications were managed by the local site manager, according to soil conditions at the trial site. As in previous years at this site, the only fertilizer applied was 140 kg/ha of DAP at sowing (Table 15).

Crop growth stage monitoring, sampling for THC testing, harvest and yield determination were carried out in a similar fashion as described above for the 2017/18 season.

Grain and stem material analyses are being carried out, and results will be added to this report at a later date.

Data were subjected to two-way analysis of variance (ANOVA) to compare variety and time of sowing at each location. Pairwise multiple comparisons were used to differentiate treatments at $P<0.05$.

# Results and discussion – 2017/18

A selection of data is displayed in the following graphs. In each case the graph for the Loxton trial site is on the left, and a separate graph for the Kybybolite trial site is on the right. However, all details of the graphs are identical, including scaling of the axes, to assist in comparing data between the two sites.

Note that throughout this discussion the term seed is used to refer to material sourced from seed suppliers for planting in the trial sites. The term grain is used for the yield harvested from the trials and tested for a range of quality parameters by the University of Adelaide.

## General crop performance – 2017/18

The depth of water applied to the trial plots is shown in Figure 1. The values represent all water applied, both irrigation and rainfall. The values vary between treatments as they are the sum of applications between sowing and harvest. As a result the earlier sown and later harvested treatments accumulated more applied water than treatments sown later or harvested earlier.

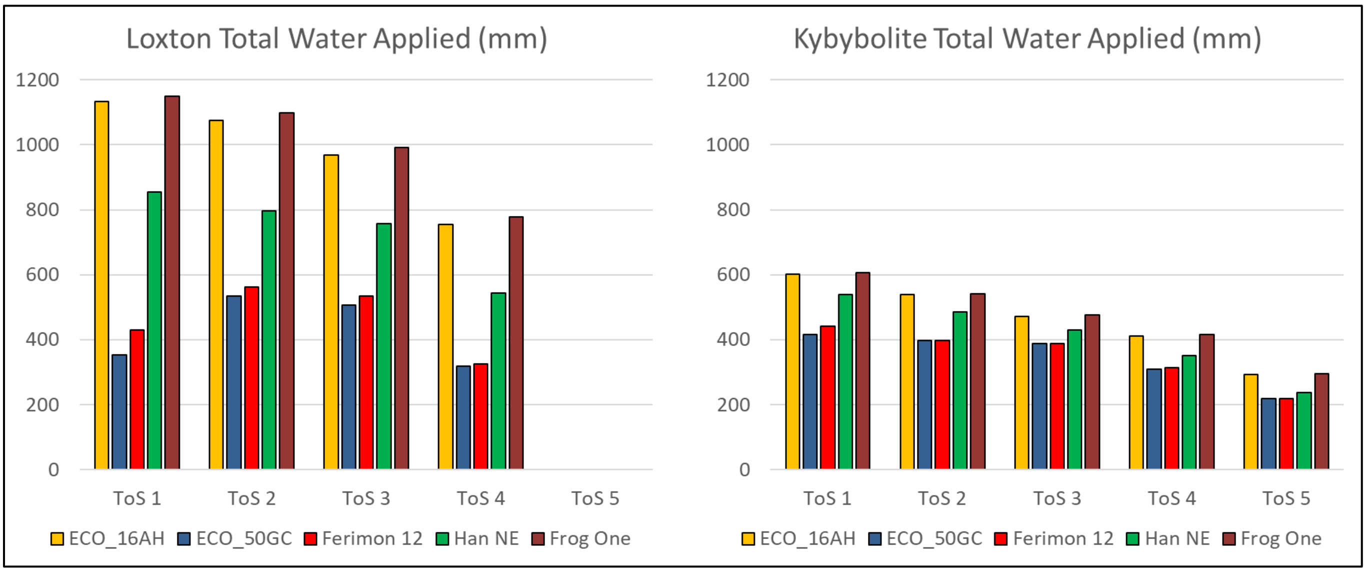


*Figure 1 Depth of water applied from sowing to harvest – 2017/18 (irrigation and rainfall)*

Differences between Loxton and Kybybolite reflect both a cooler climate at Kybybolite, and also different soils and management of the sites. Irrigation management at Kybybolite was difficult due to the heavy soil and the use of a travelling irrigator, which limited the amount of water which could be applied per pass, and as a result it appears that irrigation was possibly sub-optimal.

Figure 2 displays plant counts carried out between three and four weeks after sowing, to assess the density of plants established in each trial plot. The target plant density was 75 plants/$m^2$ in every case, and seed sowing rate was calculated according to the germination percentage provided for each batch of seed, plus an expectation that 80% of germinated seeds would result in established plants.

It is clear from Figure 2 that crop establishment was much lower than expected, with the maximum establishment density less than 50 plants/$m^2$. Major differences can also be seen between the early ToS treatments and later ToS treatments, especially at Loxton. This particularly reflects extreme weather conditions immediately following sowing of the ToS 4 and 5 treatments at Loxton. In the week following sowing of ToS 4 at Loxton there were two days with maximum temperatures of 38.7 and 40.0°C respectively, and in the week following sowing of ToS 5 there were four days above 40°C. These conditions severely impacted on the small seedlings emerging from the sandy soil, with the heat impacting the seedlings directly, and also indirectly by making it extremely difficult to maintain soil moisture in the sandy soil of the shallow seed bed, given that hemp seed needs to be sown quite shallow (< 25 mm).

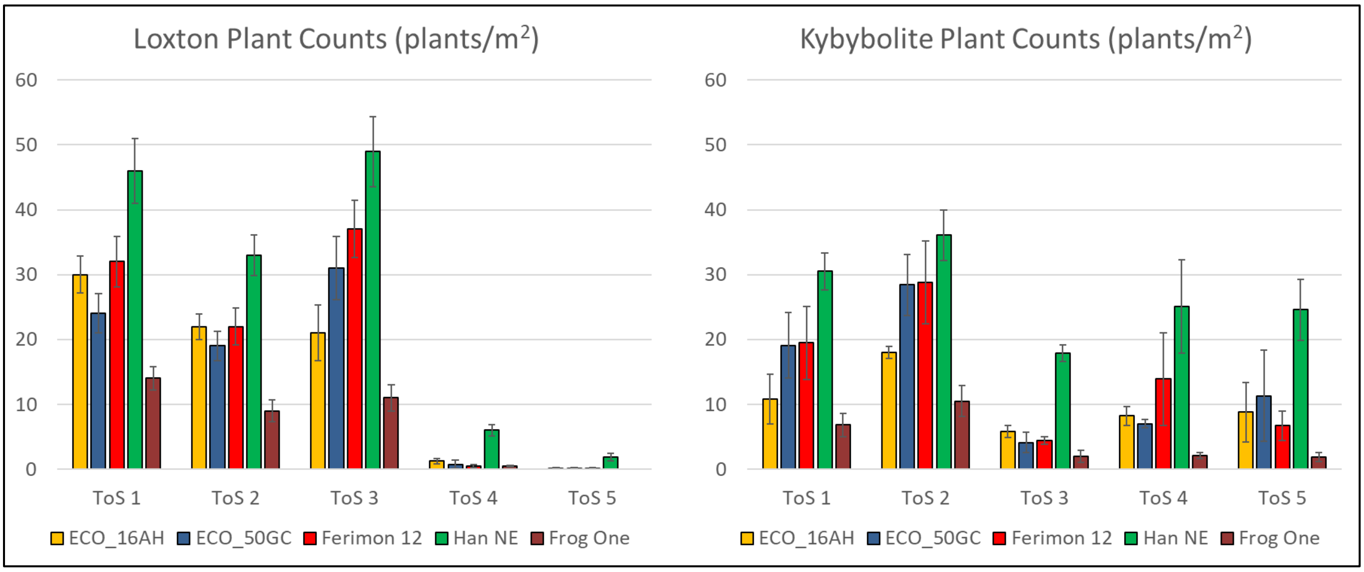


*Figure 2 Average plant count at establishment – 2017/18 (error bars are standard error (SE) across 4 replicates)*

At Kybybolite in the week following ToS 4, temperatures were milder, with the maximum not rising above 30°C. However, conditions at Kybybolite were severe following ToS 5, with two days above 40°C, so the better performance here than at Loxton at this ToS was perhaps due to the heavier soil not drying out as quickly under these severe conditions. However, at Kybybolite some of the later ToS treatments suffered from salt burn due to the high salinity of the irrigation water, and the lack of rainfall to assist with leaching salt from the rootzone at these later sowing times. It was noted that Han-NE appeared more tolerant of salt than other varieties, which was reflected in the plant counts for these later sowing dates.

The life cycle information in Figure 3 demonstrates the variation in growth habit between varieties, which are essentially split into two groups. In the first group (ECO_50GC and Ferimon 12) flowering and harvest were staggered between ToS treatments, with similar intervals between sowing, flowering and harvest independent of when they were sown. The second group (ECO_16AH, Frog One and Han NE) showed more consistency in the timing of flowering and harvest between ToS treatments, irrespective of sowing date.

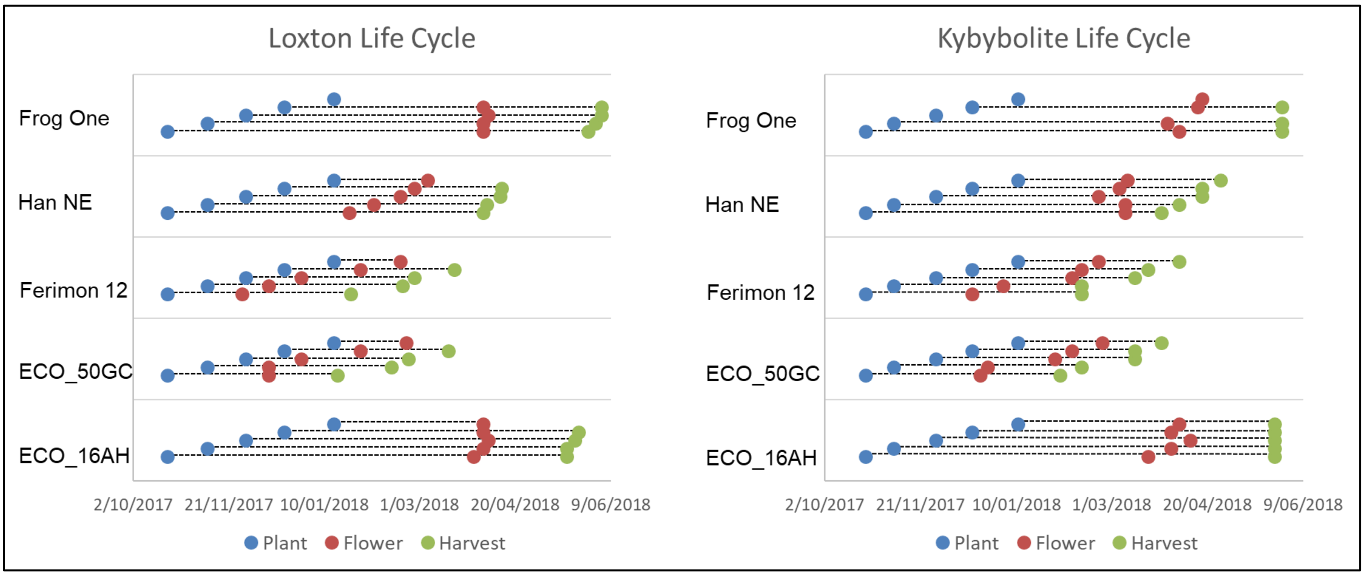


*Figure 3 Timing of key growth stages – 2017/18*

The key difference between these two groups was the trigger for flowering. In the first group flowering did not appear to be linked to day length, but this may reflect the fact that these varieties were developed in higher latitudes, where day length in summer is much longer than in South Australia. In the second group flowering did not occur until day length began to decline, after the New Year. There were also clear differences in timing within this group, with Han NE flowering in response to day length change quite quickly, followed by ECO_16AH, and Frog One was the slowest to respond.

The late flowering of Frog One resulted in harvest occurring in late May and early June, well after normal season breaking rains. In the very dry spring of 2018 this was not a problem, but in a more “average” year conditions could be expected to be quite wet at this time of year, which would make harvesting the crop much more challenging.

One result of the difference in flowering between the two groups of varieties was the final size of the plants (Figure 4). When ECO_50GC and Ferimon 12 flowered their vertical extension slowed dramatically, as the plants put energy into flower rather than vegetative growth. As a result these plants only reached a little over one metre tall. On the other hand, ECO_16AH, Frog One and Han NE continued to grow for much longer, and in the earlier ToS treatments reached over 3 m tall at Loxton, and around 3 m at Kybybolite. Interestingly Figure 4 shows a levelling out of height from late February, indicating that growth rate reduced before flowering occurred. Figure 4 presents data from ToS 1 only, but plants in ToS 2 and 3 at Loxton also exceeded 3 m in height before harvest, and plants in ToS 2 at Kybybolite approached 3 m.

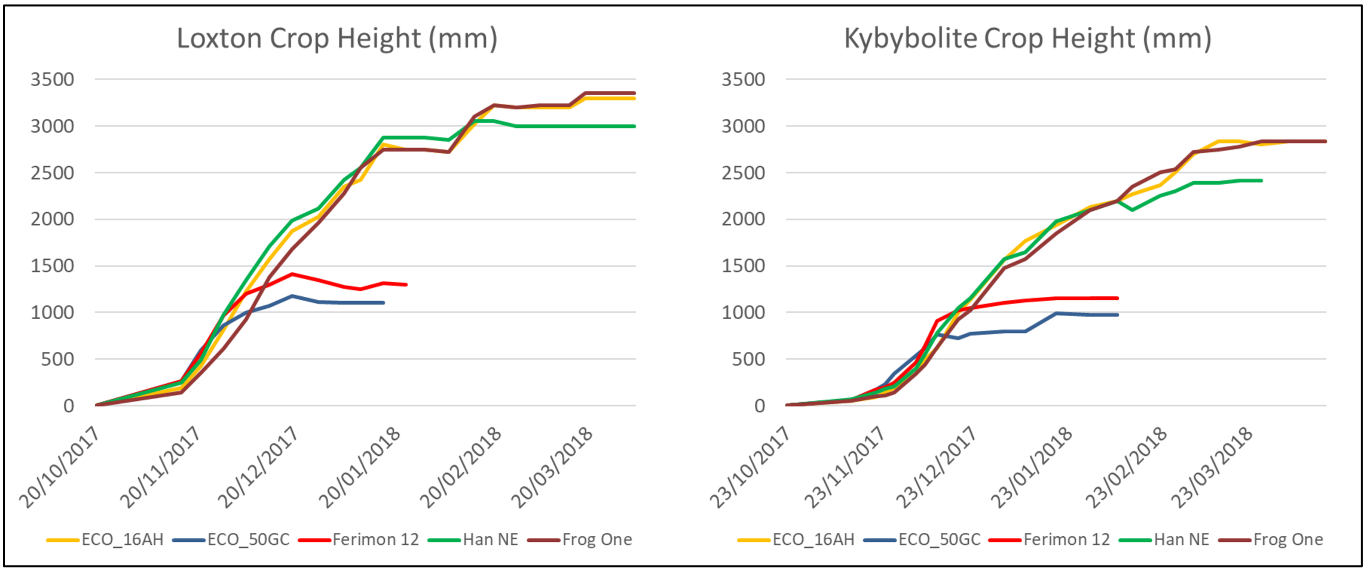


*Figure 4 Average plant height over time in ToS 1 – 2017/18*

THC testing results are displayed in Table 16. There was a difference between the early flowering varieties (ECO_50GC and Ferimon 12), which accumulated only low levels of THC, and the longer season varieties, which accumulated at least double the THC concentration in most cases. This could be due to intentional breeding for very low THC in these varieties, or may be related to the very short growing season of these early varieties, limiting cannabinoid production.

Samples collected at Loxton were below the mandatory 1% limit. There was a clear difference in THC in variety ECO_16AH between Loxton and Kybybolite. At each ToS treatment the THC levels at Kybybolite were around double the levels at Loxton, and ToS 4 was much higher, just above the 1% limit. ECO_16AH was the only variety sampled at Kybybolite, due to logistical limitations, but it is highly likely that a similar pattern of higher THC occurred in all varieties.

Reasons for the difference in THC between sites are complex, but there is evidence that the levels of active substances in a range of medicinal plants, including hemp, are raised by stress (Kleinwachter and Selmar, 2015; Latta and Eaton, 1975; Pate, 1999). It is possible that the significantly lower irrigation amounts applied to the Kybybolite site, potentially combined with the high salinity of the water, resulted in plant stress, promoting greater production of cannabinoids, including THC.

Total dry matter harvested from a small subplot within each trial plot (converted to t/ha) is shown in Figure 5. Earlier planting dates resulted in greater dry matter accumulation in ECO_16AH, Han NE and Frog One at Loxton, but this trend was less apparent at Kybybolite, due to greater variability at this site.

Lower dry matter accumulation occurred in ECO_50GC and Ferimon 12 than in other varieties, due to their earlier flowering and harvest. Note that no plots from ToS 5 at Loxton were harvested due to the extremely poor crop establishment (Figure 2).

*Table 16 THC content (%w/w) results – 2017/18*

| **THC content (% w/w)** | | | | | | |
|---|---|---|---|---|---|---|
| **Site** | **Variety** | ToS 1 | ToS 2 | ToS 3 | ToS 4 | **Average** |
| **Loxton** | **Frog One** | 0.26 | 0.37 | 0.30 | 0.26 | **0.30** |
| | **Ferimon 12** | 0.16 | 0.17 | 0.16 | 0.17 | **0.17** |
| | **Han NE** | 0.47 | 0.42 | 0.42 | 0.80 | **0.53** |
| | **ECO_50GC** | 0.17 | 0.16 | 0.17 | 0.19 | **0.17** |
| | **ECO_16AH** | 0.44 | 0.37 | 0.40 | 0.28 | **0.37** |
| **Kybybolite** | **ECO_16AH** | 0.77 | 0.80 | 0.93 | 1.01 | **0.88** |

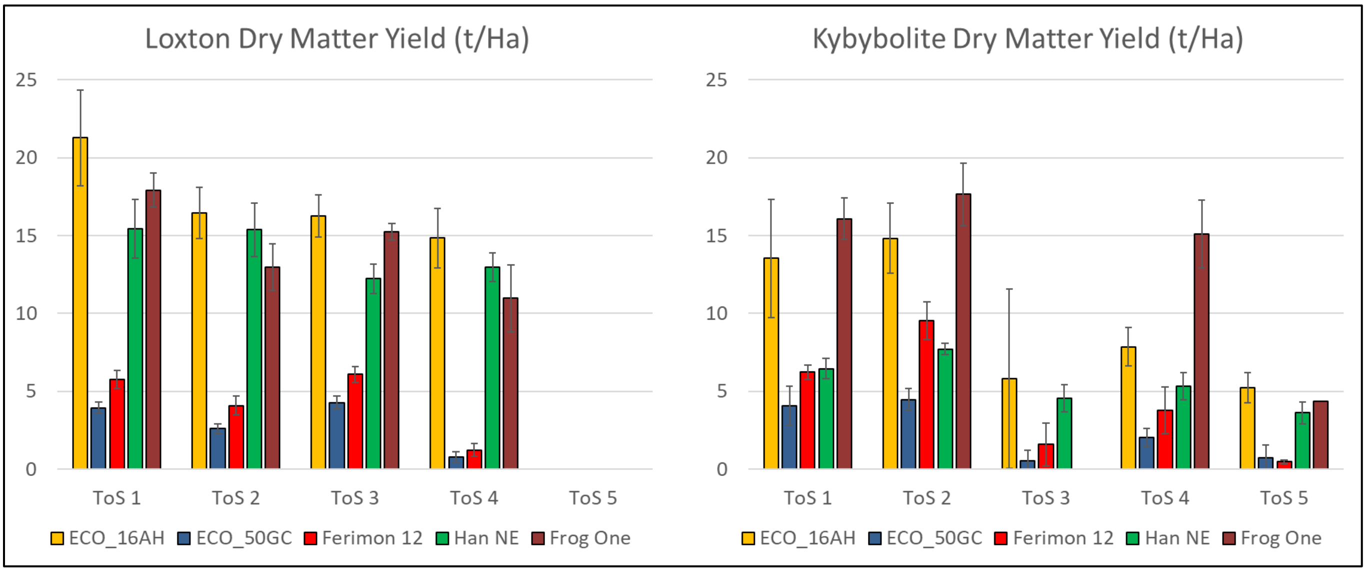


*Figure 5 Average dry matter yield – 2017/18 (error bars are SE across 4 replicates)*

## Grain production – 2017/18

The yield of grain is shown in Figure 6. Yield was variable even within ToS treatments, and performance of individual varieties was influenced by both time of sowing and site.

At the Loxton site ECO_16AH and Han NE were the top two yielding varieties in all ToS treatments, and ECO_50GC and Ferimon were the lowest yielding. Potential contributors to the poor performance of these early flowering varieties may include the small size of the plants when they flowered, limiting their ability to fill grain adequately, and also poor weed control due to sub-optimal plant density and the small and upright nature of the plants, which consequently failed to provide the same level of weed smothering as achieved by the more vigorous plants of the other varieties.

At Kybybolite there was less clarity between varieties, with ECO_50GC and Ferimon 12 yielding well in the early ToS treatments, but not in the later ToS treatments, relative to the later flowering varieties.

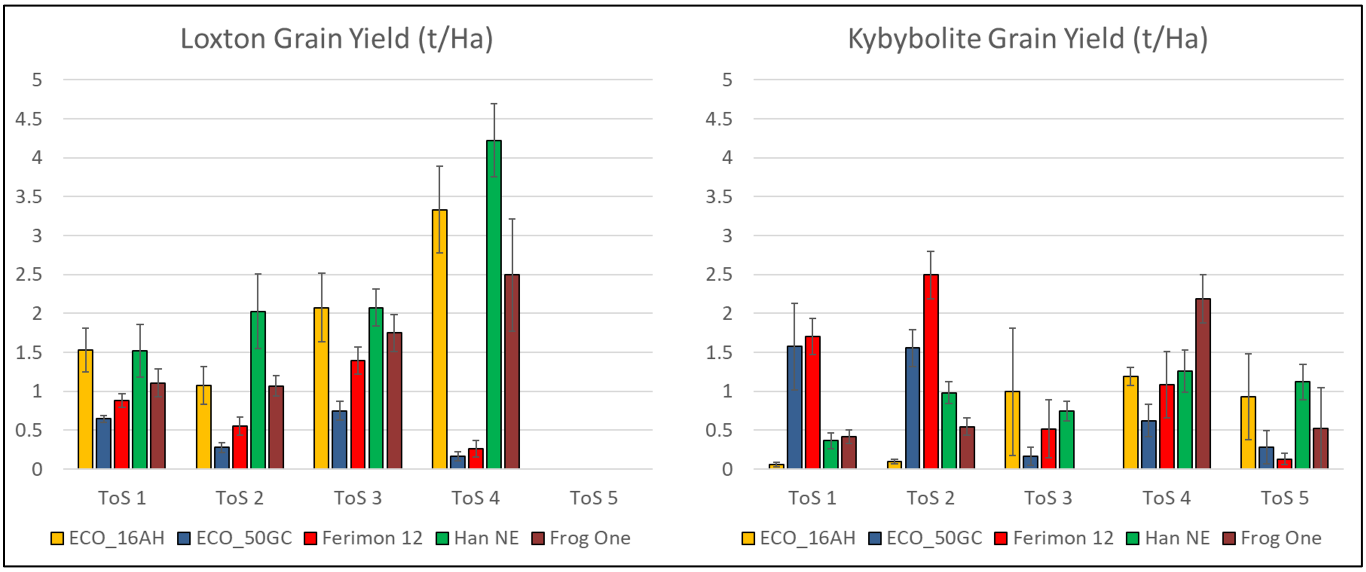


*Figure 6 Average grain yield – 2017/18 (error bars are SE across 4 replicates)*

Figure 7 shows harvest index, or grain yield as a percentage of total dry matter yield for each treatment. At both sites it was clear that, although grain yield of ECO_50GC and Ferimon 12 was lower in most instances than the later maturing varieties, the harvest index was similar or higher in these early varieties. Similarly, the later the time of sowing of the later maturing varieties, the greater the harvest index, due to a relatively shorter vegetative growth stage prior to flowering.

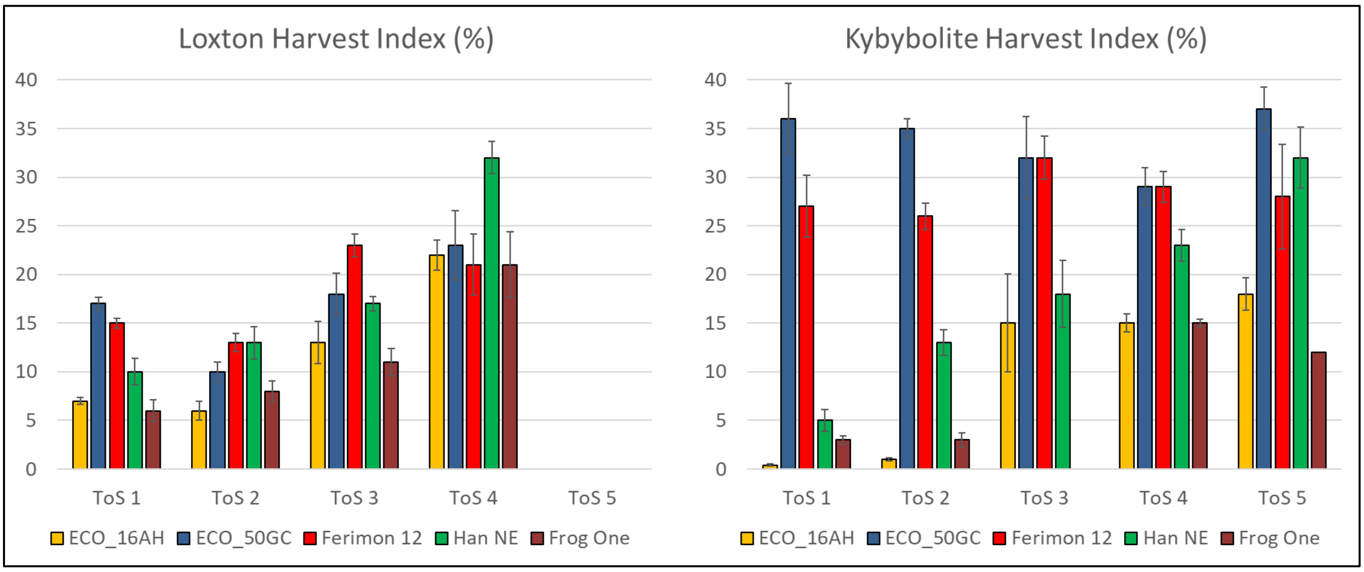


*Figure 7 Average harvest index (grain as a percentage of total dry matter) – 2017/18 (error bars are SE across 4 replicates)*

Water use efficiency, or yield per volume of water applied (t/ML) is displayed in Figure 8. Efficiency generally increased in later ToS treatments for ECO_16AH and Han NE at both sites, due primarily to the decreased amount of water applied to these later treatments. It was clear that planting these varieties early was not an advantage, as the increased cumulative water application did not result in additional yield (Figure 6), and as a result water use efficiency was decreased.

Gross yield is only one aspect of production, especially when considering marketing grain for human consumption. The University of Adelaide conducted a number of tests to analyse the quality of the grain produced in the trials.

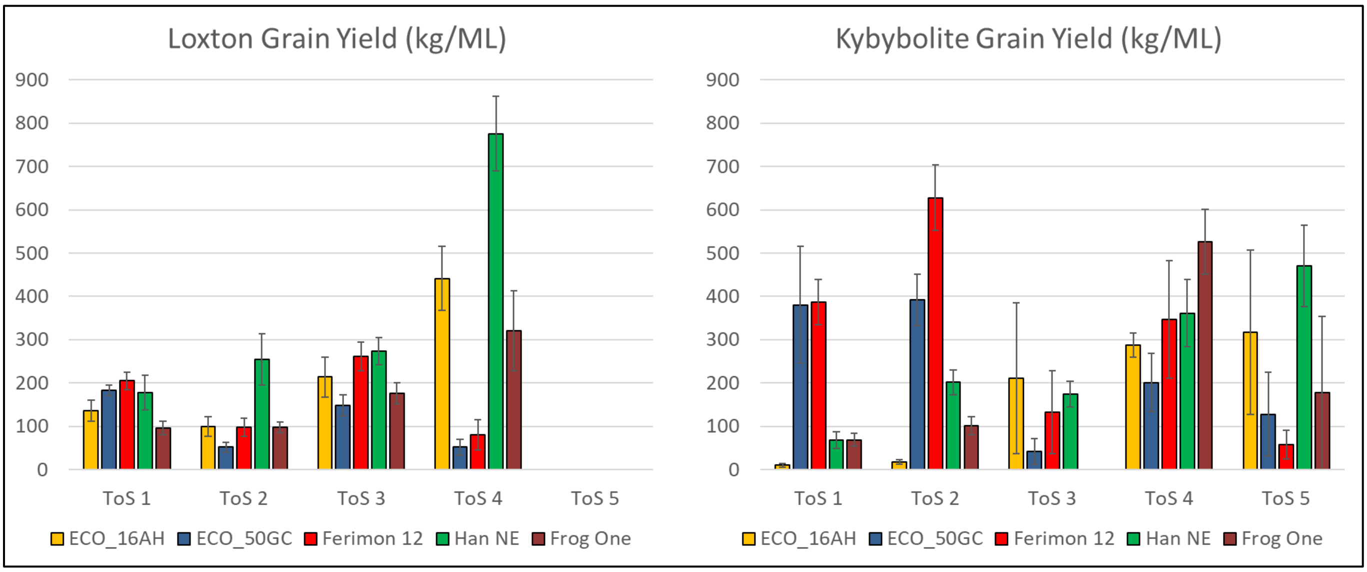


*Figure 8 Average grain yield per volume of water applied – 2017/18 (error bars are SE across 4 replicates)*

Figure 9 displays relative grain weight (weight per 1000 grains), and demonstrates a reduction in relative grain weight in the early flowering varieties (ECO_50GC and Ferimon 12) compared to the later flowering varieties at Loxton, with much less difference at Kybybolite. Grain weight provides an approximation of grain size, which will likely be an important factor in determining crop returns for grain destined for hemp hearts or wholegrains, but less important for grain going to other end uses such as oil or flour production.

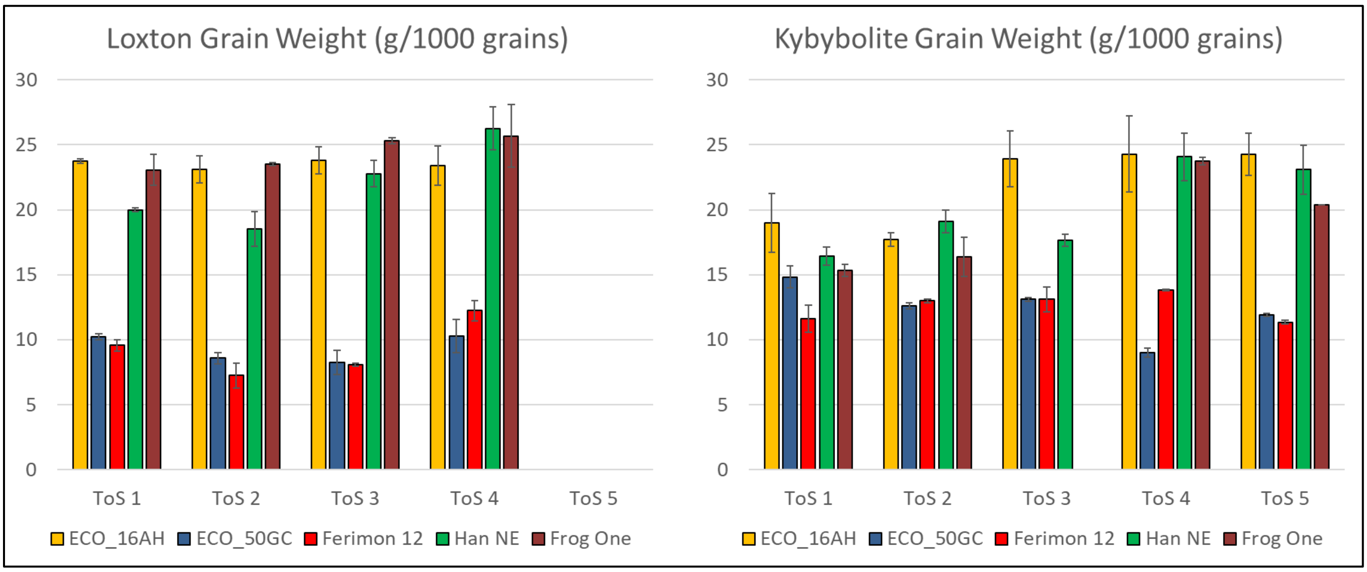


*Figure 9 Average weight of 1000 grains – 2017/18 (error bars are SE across 2 technical replicates)*

Another key factor affecting eating quality of wholegrain, and yield of hemp hearts, is heart to hull ratio. Data in Figure 10 shows heart:hull for one replicate of each variety/ToS/site combination, with a 1.0 ratio line (equal weight of heart and hull) included for easy comparison.

At Loxton, ECO_50GC consistently produced grain with less heart than hull (ratio <1.0), which is not a desirable trait for eating or heart yield. Ferimon 12 also produced very low heart:hull in three of the four ToS treatments at Loxton, while Han NE had the highest ratio across treatments. At Kybybolite no variety consistently produced grain with heart:hull >1.0, but again Han NE averaged the highest ratio across all treatments, followed by Ferimon 12. The inconsistency in performance of some varieties between the two trial sites is unexplained to date.

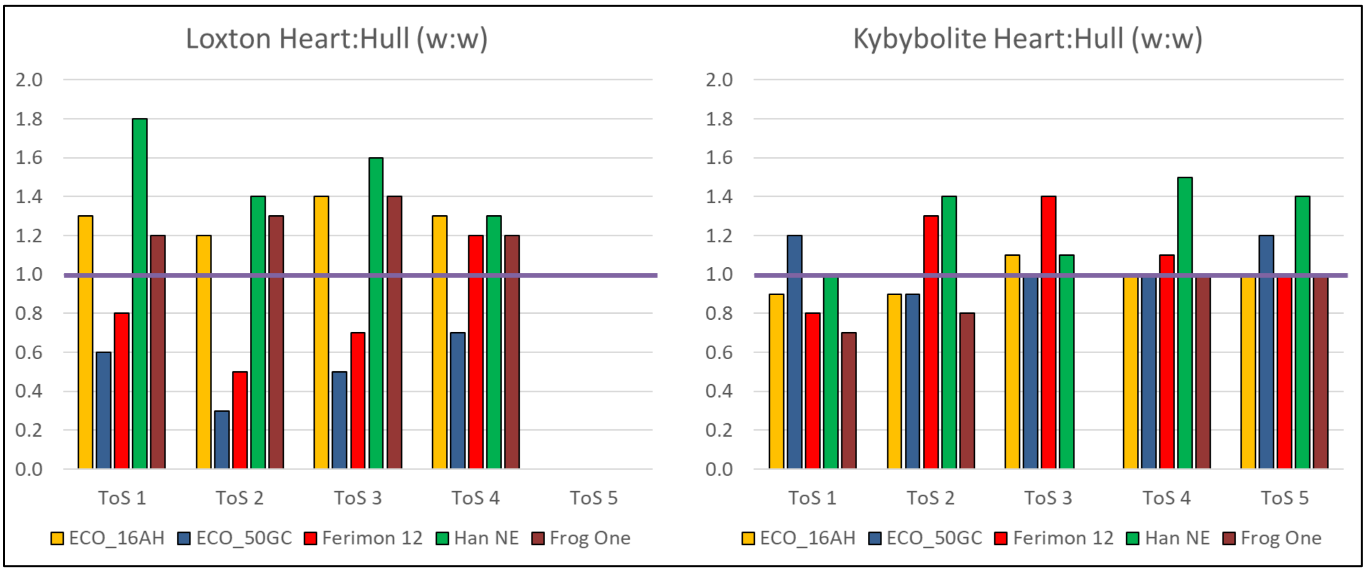


*Figure 10 Ratio of heart to hull by weight – 2017/18 (sample size 25 grains), including 1:1 line for comparison*

During harvest and grain threshing it became clear that a significant amount of grain in some treatments was empty when cracked open. Schluttenhofer and Yuan (2017) reported that darker grain was generally filled, and lighter coloured grain was immature and unfilled. Visual assessment of grain was carried out (dark grain filled, light grain unfilled), and the results are displayed in Figure 11, presented as the percentage of grain which was properly filled. Note that the percentage axis begins at 50%, to enhance the differences between treatments.

All varieties showed some level of unfilled grain (< 100% filled grain), with some individual treatments recording as low as 60% filled grain (40% unfilled). It was difficult to identify clear trends, especially as the data comes from only one replicate of each treatment.

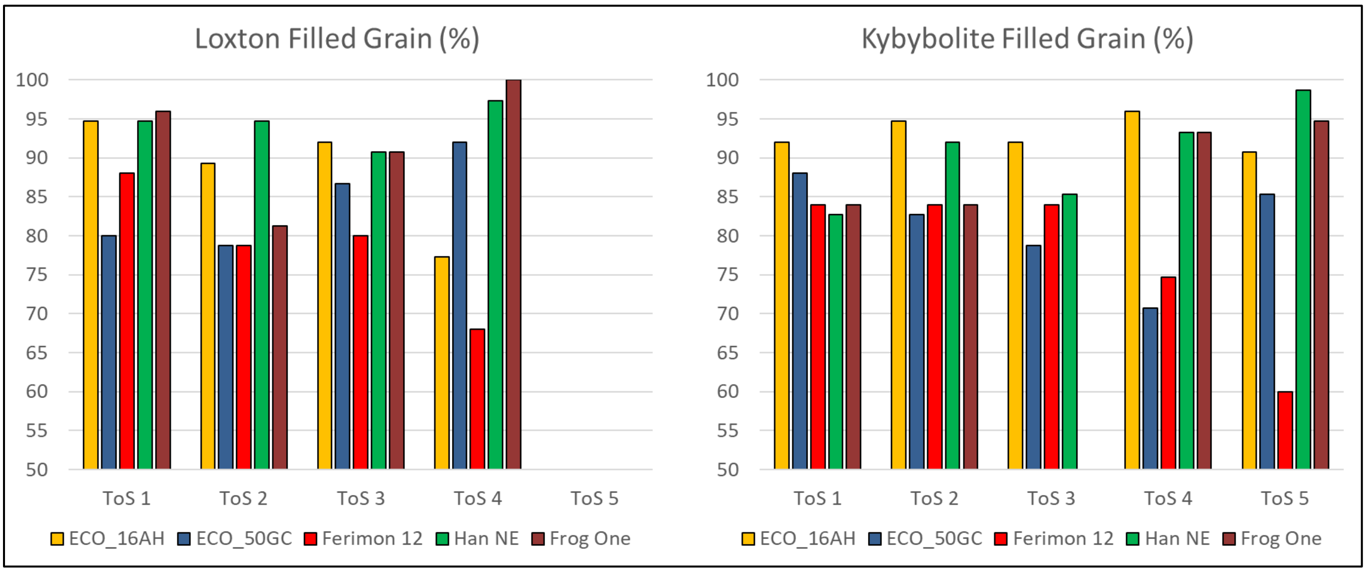


*Figure 11 Percentage of fully filled grain – 2017/18 (sample size 75 grains)*

Chemical analysis of samples of the grain was carried out by a commercial laboratory, using a single sample from each variety at each trial site, for ToS treatments 1 and 4 only, due to cost being a barrier to conducting full analyses on all replicates of all treatments. The replicate with the highest 1000 grain weight was selected for analysis from within each treatment tested.

Protein content of the grain within these samples (Figure 12) was between 19 and 25% for all samples tested. There were no significant differences observed between locations, varieties or times of sowing.

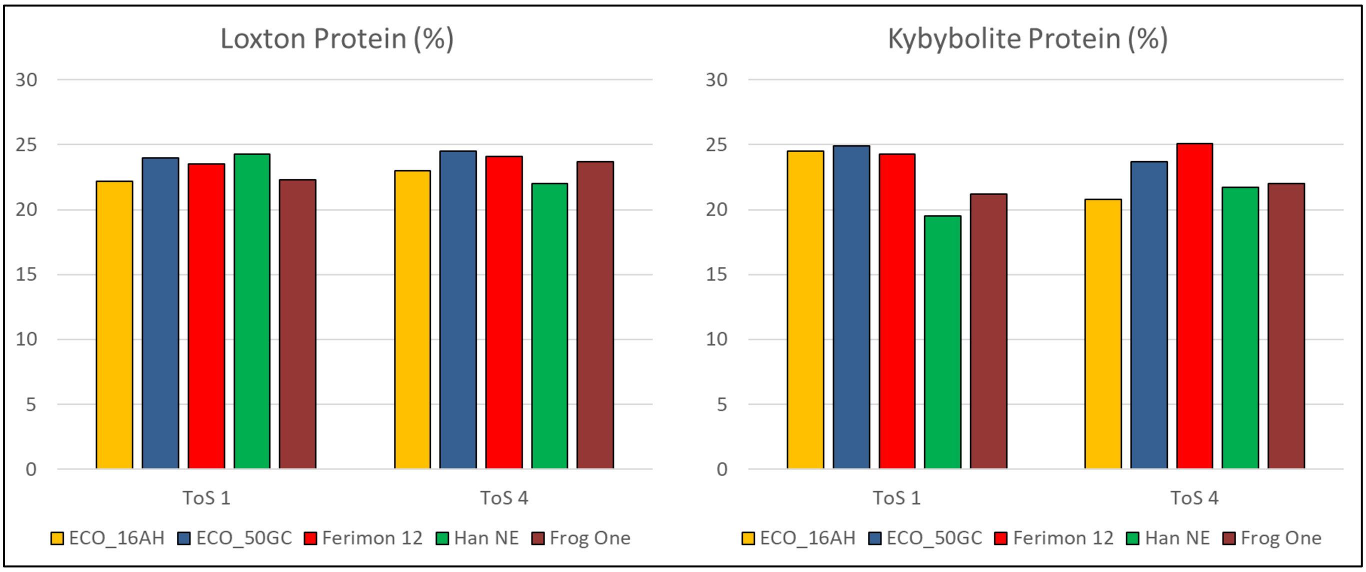


*Figure 12 Protein content of grain – 2017/18 (one replicate of two ToS treatments)*

Total fat content of grain within the samples tested is displayed in Figure 13. Values ranged between 20 and 34%. Again there were no significant differences between locations, varieties and times of sowing.

During pre-screening for these field trials, grain from 20 varieties collected from a range of sources across Australia were analysed for a similar set of parameters (Schultz et al., 2020). Interestingly, results for protein content in the two sample groups were similar (22 to 27% in pre-screening, 19 to 25% in the field trials).

However, the fat content of the pre-screening grain (27 to 38%) was somewhat higher than the values obtained from the field trials (20 to 34%), and a direct comparison of the five field tested varieties reveals that fat content was between 2 and 17% higher in the pre-screening grain than the field trial grain. Reasons for this are unclear, and multi-season data is required to clarify the likely causes.

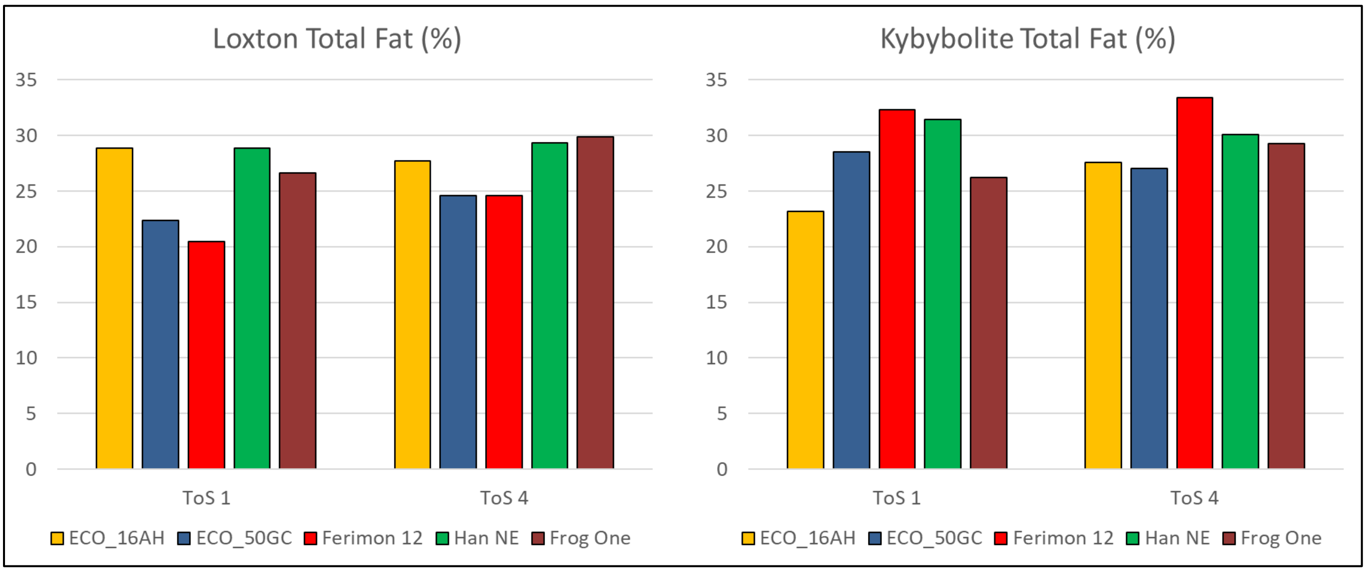


*Figure 13 Total fat content of grain – 2017/18 (one replicate of two ToS treatments)*

The percentages of different fats making up the total fat profile of hemp grain is displayed in Figure 14. Omega 6 made up more than 50% of total fat in all cases, while omega 7 was less than 1.5% across all samples. Saturated fat (10 to 13%), omega 9 (9 to 17%) and omega 3 (13 to 25%) made up the remainder of the total.

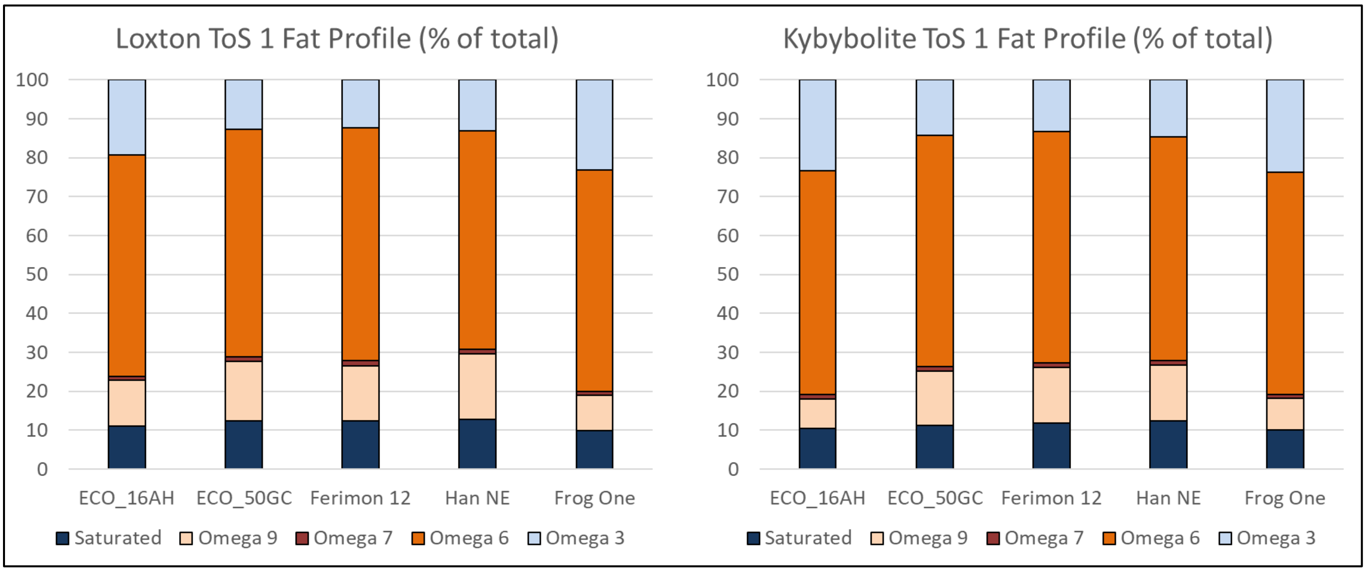


*Figure 14 Breakdown of fats in grain – 2017/18 (one replicate of ToS 1 treatment)*

Statistical analysis revealed significant differences in the levels of different fats across varieties and trial sites. ECO_16AH and Frog One both displayed significantly lower amounts of saturated fat and omega 9 & 7 than the other three varieties, and significantly higher levels of omega 3. There was also significantly higher saturated fat and omega 9 & 7, and significantly lower omega 3 at Loxton compared to Kybybolite. There was no significant difference between ToS 1 and ToS 4 for any of the compounds analysed.

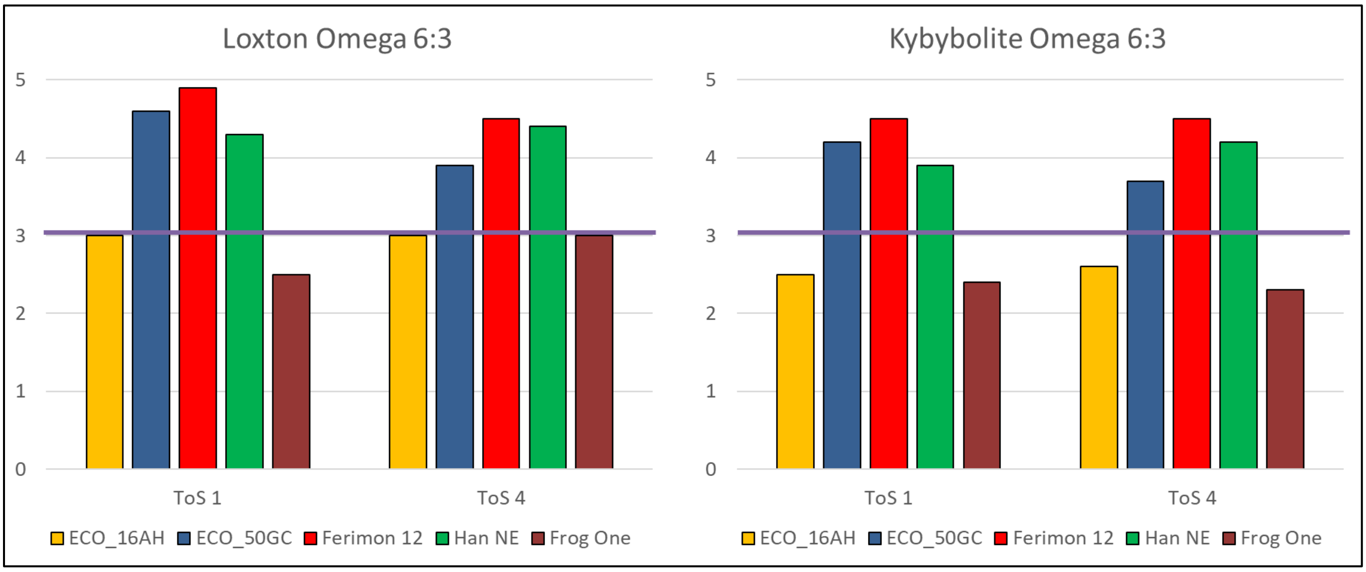


*Figure 15 Omega 6:3 fatty acid ratio of grain – 2017/18 (one replicate of two ToS treatments), including 3.0 ratio line for comparison*

A result of the higher omega 3 content in ECO_16AH and Frog One was the significantly lower omega 6:3 found in these samples (Figure 15). All samples of these two varieties had ratios of 3 or less, whilst all samples of the other three varieties had ratios of 3.7 or greater. Consumption of foods with omega 6:3 less than 3 are reported to be desirable for improved human health outcomes (Saini and Keum, 2018; Simopoulos, 2016). Samples from Kybybolite also showed lower omega 6:3 than grain from Loxton, but multi-season trials will be required to determine how much influence growing conditions have on this characteristic of hemp grain.

## Fibre and hurd production – 2017/18

Yield of fibre (Figure 16) was determined by extracting fibre from a sample of stem material from each variety from the first three ToS treatments, to determine percent fibre yield per unit of stem weight. This figure was multiplied by the weight of stem material harvested from each plot to estimate fibre yield per plot, and consequently fibre yield per hectare.

Fibre yield showed similar patterns to dry matter yield, in that less fibre was produced in shorter growing season treatments (early harvest and/or late sowing), and higher figures came from earlier sown and later harvested treatments.

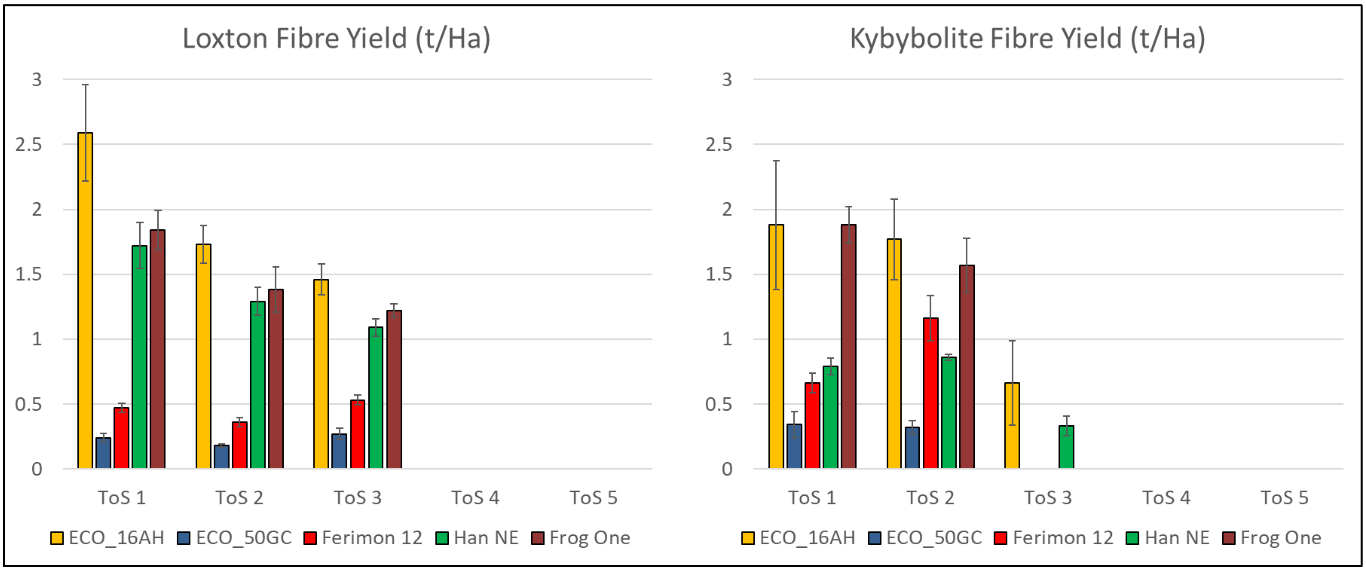


*Figure 16 Average fibre yield – 2017/18 (error bars are SE across 4 replicates)*

Fibre yield as a percentage of total dry matter (Figure 17) shows less variation between treatments, and no clear patterns, resulting in few significant differences. It appears that, amongst the varieties present in this trial, the major determinant of fibre yield may simply be the total dry matter accumulation (which was influenced by the length of the growing season), rather than any intrinsic characteristics of the varieties.

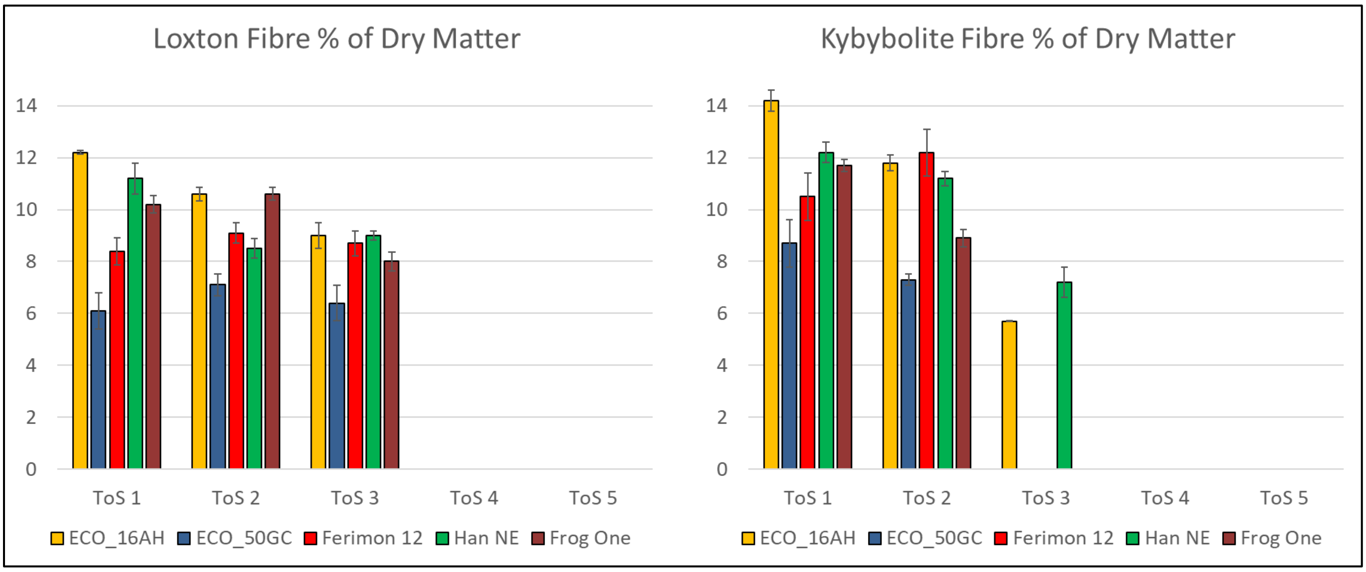


*Figure 17 Average fibre yield as a percentage of total dry matter – 2017/18 (error bars are SE across 4 replicates)*

Statistical analysis of fibre strength data (Figure 18) indicates significant differences exist between varieties, locations and times of sowing, when analysed in pairs by two-way ANOVA (missing data due to a shortage of material for some treatments precluded the use of three-way ANOVA).

The fibres from varieties Frog One and ECO_50GC were significantly stronger (higher breaking tenacity) than fibres from ECO_16AH and Ferimon 12, when all data was considered. However, interactions were found in the performance of variety with both time of sowing and location. Fibre from ToS 1 showed the greatest differences between varieties, compared to ToS 2 & 3. At Loxton Frog One and ECO_50GC were the better performers, whereas at Kybybolite Han NE and ECO_16AH performed well.

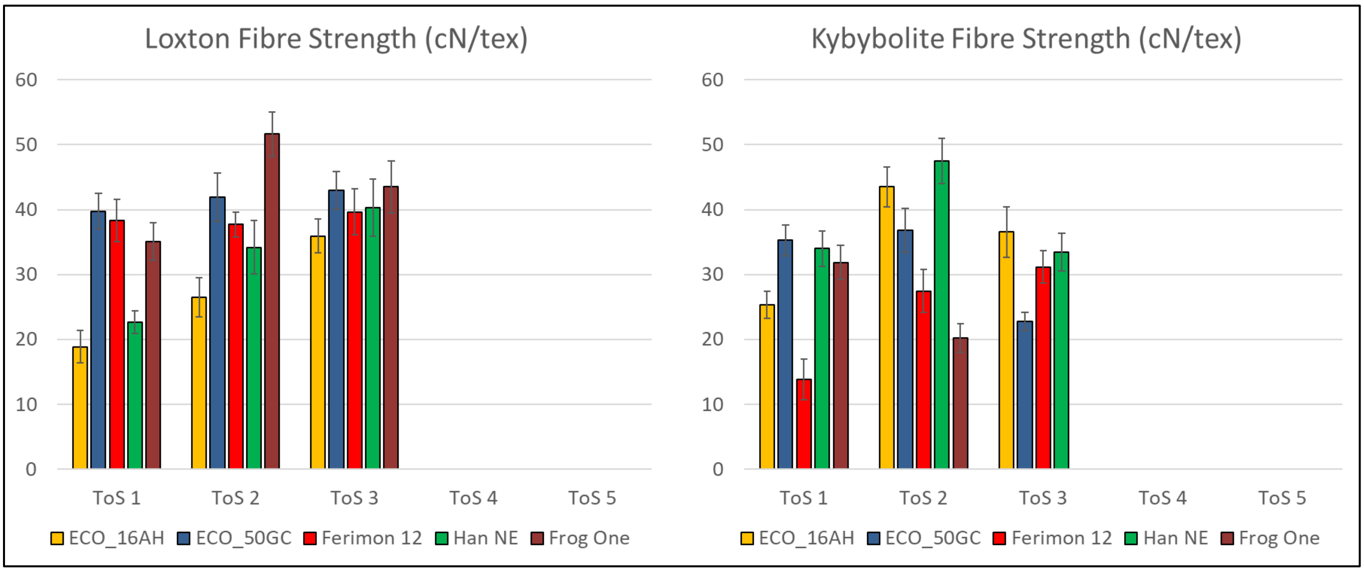


*Figure 18 Average strength of unretted fibres – 2017/18 (error bars are SE across 25 technical replicates)*

Averaged across all varieties and ToS treatments, fibres grown at Loxton were significantly stronger than those from Kybybolite. However, when separated based on variety, the strongest fibres of Han NE and ECO_16AH came from Kybybolite, whereas Loxton produced the strongest fibres of ECO_50GC, Ferimon 12 and Frog One. No significant interaction was found between location and time of sowing.

Finally, ToS 1 produced significantly weaker fibres than the other two ToS treatments. Again there was an interaction with variety, but in all cases ToS 1 either produced the weakest fibre, or there was no significant difference from the other ToS treatments.

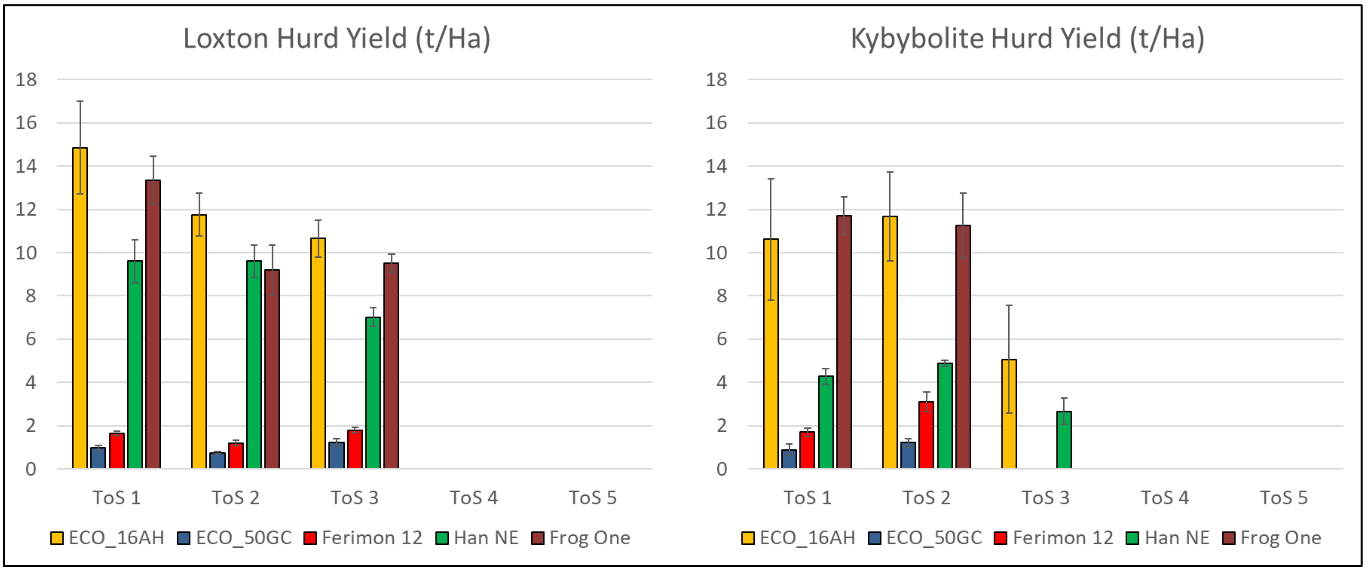


*Figure 19 Average hurd yield – 2017/18 (error bars are SE across 4 replicates)*

Hurd yield data (Figure 19) tells a similar story to fibre yield. The two early harvested varieties (ECO_50GC and Ferimon 12) produced very little hurd, whilst the later harvested varieties produced much more, with the amount reflecting the length of the growing season to a large extent.

Hurd content as a percentage of total dry matter (Figure 20) tells a similar story in terms of the impact of variety, again indicating that the early varieties put relatively more resources into flowering and less into vegetative growth than the later maturing varieties.

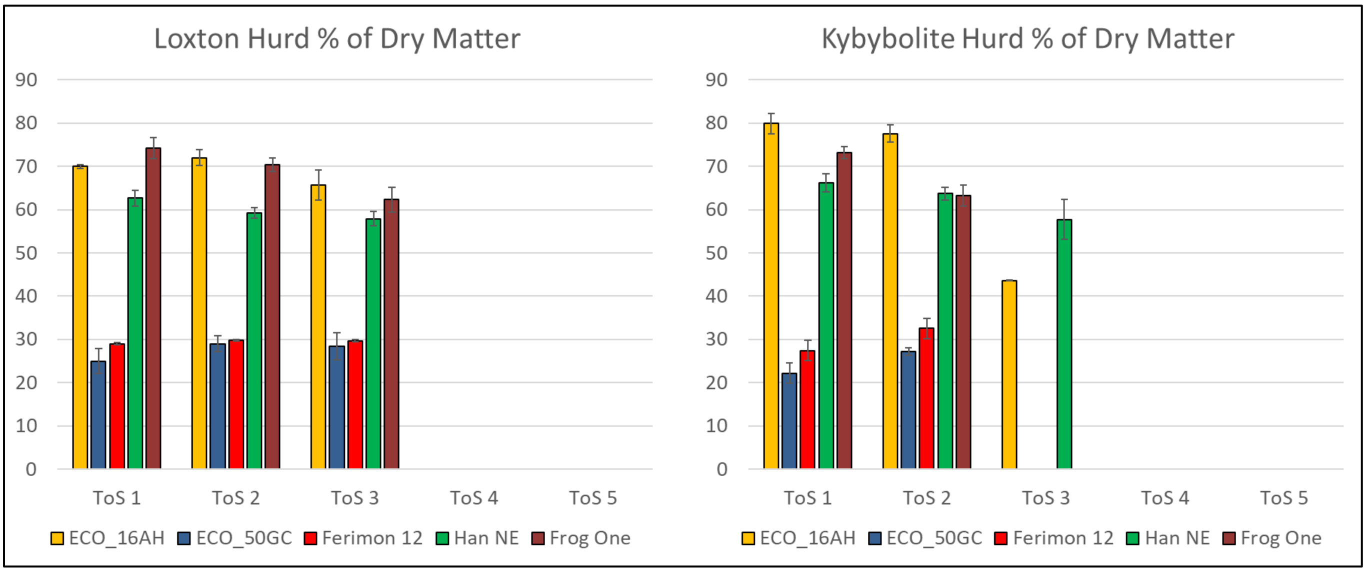


*Figure 20 Average hurd yield as a percentage of total dry matter – 2017/18 (error bars are SE across 4 replicates)*

The same theme was continued in the data for “other” as a percentage of total dry matter (Figure 21). This fraction was primarily composed of flower head vegetative material, and was calculated as the remainder of total dry matter after the contributions of grain, fibre and hurd were accounted for. The large figures for ECO_50GC and Ferimon 12 do not necessarily reflect larger flower heads on these varieties, rather they reflect the overall lower dry matter produced in these varieties (Figure 5), with the result that the flower heads make up a larger percentage of the total.

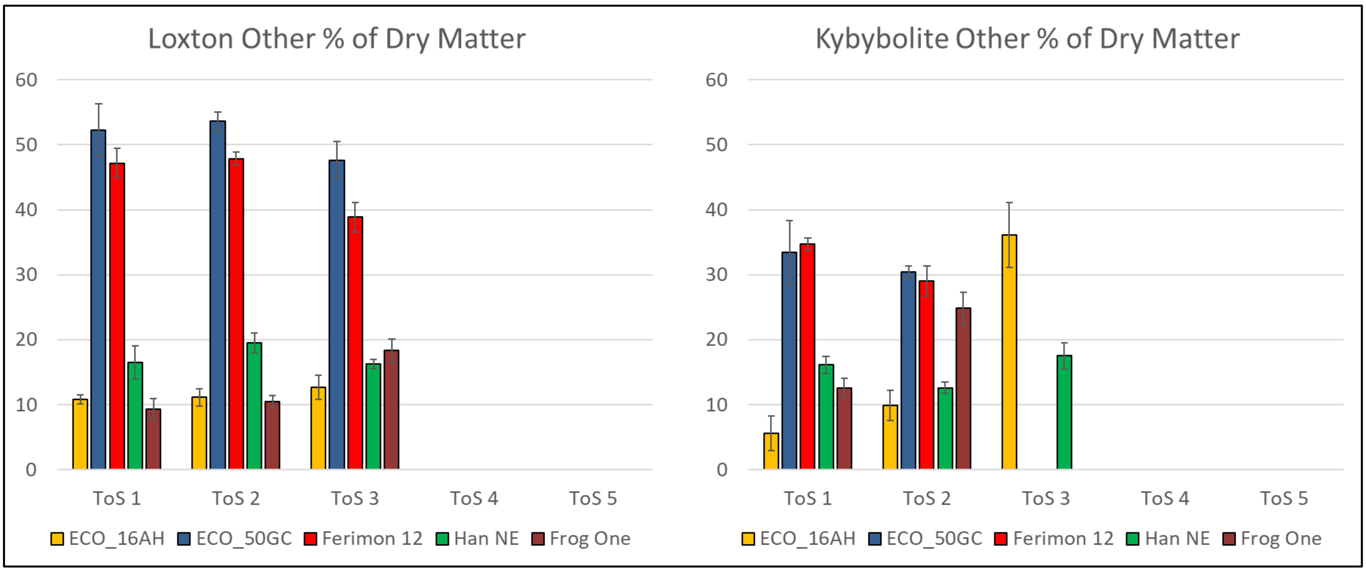


*Figure 21 Average 'other' yield as a percentage of total dry matter – 2017/18 (error bars are SE across 4 replicates)*

# Results and discussion – 2018/19

## General crop performance – 2018/19

The depth of water applied to the trial plots is shown in Figure 22. The values represent all water applied, both irrigation and rainfall. The values vary between treatments as they are the sum of all applications between sowing and harvest. As a result the longer the growing season, the more water was applied.

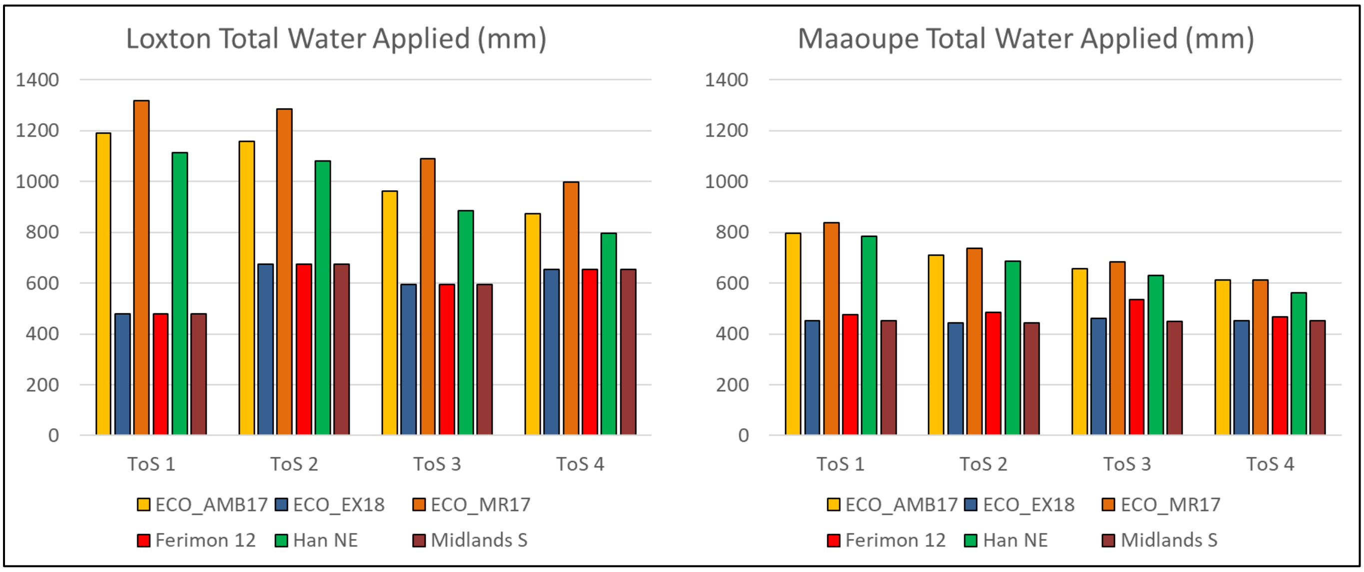


*Figure 22 Depth of water applied from sowing to harvest – 2018/19 (irrigation and rainfall)*

Differences between Loxton and Maaoupe reflect both a cooler climate at Maaoupe, and also different soils and management of the sites. On average the treatments at Loxton tended to receive approximately 40% more water than the equivalent treatments at Maaoupe.

The contribution of rainfall ranged from 1 to 12% of the total water applied at Loxton, and 6 to 20% at Maaoupe. The lowest rainfall percentage figures were associated with the latest sowing date at each site, and reflect the lack of rainfall in late summer and autumn, whilst the highest rainfall percentage figures came from the earliest sowing dates, and reflect higher rainfall totals during late spring and early summer.

Figure 23 displays plant counts carried out between two and six weeks after sowing, to assess the density of plants established in each trial plot. The target plant density was 100 plants/m$^2$ in 2018/19, and seed sowing rate was calculated according to the germination percentage provided for each batch of seed, plus an expectation that 65% of germinated seeds would result in established plants.

It is clear from Figure 23 that crop establishment was much lower than expected at Loxton, with the maximum plant count less than 70 plants/m$^2$. In contrast, all but one treatment at Maaoupe achieved greater than 70 plants/m$^2$, indicating very good establishment at that site.

The difference is most easily explained by the differences in the soil at the two sites. The Loxton trial was planted in sandy soil, and sand drift was again a problem during emergence (as was the case in 2017/18). The seeder used also created relatively deep furrows, into which the drifting sand collected readily. The result of sand drift was to bury the germinating seedlings to a depth beyond which they were unable to successfully emerge.

The soil at Maaoupe, on the other hand, was a rich self-mulching clay loam, which did not drift and provided a perfect seed bed when appropriately prepared. Observations suggest that seed germination was similar at the two sites, but seedling emergence and establishment was superior at Maaoupe.

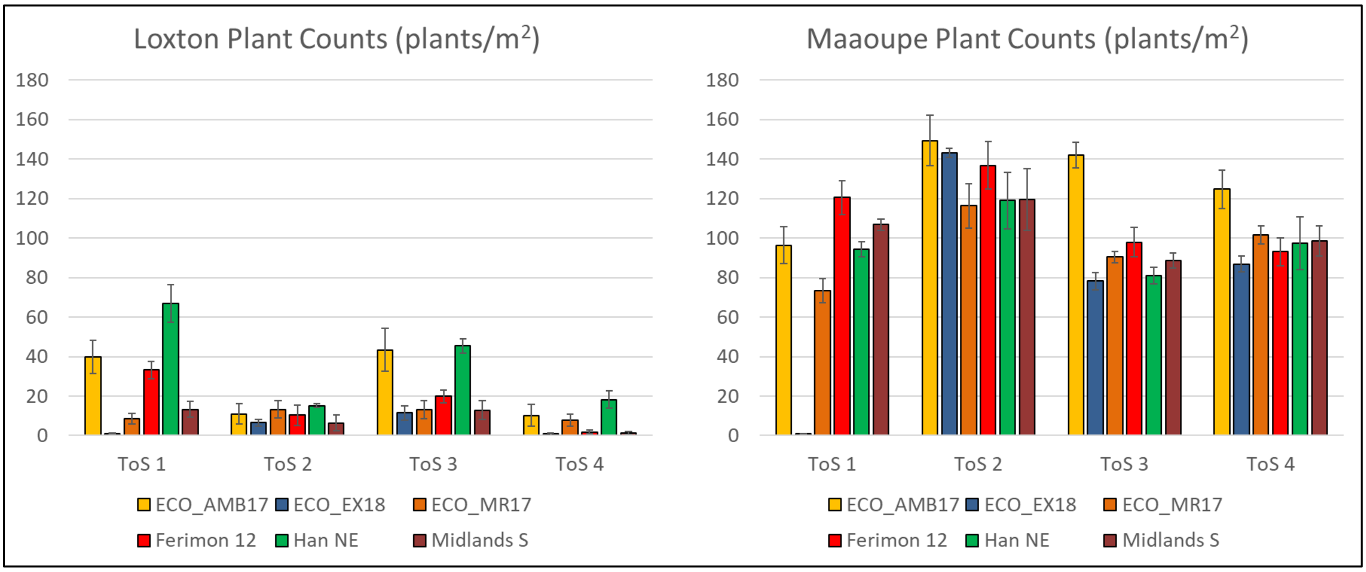


*Figure 23 Average plant count at establishment – 2018/19 (error bars are standard error (SE) across 4 replicates)*

Because of the sand drift issues at Loxton, in ToS 4 the soil was not disturbed prior to sowing, to try to minimise the depth of the furrows and the potential for sand drift. It was not clear whether this improved emergence of seedlings, but it did hamper control of weeds at sowing, and the weeds smothered the seedlings before they could establish and grow above the weed canopy. As a result no harvest was taken from ToS 4 at Loxton.

The very low plant count of ECO_EX18 in ToS 1 at both sites was due to very poor germination of the first batch of seed of this variety. There was no opportunity to carry out germination tests between receiving the seed and planting the trial sites, so this poor germination was not identified until after the plots were sown. The second batch of seed supplied had much better germination, and subsequent ECO_EX18 treatments were far more successful. No harvest was taken from ECO_EX18 in ToS 1 at either site.

The life cycle information in Figure 24 demonstrates the variation in growth habit and season length between the six varieties, which fell into two groups. In the first group (ECO_EX18, Ferimon 12 and Midlands S) flowering and harvest were staggered between ToS treatments, with similar intervals between sowing, flowering and harvest independent of when they were sown. The second group (ECO_AMB17, ECO_MR17 and Han NE) showed more consistency in the timing of flowering and harvest between ToS treatments, irrespective of sowing date.

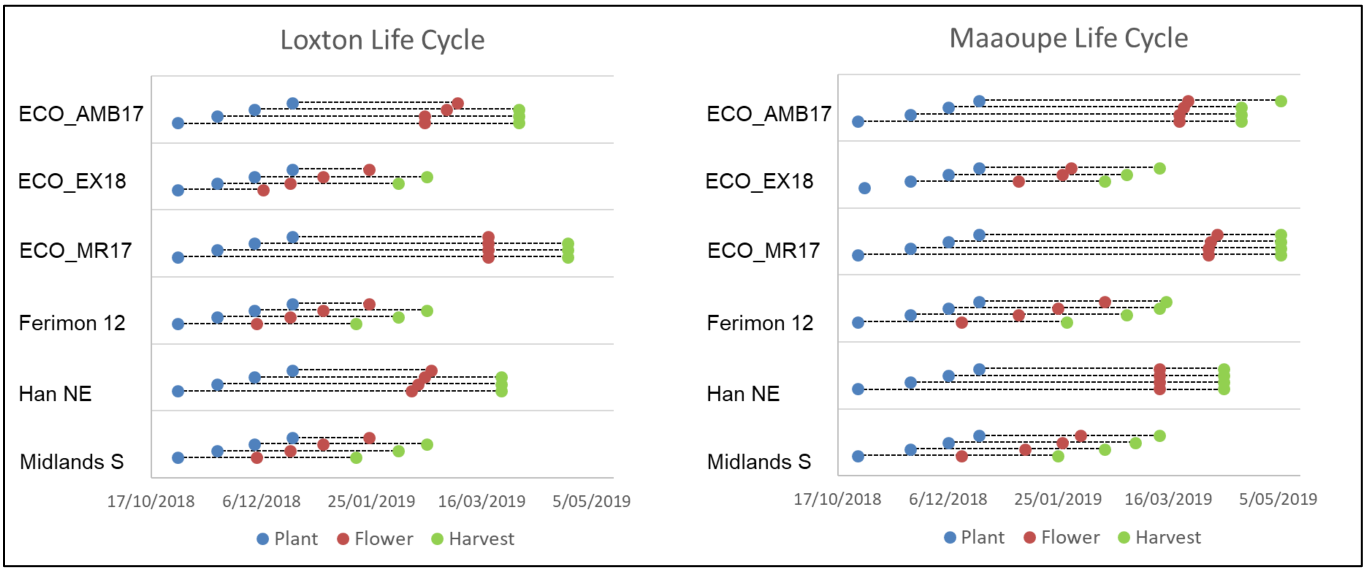


*Figure 24 Timing of key growth stages – 2018/19*

The key difference between these two groups was the trigger for flowering. Under the growing conditions and planting times experienced at the two trial sites, the first group flowered independently of changes in day length, while the second group exhibited day length sensitivity, as flowering did not occur until day length began to decline and night length to increase after the summer solstice. There were also clear differences in timing within the day length sensitive group, with Han NE changing from vegetative to reproductive growth quite rapidly in response to the shortening days and lengthening nights, followed by ECO_AMB17, and ECO_MR17 was the slowest to respond, not being harvested until early May.

One result of the difference in flowering between the two groups of varieties was the final size of the plants (Figure 25). When ECO_EX18, Ferimon 12 and Midlands S flowered, their vertical extension slowed dramatically as the plants put energy into flower rather than vegetative growth. As a result these plants were much shorter than the late flowering varieties ECO_AMB17, ECO_MR17 and Han NE, which continued to grow for much longer. Interestingly Figure 25 shows a levelling out of height from mid-February, indicating that growth rate reduced before flowering occurred.

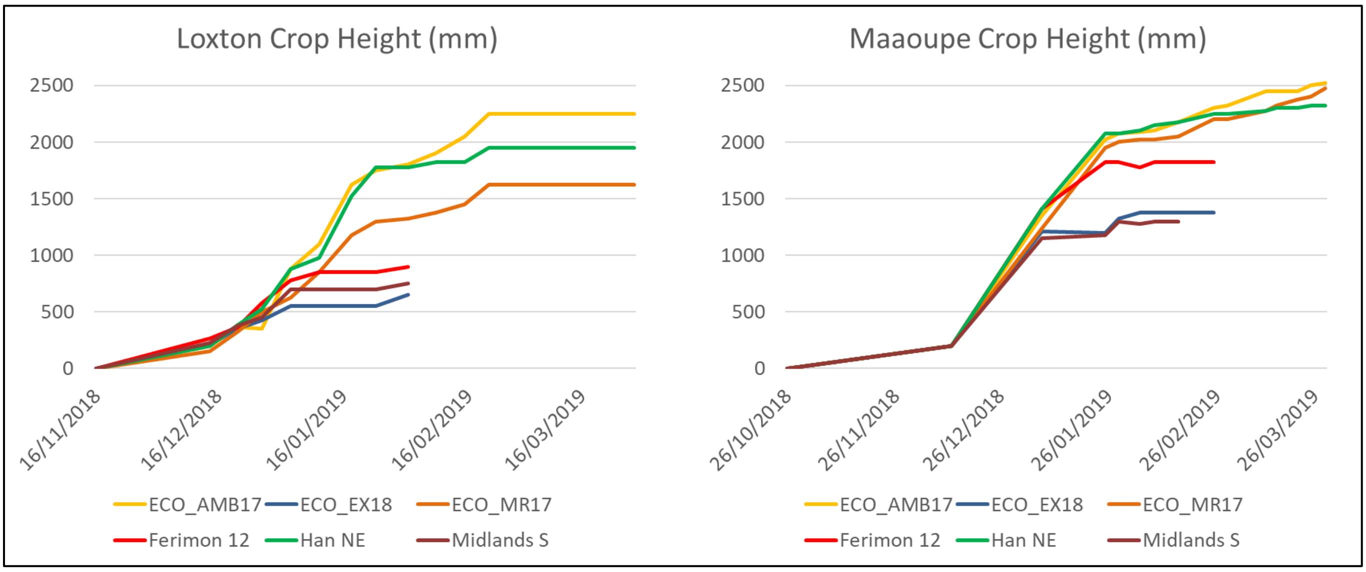


*Figure 25 Average plant height over time in ToS 2 – 2018/19*

Figure 25 presents data from ToS 2 only. This data was selected because of the failure of ECO_EX18 in ToS 1, and the resultant lack of data for that treatment. Table 17 shows the final average heights at harvest of all treatments, and it was clear from this data that plants in ToS 2 at Loxton tended to be shorter than those of the same variety in ToS 1 & 3. This was likely in large part due to the low plant count in ToS 2 (Figure 25). The less crowded plants in ToS 2 tended to develop more side branches and less vertical growth, whereas those in the more crowded plantings of ToS 1 & 3, and all of the Maaoupe plantings, put their resources into vertical extension, increasing their height at a faster rate and reaching a greater final height.

Another trend revealed in Table 17 is that the difference in height between Loxton and Maaoupe was greater in the earlier flowering, shorter varieties than the later flowering, taller varieties. Average height across all ToS treatments at Loxton as a percentage of height at Maaoupe was lower for ECO_EX18 (52.1%), Ferimon 12 (58.9%) and Midlands S (61.2%) than for ECO_AMB17 (93.0%), ECO_MR17 (85.6%) and Han NE (82.4%). This aligns with the life cycle data in Figure 24, which indicates that the shorter varieties flowered even earlier at Loxton than at Maaoupe, reducing the vegetative growth phase and limiting the height of the plants at Loxton relative to Maaoupe.

*Table 17 Average plant height (mm) at harvest, all 2018/19 treatments*

| Plant height at harvest (mm) | | | | | | |
|---|---|---|---|---|---|---|
| **Variety** | **Location** | ToS 1 | ToS 2 | ToS 3 | ToS 4 | **Average** |
| **ECO_AMB17** | **Loxton** | 2850 | 2250 | 2500 | 1400 | **2250** |
| | **Maaoupe** | 2625 | 2525 | 2350 | 2175 | **2419** |
| **ECO_EX18** | **Loxton** | - | 750 | 750 | 700 | **733** |
| | **Maaoupe** | - | 1375 | 1550 | 1300 | **1408** |
| **ECO_MR17** | **Loxton** | 2450 | 1625 | 2525 | 1700 | **2075** |
| | **Maaoupe** | 2600 | 2475 | 2375 | 2275 | **2425** |
| **Ferimon 12** | **Loxton** | 1075 | 900 | 1100 | 900 | **994** |
| | **Maaoupe** | 1675 | 1825 | 1850 | 1388 | **1685** |
| **Han NE** | **Loxton** | 2500 | 1950 | 2000 | 950 | **1850** |
| | **Maaoupe** | 2475 | 2325 | 2175 | 2000 | **2244** |
| **Midlands S** | **Loxton** | 825 | 750 | 850 | 800 | **806** |
| | **Maaoupe** | 1250 | 1300 | 1450 | 1263 | **1316** |

THC testing results are displayed in Table 18. There was a difference between the early flowering varieties (ECO_EX18, Ferimon 12 and Midlands S), which accumulated low levels of THC, and the longer season varieties, which in general accumulated higher levels of THC. The high THC levels in ECO_AMB17 in this trial may be of concern, suggesting that, under certain seasonal conditions in South Australia, this variety may have the potential to exceed the allowable THC concentration of 1.0%.

*Table 18 THC content (% w/w) results – 2018/19*

| THC content (%w/w) | | | | | | |
|---|---|---|---|---|---|---|
| **Variety** | **Location** | ToS 1 | ToS 2 | ToS 3 | ToS 4 | **Average** |
| **ECO_AMB17** | **Loxton** | 1.08 | 1.02 | 0.77 | | **0.96** |
| | **Maaoupe** | 0.92 | 0.66 | 0.83 | 0.64 | **0.76** |
| **ECO_EX18** | **Loxton** | | 0.07 | 0.04 | | **0.06** |
| | **Maaoupe** | 0.07 | 0.07 | 0.05 | 0.05 | **0.06** |
| **ECO_MR17** | **Loxton** | 0.30 | 0.08 | 0.15 | | **0.18** |

| | | | | | | |
|---|---|---|---|---|---|---|
| | **Maaoupe** | 0.26 | 0.43 | 0.13 | 0.18 | **0.25** |
| **Ferimon 12** | **Loxton** | 0.08 | 0.07 | 0.07 | | **0.07** |
| | **Maaoupe** | 0.07 | 0.06 | 0.06 | 0.06 | **0.06** |
| **Han NE** | **Loxton** | 0.24 | 0.35 | 0.36 | | **0.32** |
| | **Maaoupe** | 0.35 | 0.34 | 0.38 | 0.28 | **0.34** |
| **Midlands S** | **Loxton** | 0.15 | 0.17 | 0.08 | | **0.13** |
| | **Maaoupe** | 0.07 | 0.10 | 0.14 | 0.09 | **0.10** |

Total dry matter harvested from a small subplot within each trial plot (converted to t/ha) is shown in Figure 26. There was a trend towards greater dry matter accumulation in earlier plantings of ECO_AMB17, ECO_MR17 and Han NE at Maaoupe, but this trend was less apparent at Loxton, possibly due to the lower planting densities achieved at this site. Significantly lower dry matter accumulation occurred in ECO_EX18 and Midlands S at both sites, and Ferimon 12 at Loxton, most likely due to their earlier flowering and shorter lifecycle at this latitude. Note that no plots of ECO_EX18 in ToS 1 at either site, nor any varieties in ToS 4 at Loxton were harvested, due to the extremely poor crop establishment (Figure 23).

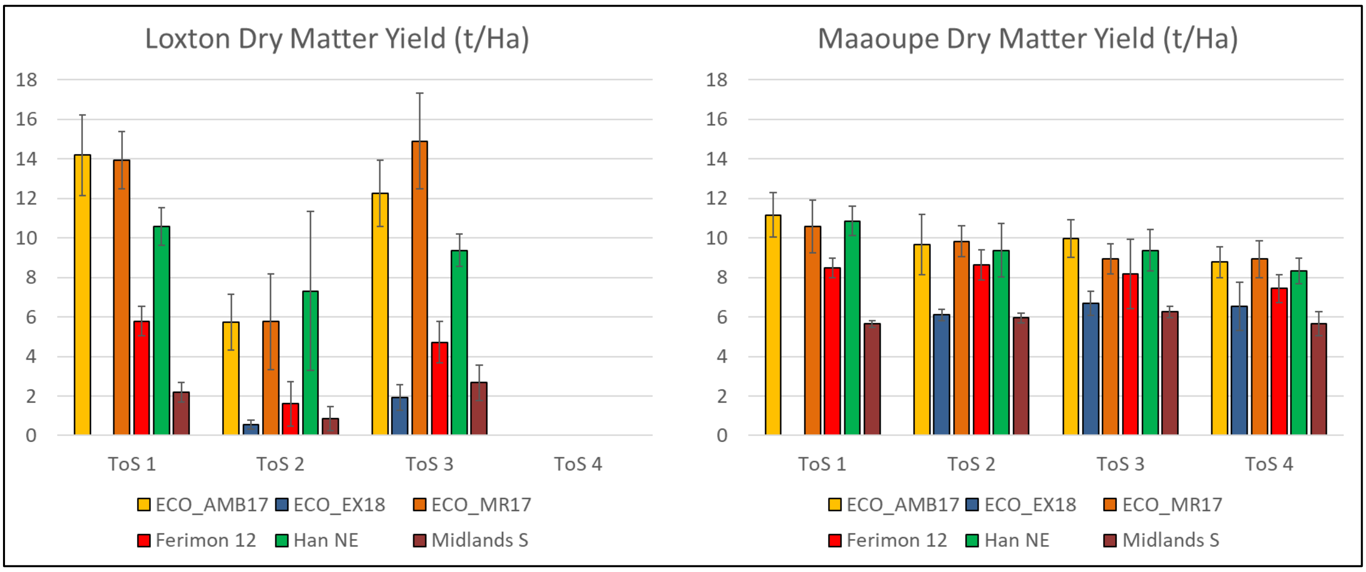


*Figure 26 Average dry matter yield – 2018/19 (error bars are SE across 4 replicates)*

## Grain production – 2018/19

The yield of grain is shown in Figure 27. Yield was variable within ToS treatments, and performance of individual varieties was influenced by both time of sowing and site. Analysis of variance results showed a significant interaction between location and variety.

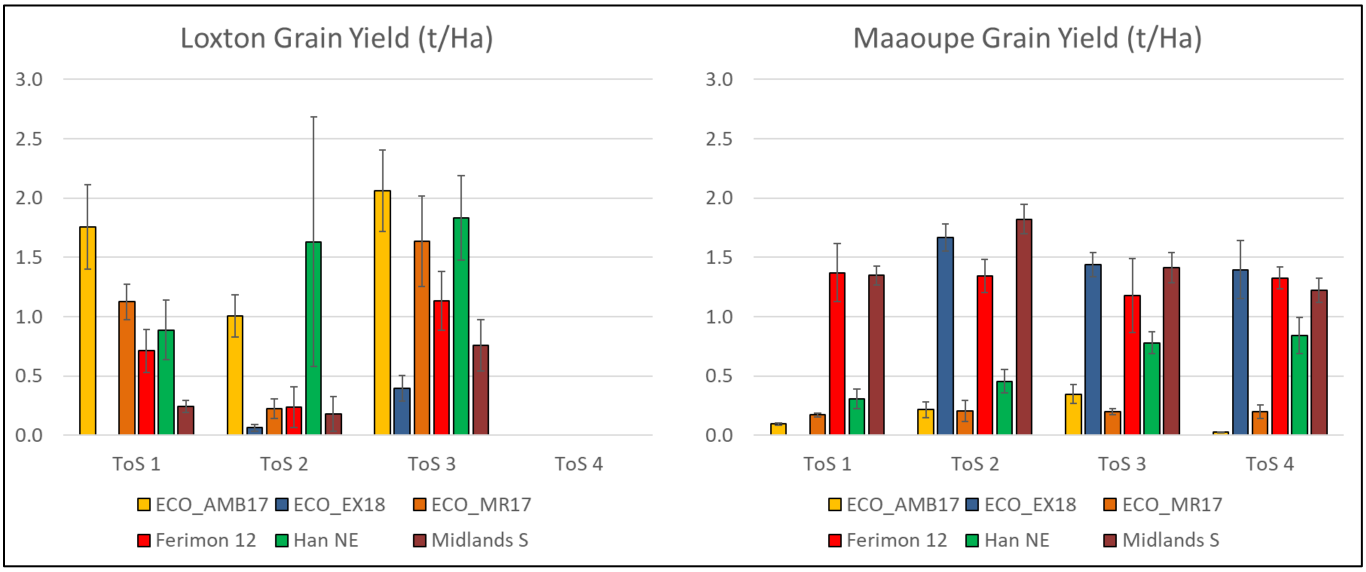


*Figure 27 Average grain yield – 2018/19 (error bars are SE across 4 replicates)*

At the Loxton site ECO_AMB17 out-yielded ECO_EX18, Ferimon 12 and Midlands S, and Han NE out-yielded ECO_EX18 and Midlands S. In addition, ToS 3 out-yielded both earlier times of sowing overall, although differences for specific varieties were not always significant.

At Maaoupe the performance of varieties was essentially reversed, with ECO_EX18, Ferimon 12 and Midlands S out-yielding all other varieties. Han NE also yielded significantly more than ECO_AMB17 and ECO_MR17 at Maaoupe. Time of sowing produced no significant differences in grain yield at Maaoupe.

Figure 28 shows harvest index for each treatment. At Maaoupe the pattern was similar to grain yield (Figure 27), as total dry matter varied much less at this site. At Loxton the short season varieties (ECO_EX18, Ferimon 12 and Midlands S) performed relatively better for harvest index than for grain yield due to the very low dry matter production as a result of a relatively shorter vegetative growth stage prior to flowering.

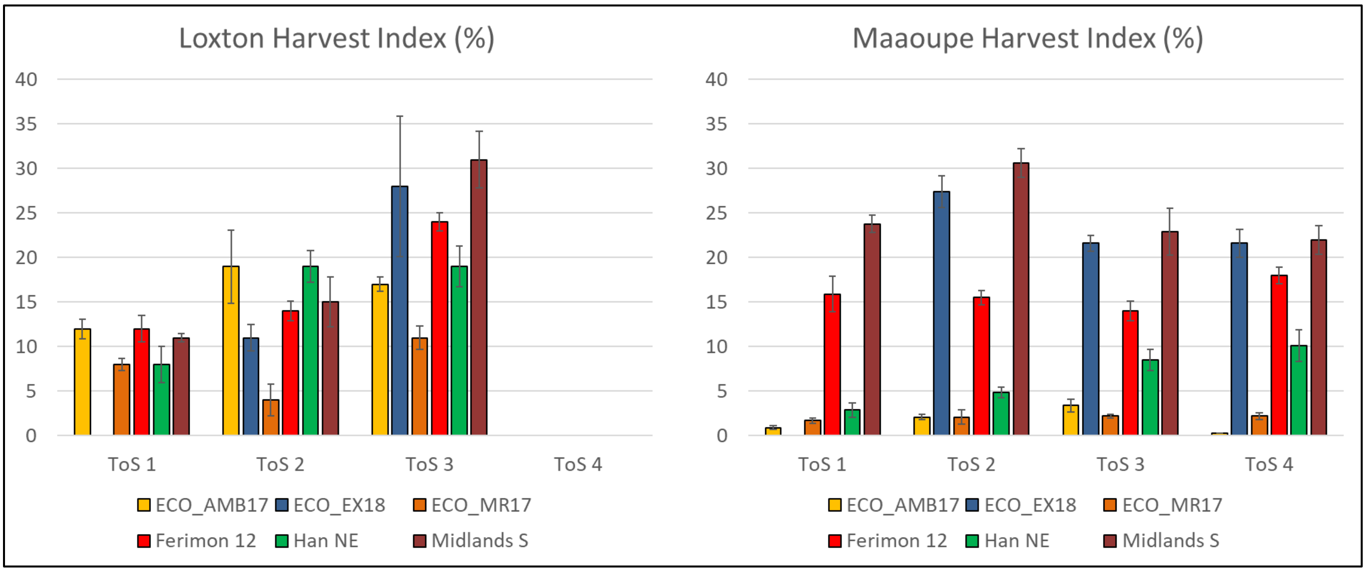


*Figure 28 Average harvest index (grain as a percentage of total dry matter) – 2018/19 (error bars are SE across 4 replicates)*

Water use efficiency, or yield per volume of water applied (kg/ML) is displayed in Figure 29. Overall, water use efficiency was higher at Maaoupe than at Loxton, due to the combination of lower water application (Figure 22) and higher grain yields (Figure 27). However, this relationship did not apply to all varieties.

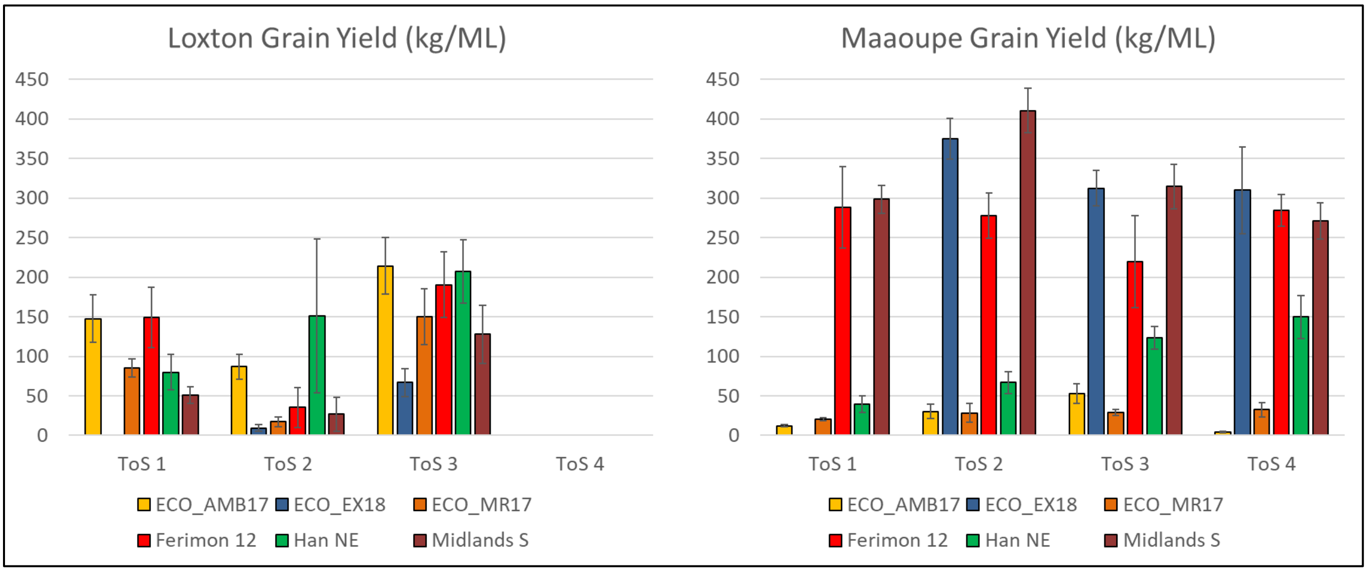


*Figure 29 Average grain yield per volume of water applied – 2018/19 (error bars are SE across 4 replicates)*

At Loxton ECO_AMB17 and Han NE gave greater yield per water volume than ECO_EX18, but there was no clear difference between other varieties. However, at Maaoupe ECO_EX18 and Midlands S exhibited the highest water use efficiency, and ECO_AMB17 and ECO_MR17 were the lowest. Interestingly, ECO_EX18 was at opposite ends of the spectrum at the two sites, suggesting that it is well adapted to the Limestone Coast region, but less so to the Murraylands.

Grain weight, reported as the weight of 1,000 grains, is shown in Figure 30. There were clear differences between the two sites, with the later/taller varieties (ECO_AMB17, ECO_MR17 and Han NE) producing significantly heavier grains across all times of sowing at Loxton, whilst the difference in grain weight between varieties at Maaoupe was much less.

Of particular note was ECO_AMB17, which produced the equal heaviest grains at Loxton when analysed across all ToS treatments, but the statistically lightest weight grains across all ToS treatments at Maaoupe. Consideration of yield data as well (Figure 27) indicates that ECO_AMB17 produced high yields of heavy grains at Loxton, and low yields of lightweight grains at Maaoupe, suggesting that ECO_AMB17 is well suited to grain production under Murraylands conditions but less suited for grain production in the Limestone Coast.

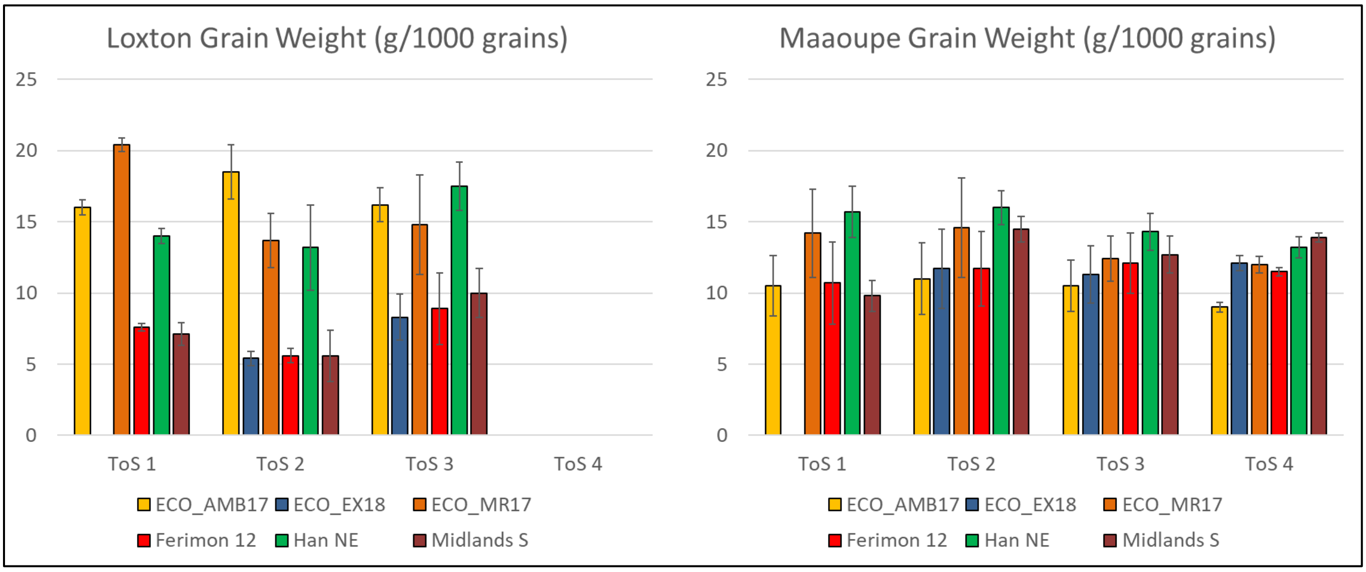

*Figure 30 Average weight of 1000 grains – 2018/19 (error bars are SE across 4 replicates)*

Heart to hull ratio for grain from ToS 3 is displayed in Figure 31, along with a 1:1 line for comparison. Heart to hull ratio greater than 1.0 is preferable for processing of whole hemp seeds for food applications, and for maximising yield of hemp hearts. The pattern of performance was similar between the two sites, with ECO_AMB17 producing the highest (Maaoupe) or equal highest (Loxton) ratio, and ECO_MR17 being in the lowest group at both sites.

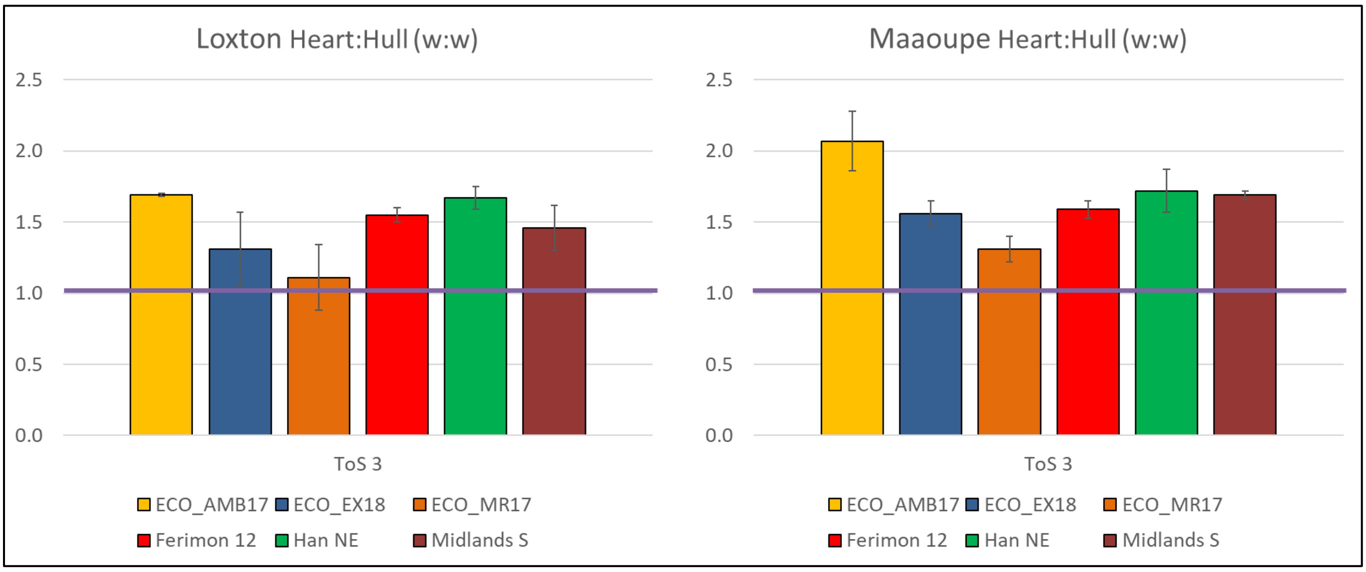


*Figure 31 Ratio of heart to hull for ToS 3 – 2018/19 (error bars are SE across 3 replicates), including 1:1 line for comparison*

Interestingly, the values obtained in 2018/19 (overall average of 1.46 at Loxton and 1.66 at Maaoupe) were higher than those obtained in 2017/18 (1.09 at Loxton and 1.07 at Kybybolite). This may reflect the selection of large, dark seed for this analysis (see Materials and Methods – 2018/19). There was, however, an interesting difference between Ferimon 12 and Han NE, which were grown in both seasons. The average heart:hull values obtained for ToS 3 at Loxton were similar between the two seasons for Han NE (1.64 in 2017/18 and 1.67 in 2018/19), whereas there was a large difference between values for Ferimon 12 (0.68 and1.55). This could reflect more uniform heart:hull across grain from Han NE than that from Ferimon 12 under Loxton conditions, reducing the impact of selecting for the "best" grain.

It is also worth noting that the order of ranking for heart:hull in the results above was quite different to results obtained in early pre-screening work carried out by the University of Adelaide (Schultz et al., 2020). In this earlier work the ranking order of five of the varieties above was Ferimon 12, ECO_AMB17, Midlands S, ECO_MR17, Han NE (from highest to lowest, ECO_EX18 was not tested). The samples for this earlier work were sourced from all across Australia, and the differences in ranking are indicative of the impact of growing conditions on the expression of the genetic basis for this characteristic.

# Results and discussion – 2019/20

## General crop performance – 2019/20

The depth of water applied to the trial plots is shown in Figure 32. The values represent all water applied, both irrigation and rainfall. As with previous seasons, the values vary between treatments and sites due to different season lengths (planting to harvest) between varieties, and different climatic conditions, soils and management between sites. On average in 2019/20 the treatments at Loxton received approximately 70% more water than the equivalent treatments at Maaoupe.

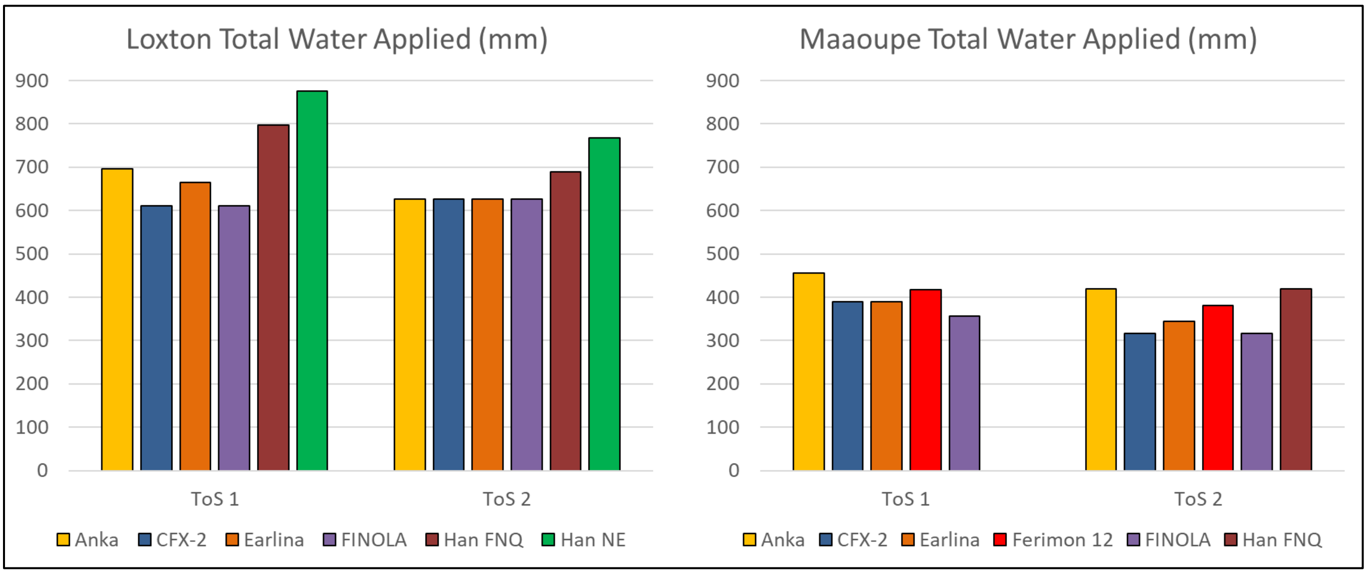


*Figure 32 Depth of water applied from sowing to harvest – 2019/20 (irrigation and rainfall)*

The contribution of rainfall ranged from 6 to 8% of the total water applied at Loxton, and 14 to 18% at Maaoupe. The rainfall contribution was fairly even across varieties and sowing times at each site, indicating a more even spread of rainfall events in 2019/20 compared to 2018/19.

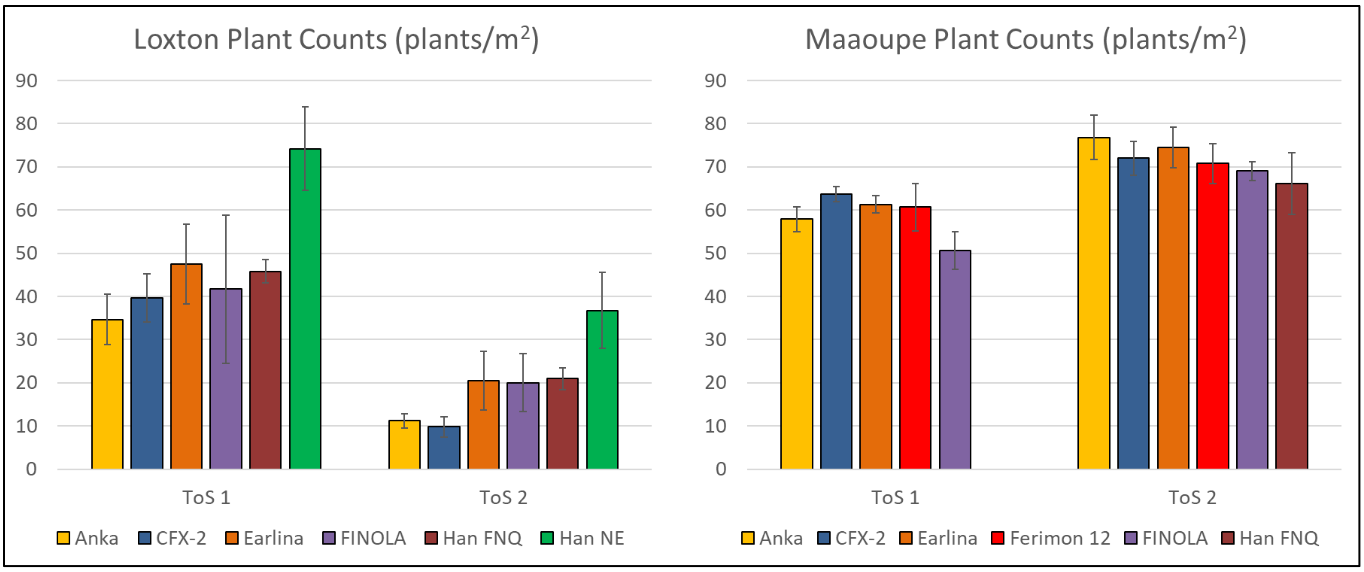


*Figure 33 Average plant count at establishment – 2019/20 (error bars are standard error (SE) across 4 replicates)*

Figure 33 displays plant counts carried out between two and six weeks after sowing, to assess the density of plants established in each trial plot. The target plant density was 100 plants/m$^2$ in 2019/20, and seed sowing rate was calculated according to the germination percentage provided for each batch of seed. An additional allowance was made for expected seedling survival of 65% at Loxton, and 85% at Maaoupe, based on previous experience with good establishment at Maaoupe and poor establishment at Loxton.

Even with the extra seed sown at Loxton, establishment was still poorer than at Maaoupe in every treatment, with the single exception of Han NE in ToS 1. This mirrors the results from 2018/19, and reflects the sandy soil found at Loxton, in which sand drift has been an issue at establishment right across the three years of trials. The heavier soil at Maaoupe, on the other hand, seems to provide much more ideal conditions for seedling emergence and establishment.

The life cycle information in Figure 34 displays planting, flowering and harvest dates, and allows assessment of season length for the various treatments. Han FNQ behaved similarly to Han NE at Loxton, in that harvest was the between the two times of sowing, whereas most other varieties showed earlier harvest in earlier sowing dates, as seen in previous seasons.

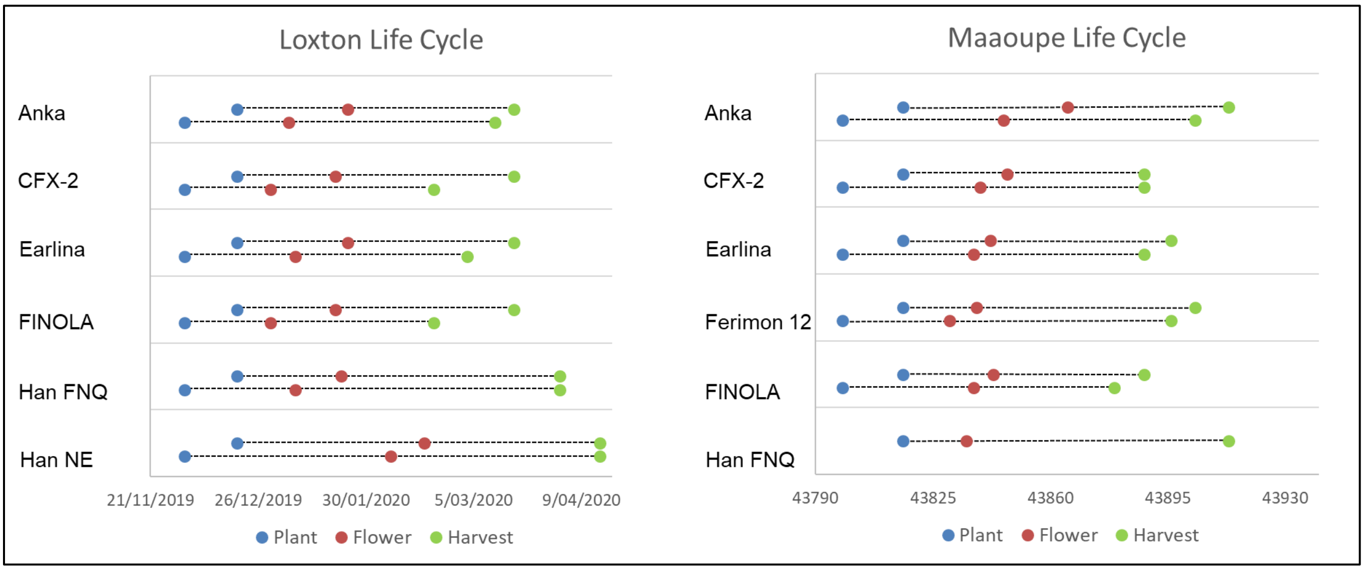


*Figure 34 Timing of key growth stages – 2019/20*

In previous seasons, flowering time was related plant height, with earlier flowering varieties being shorter due to the earlier cessation of vegetative growth. Figure 35 displays height data for 2019/20, with data for ToS 2 presented due to Han FNQ seed arriving too late for this variety to be included in ToS 1 at Maaoupe.

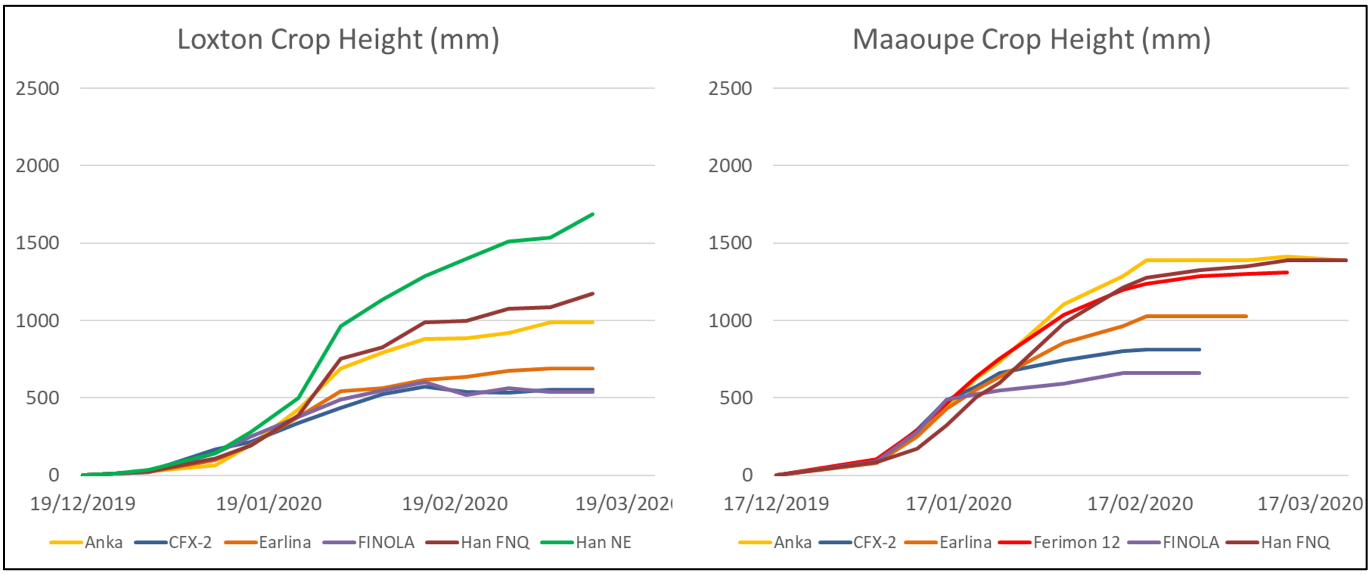


*Figure 35 Average plant height over time in ToS 2 – 2019/20*

Table 19 shows the final average heights at harvest of all treatments, and confirms a trend evident in Figure 35, that plant height at Maaoupe was greater than at Loxton for almost all variety by ToS combinations. Further, ToS 2 at Loxton generally produced shorter plants than ToS1, but at Maaoupe the ToS 2 plants grew taller than ToS 1.

Reference to previous season's data indicates a degree of variability in plant height between seasons, varieties and times of sowing. The heights recorded in 2019/20 (Table 19) are all suitable for machine harvesting. Plants that are too tall require specially modified machinery or the processing of too much vegetative material, and plants that are too short are hard to harvest without damaging machinery through ground strikes, and may also suffer from weed seed contamination if they do not grow well beyond the height of local weed species.

*Table 19 Average plant height (mm) at harvest, all 2019/20 treatments*

| **Plant height at harvest (mm)** | | | | |
|---|---|---|---|---|
| **Variety** | **Location** | ToS 1 | ToS 2 | **Average** |
| **Anka** | **Loxton** | 1113 | 988 | **1051** |
| | **Maaoupe** | 1175 | 1388 | **1282** |
| **CFX-2** | **Loxton** | 825 | 555 | **690** |
| | **Maaoupe** | 688 | 813 | **751** |
| **Earlina** | **Loxton** | 810 | 688 | **749** |
| | **Maaoupe** | 825 | 1025 | **925** |
| **FINOLA** | **Loxton** | 583 | 540 | **562** |
| | **Maaoupe** | 600 | 663 | **632** |
| **Han FNQ** | **Loxton** | 1263 | 1088 | **1176** |
| | **Maaoupe** | - | 1388 | **1388** |
| **Han NE** | **Loxton** | 1588 | 1725 | **1657** |
| **Ferimon 12** | **Maaoupe** | 1063 | 1313 | **1188** |

THC testing results are displayed in Table 20. Although most of the varieties produced very low readings, the two Chinese varieties (Han NE and Han FNQ) returned readings close to and well above the mandatory 1.0% required under the South Australian licencing system.

Reference to previous seasons indicates that Han NE has previously returned readings between 0.24 and 0.47%, with a single previous reading of 0.80% in the first season. Given that values from plants of the same variety can fluctuate from site to site and year to year, it is clear that some margin for error is needed for those occasions when conditions induce a significant increase in THC content. It appears that these two Han varieties do not have sufficient margin for error to preclude that potential of excessive THC readings.

As a result of the high THC readings from these two varieties, they cannot be recommended as suitable varieties for industrial hemp production in South Australia, despite their otherwise generally good performance (see previous seasons and below). The risk that the crop may need to be destroyed due to exceeding the THC limit in some seasons will likely make them unacceptable to growers.

*Table 20 THC content (% w/w) results – 2019/20*

| THC content (%w/w) | | | | |
|---|---|---|---|---|
| **Variety** | **Location** | ToS 1 | ToS 2 | **Average** |
| **Anka** | **Loxton** | 0.31 | 0.04 | **0.18** |
| | **Maaoupe** | 0.11 | 0.09 | **0.10** |
| **CFX-2** | **Loxton** | 0.03 | 0.10 | **0.08** |
| | **Maaoupe** | 0.20 | 0.19 | **0.20** |
| **Earlina** | **Loxton** | 0.05 | 0.03 | **0.04** |
| | **Maaoupe** | 0.04 | 0.03 | **0.04** |
| **FINOLA** | **Loxton** | 0.44 | 0.03 | **0.24** |
| | **Maaoupe** | 0.04 | - | **0.04** |
| **Han FNQ** | **Loxton** | 2.60 | 0.60 | **1.60** |
| | **Maaoupe** | - | 0.97 | **0.97** |
| **Han NE** | **Loxton** | 0.68 | 1.50 | **1.09** |
| **Ferimon 12** | **Maaoupe** | 0.06 | 0.04 | **0.05** |

The total dry matter harvested from a small subplot within each trial plot (converted to t/ha) is shown in Figure 36. In contrast to the trend in 2018/19, there was greater dry matter accumulation in later plantings in 2019/20. The Han varieties accumulated high levels of dry matter, as was the case for Han NE in previous seasons. Results for some other varieties (Earlina and FINOLA) were variable, and results were more variable at Loxton than Maaoupe. Apart from the Han varieties, all other varieties are promoted for grain production rather than dual purpose, apart from Anka. However, under conditions at the two trial sites during this season, Anka did not produce consistently higher total dry matter yields than other varieties, with the possible exception of CFX-2.

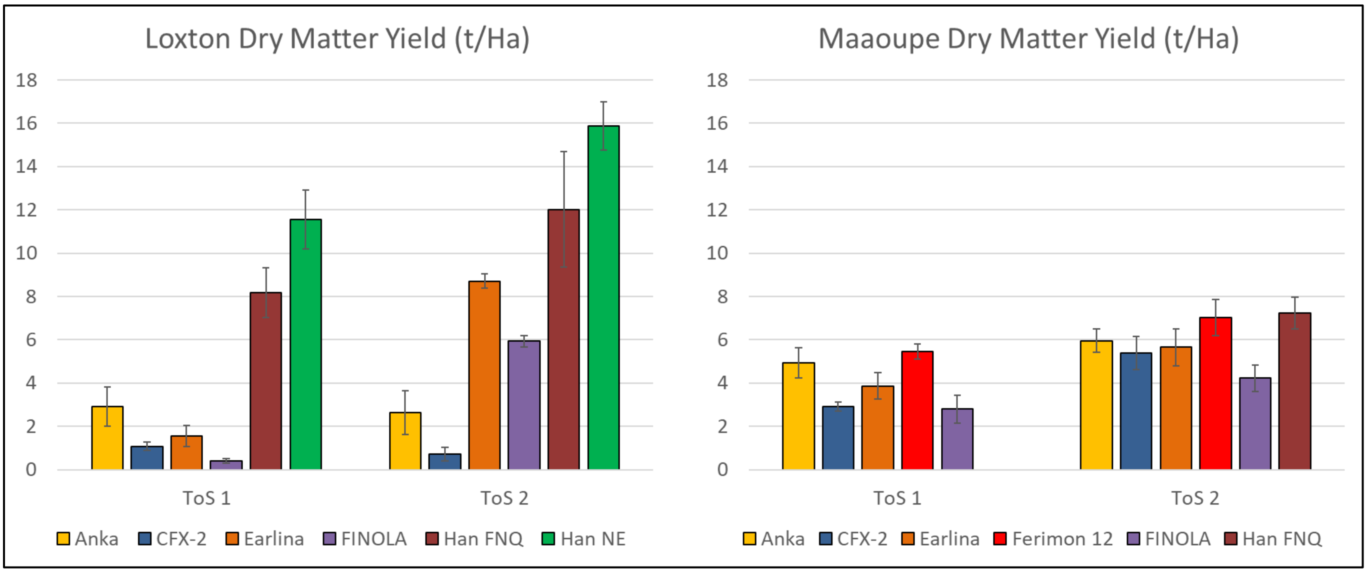


*Figure 36 Average dry matter yield – 2019/20 (error bars are SE across 4 replicates)*

## Grain production – 2019/20

The yield of grain from subplots is shown in Figure 37. Apart from the two Han varieties at Loxton, yields were very disappointing in 2019/20, especially when compared with some of the results achieved in previous seasons (Figure 6, Figure 27).

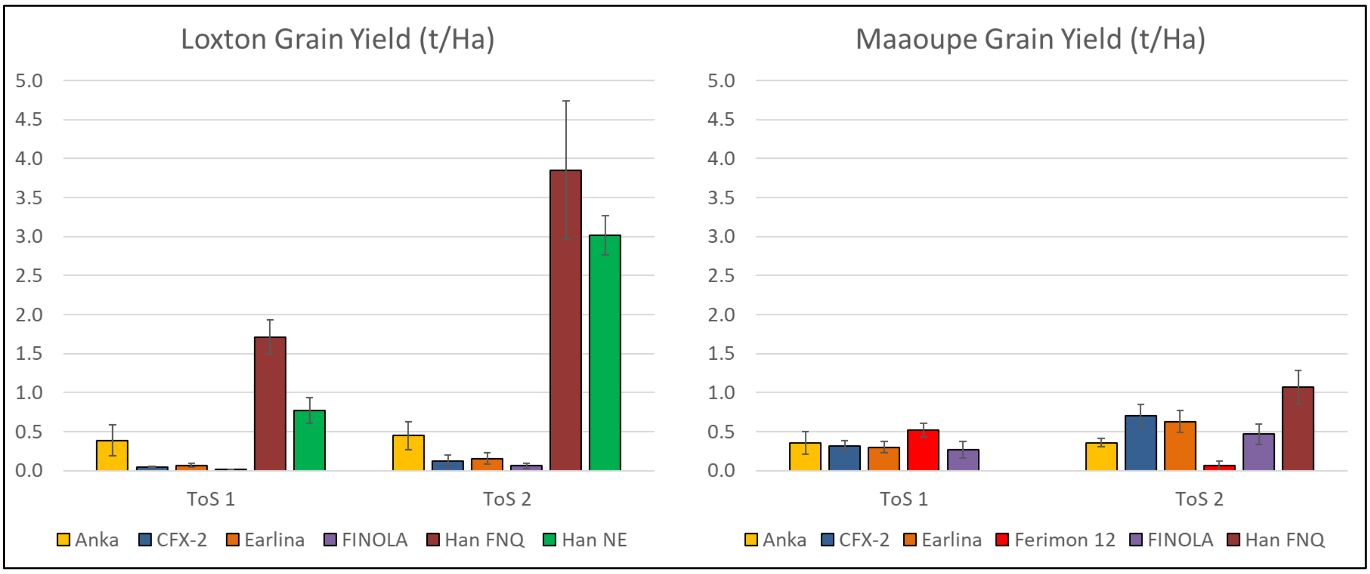


*Figure 37 Average grain yield – 2019/20 (error bars are SE across 4 replicates)*

Parrots were observed feeding on the grains in the flower heads of Han NE at Loxton when it was ready for harvest, and there was clear evidence that significant amounts of grain had been removed by the birds. Thus, the actual yield from this variety is likely to have been higher in both ToS treatments. The parrots found the crop late in the season, and no bird damage was observed prior to or during the harvest of the other varieties, which were all harvested earlier than Han NE.

Figure 38 shows harvest index for each treatment. At Maaoupe the pattern was similar to grain yield (Figure 37), as total dry matter varied much less at this site. At Loxton the Han varieties tended to still perform well, despite having higher dry matter production, because their grain yields were so much higher than most of the other varieties.

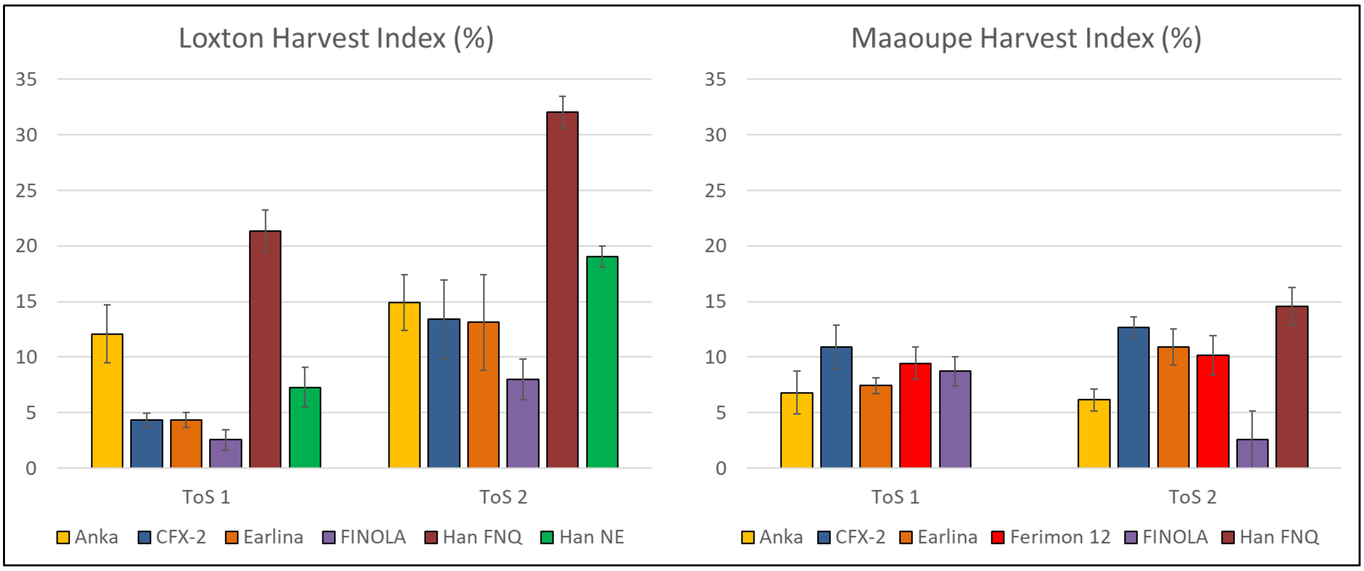


*Figure 38 Average harvest index (grain as a percentage of total dry matter) – 2019/20 (error bars are SE across 4 replicates)*

Water use efficiency, or yield per volume of water applied (kg/ML) is displayed in Figure 39. For most varieties water use efficiency was higher at Maaoupe than at Loxton, due to the lower water application (Figure 32). At Loxton the Han varieties outperformed the other varieties due to their higher yield, despite the fact that they used more water due to their longer growing season. This also explains the variation in Han FNQ across two sites and ToS.

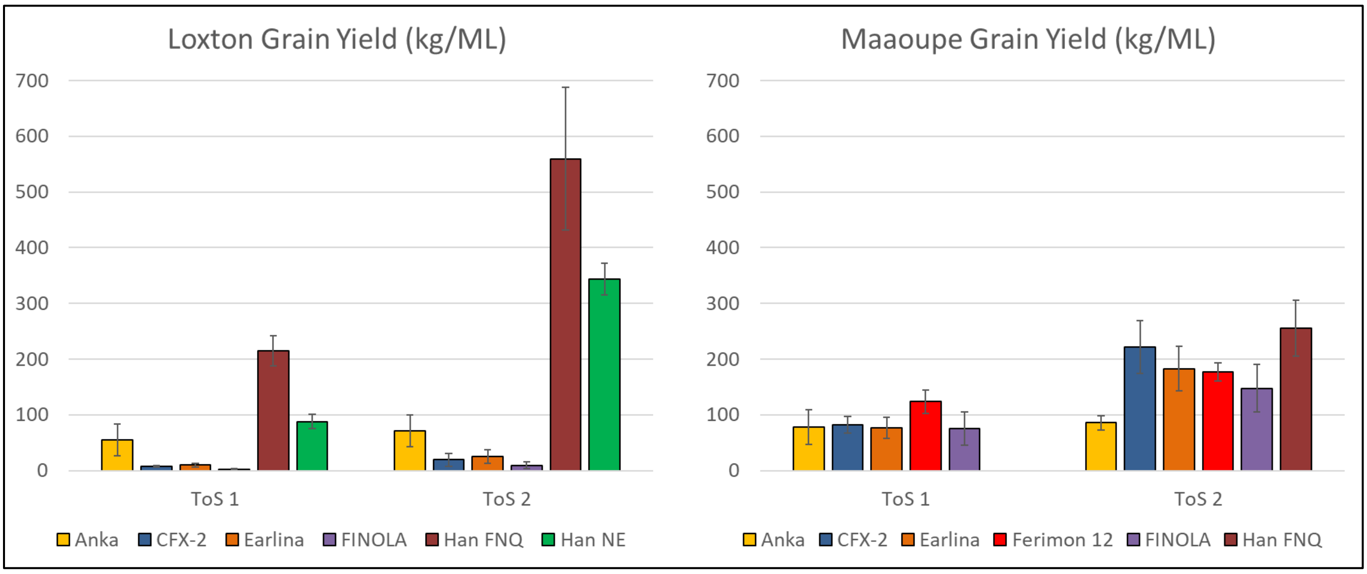


*Figure 39 Average grain yield per volume of water applied – 2019/20 (error bars are SE across 4 replicates)*

Figure 40 presents average grain weight, expressed as the weight of 100 grains. Results are consistent across the two sites and across ToS treatments. Han NE produced the largest grains and Earlina and FINOLA produced the smallest grains. At Loxton Han FNQ produced significantly larger grains than all varieties apart from Han NE, whilst at Maaoupe the grain size was not significantly larger than that produced by Anka and Ferimon 12.

Bulk density (Figure 41) is a measure of the weight of seed in a given volume, expressed as kilograms per hectolitre (kg/hL). Low bulk density of grain is usually associated with poor quality. In hemp low bulk density may indicate the presence of shrivelled hearts within a fully developed shell.

At Loxton Han NE and Han FNQ produced the highest grain bulk density, followed by Anka, with all other varieties having significantly lower bulk density. At Maaoupe Han FNQ, Anka and Ferimon 12 produced significantly higher bulk density than the other three varieties. Thus, CFX-2, Earlina and FINOLA had consistently low bulk density across trial locations and ToS treatments.

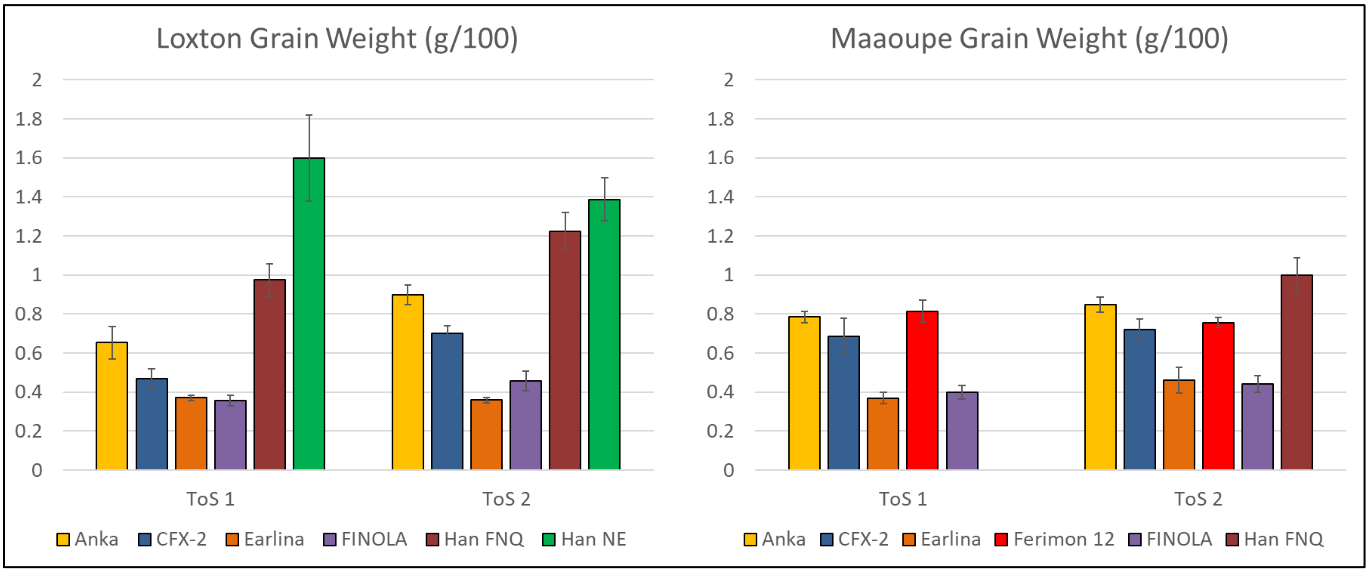


*Figure 40 Average weight of 100 grains – 2019/20 (error bars are SE across 4 replicates)*

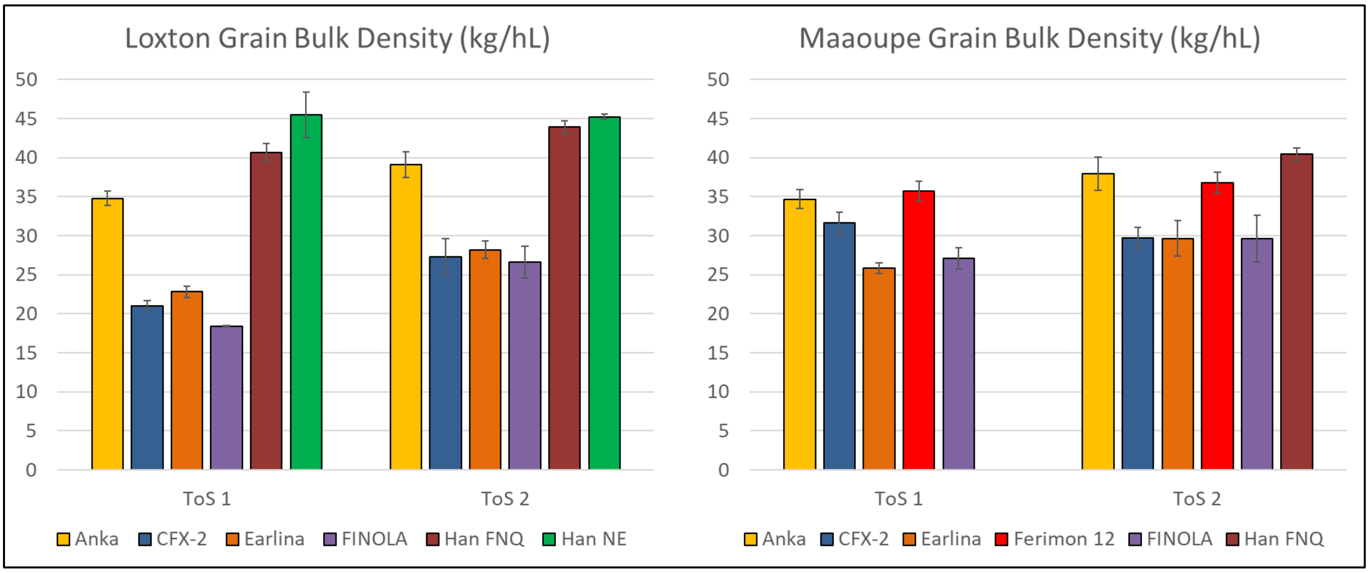


*Figure 41 Average bulk density of grain sample – 2019/20 (error bars are SE across 4 replicates)*

# Results and discussion – 2020/21

## General crop performance – 2020/21

There is no data for Canda, Felina 32 and Ferimon 12 for ToS 2 in the figures below. Poor establishment, extreme weather and an infestation of Rutherglen bugs led to the destruction of all plots of these varieties in ToS 2. There were sufficient plots remaining of the other three varieties to complete harvest and to analyse the data collected.

The depth of water applied to the trial plots is shown in Figure 42. The values represent all water applied, both irrigation and rainfall. As with previous seasons, the values vary between ToS treatments due to different season lengths (planting to harvest), and between varieties. Time of sowing 1 resulted in more water being applied over the life of the crop than in the later ToS.

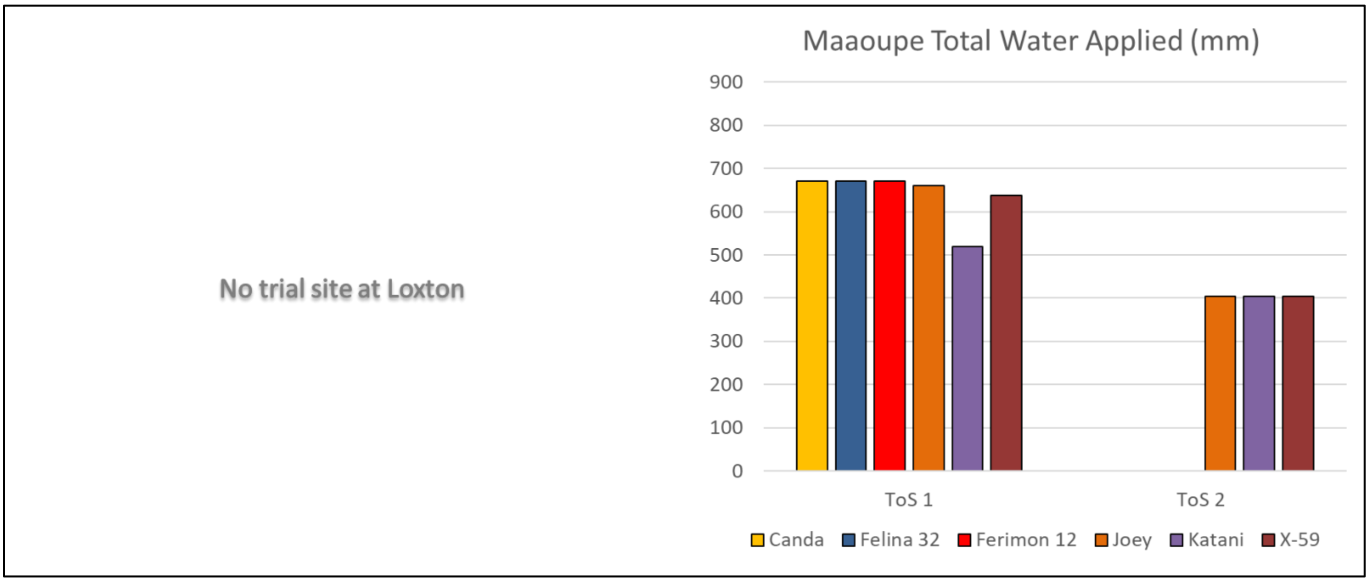


*Figure 42 Depth of water applied from sowing to harvest – 2020/21 (irrigation and rainfall)*

The contribution of rainfall ranged from 14 to 21% of total water applied, similar to the result for 2019/20.

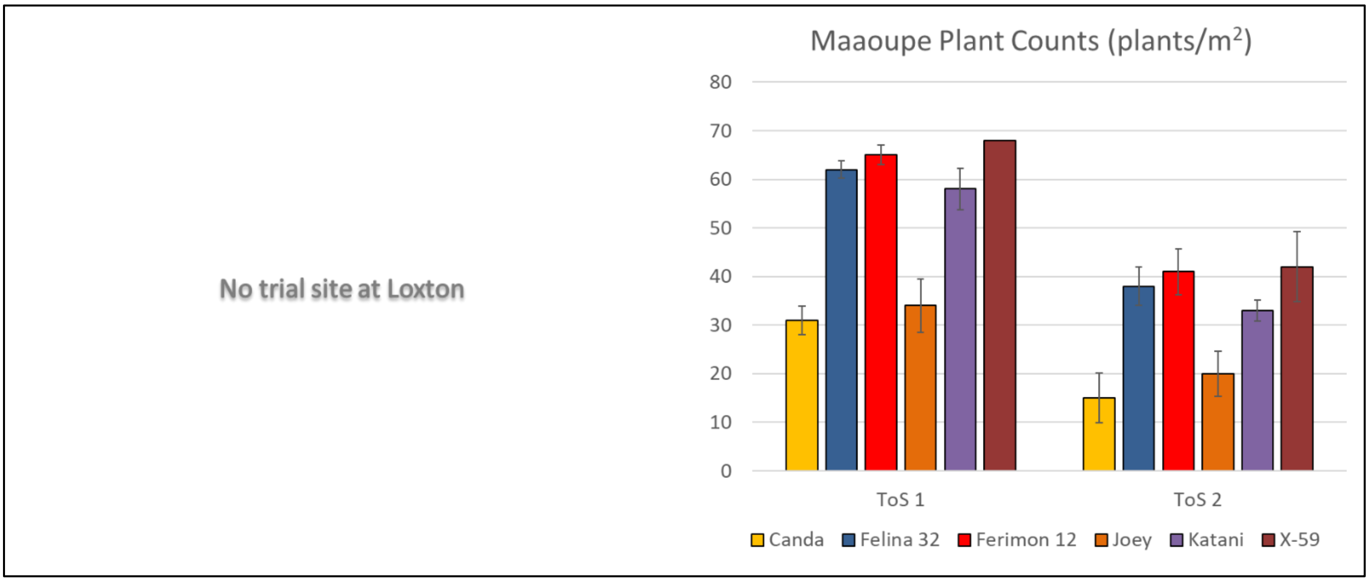


*Figure 43 Average plant count at establishment – 2020/21 (error bars are standard error (SE) across 4 replicates)*

Figure 43 displays plant counts carried out between two and six weeks after sowing, to assess the density of plants established in each trial plot. The target plant density was 100 plants/m$^2$, and seed sowing rate was calculated according to the germination percentage provided for each batch of seed. An additional allowance was made for expected seedling survival of 85% at Maaoupe, based on previous experience.

Establishment was higher in ToS 1, averaging above 50 plants/m$^2$, whilst none of the varieties achieved 50 plants/m$^2$ in the second ToS. Canda and Joey achieved lower plant count than the other varieties across both times of sowing.

The life cycle information in Figure 44 displays planting, flowering and harvest dates, and allows assessment of season length for the various treatments. Katani was the first variety harvested, followed by Joey, despite flowering occurring at a similar time in TOS 1. However, whilst flowering of Joey in ToS 2 was earlier than the other varieties, harvest was delayed. The reason for this is not clear.

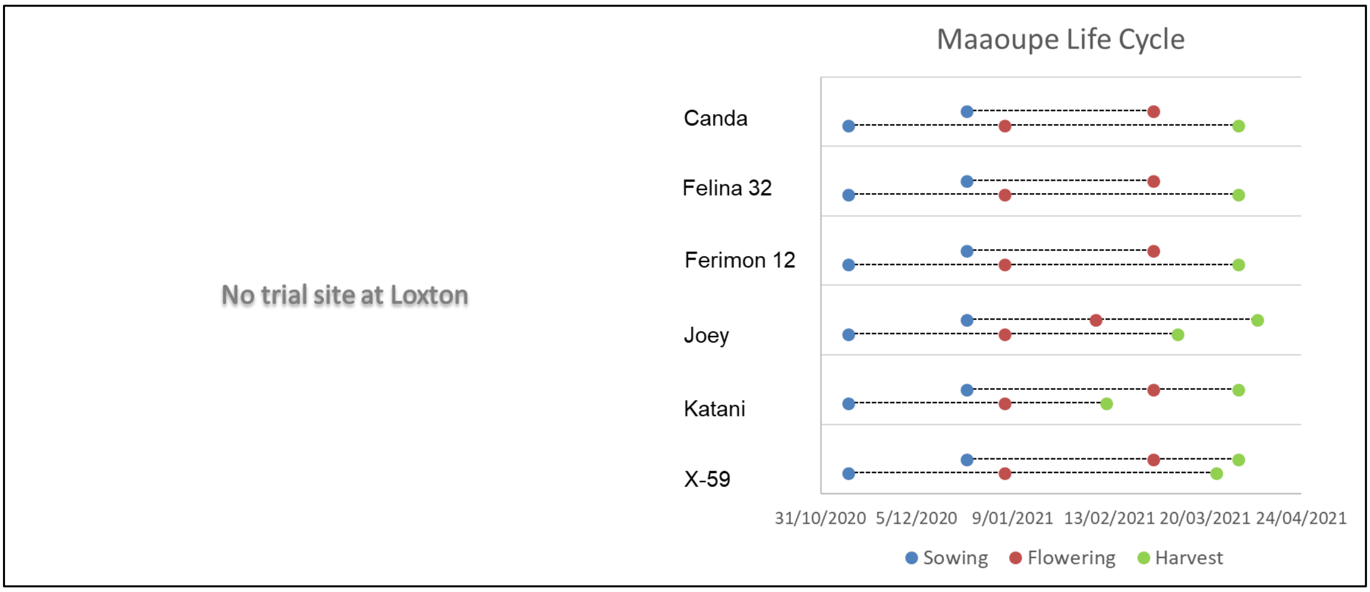


*Figure 44 Timing of key growth stages – 2020/21*

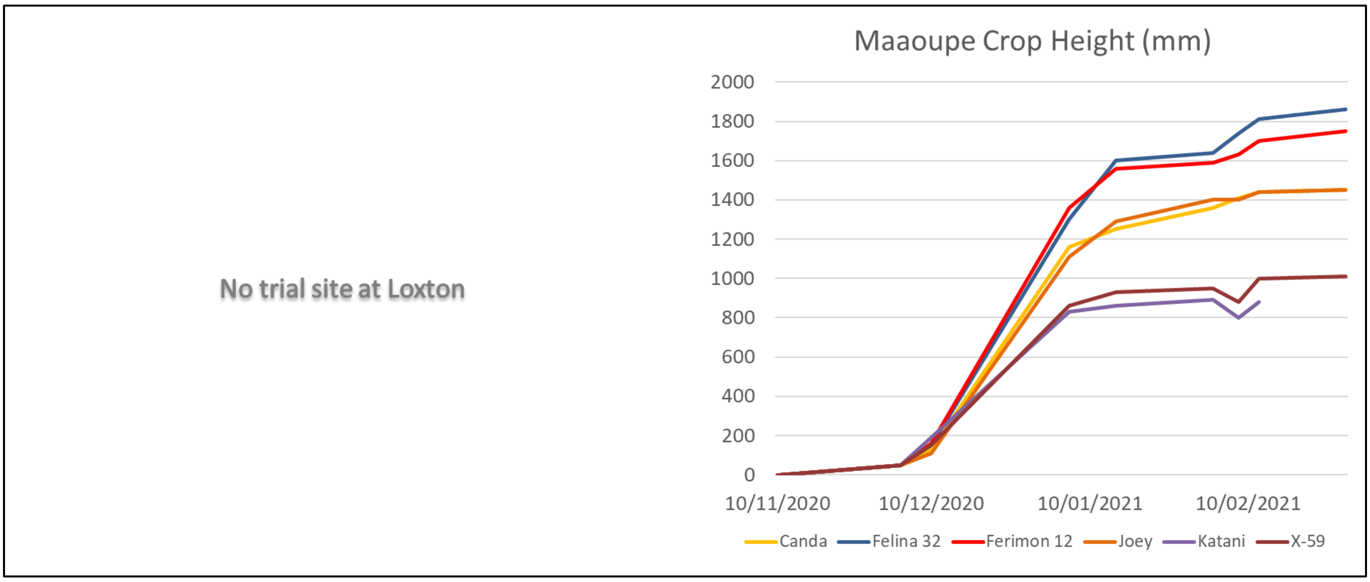


*Figure 45 Average plant height over time in ToS 1 – 2020/21*

In previous seasons, flowering time was related to plant height, with earlier flowering varieties being shorter due to the earlier cessation of vegetative growth. Height data for ToS 1 in 2020/21 (Figure 45) indicates that there are differences between varieties, however as flowering occurred at the same time for all varieties in ToS 1, there is no correlation between flowering timing and plant height. The impact of flowering on growth is clear, however, from the shape of the growth curve.

Table 21 displays the final average heights at harvest of all treatments (even where there was insufficient crop to harvest in ToS 2, the few remaining plants were measured). The results are consistent, with plants from ToS 1 being taller than those from ToS 2, and Felina 32 & Ferimon 12 being the tallest in both ToS treatments, and Katani and X-59 being the shortest.

*Table 21 Average plant height (mm) at harvest, all 2020/21 treatments*

| **Plant height at harvest (mm)** | | | | |
|---|---|---|---|---|
| **Variety** | **Location** | ToS 1 | ToS 2 | **Average** |
| **Canda** | **Maaoupe** | 1450 | 1000 | **1225** |
| **Felina 32** | **Maaoupe** | 1860 | 1290 | **1575** |
| **Ferimon 12** | **Maaoupe** | 1750 | 1200 | **1475** |
| **Joey** | **Maaoupe** | 1450 | 1020 | **1235** |
| **Katani** | **Maaoupe** | 880 | 830 | **855** |
| **X-59** | **Maaoupe** | 1010 | 950 | **980** |

THC testing results are displayed in Table 22. All of the varieties trialled in 2020/21 returned THC levels well below the statutory limit of 1.0%, making them very suitable for growing under the South Australian Industrial Hemp licencing system.

*Table 22 THC content (% w/w) results – 2020/21*

| **THC content (%w/w)** | | | | |
|---|---|---|---|---|
| **Variety** | **Location** | ToS 1 | ToS 2 | **Average** |
| **Canda** | **Maaoupe** | 0.20 | 0.03 | **0.12** |
| **Felina 32** | **Maaoupe** | 0.08 | 0.08 | **0.08** |
| **Ferimon 12** | **Maaoupe** | 0.06 | 0.06 | **0.06** |
| **Joey** | **Maaoupe** | 0.05 | 0.05 | **0.05** |
| **Katani** | **Maaoupe** | 0.08 | 0.12 | **0.10** |
| **X-59** | **Maaoupe** | 0.03 | 0.04 | **0.04** |

The total dry matter harvested from a small subplot within each trial plot (converted to t/ha) is shown in Figure 46. Similar to most previous seasons, there was greater dry matter accumulation in the earlier plantings, although the differences were small, and X-59 showed an opposite, but not significant, trend.

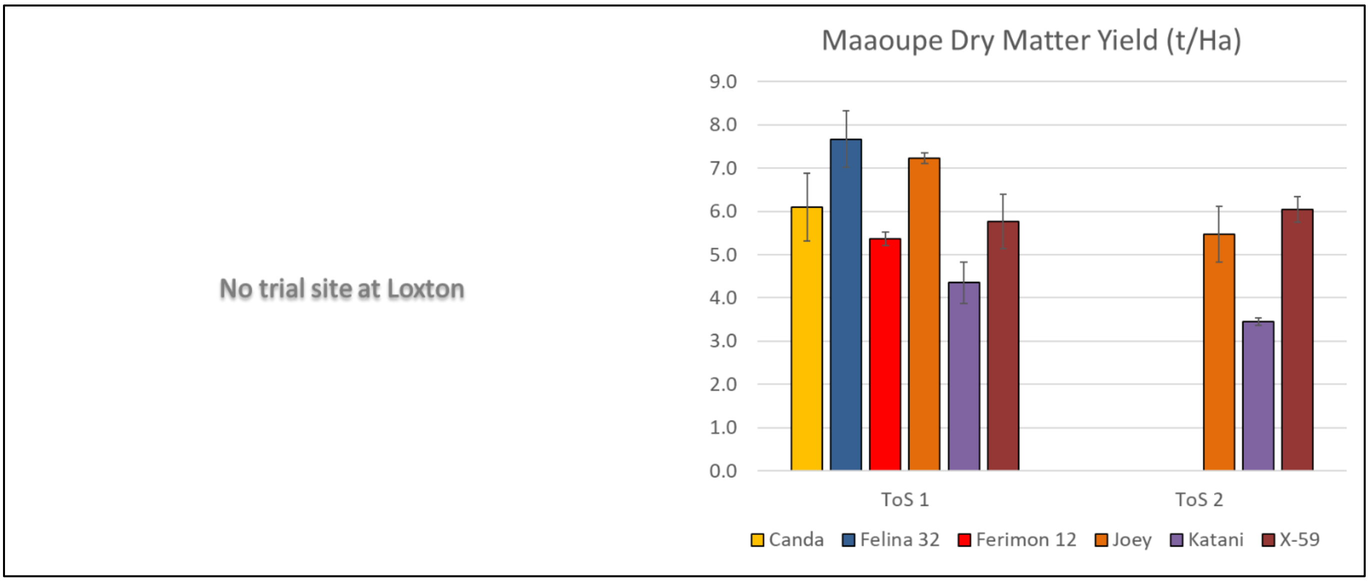


*Figure 46 Average dry matter yield – 2020/21 (error bars are SE across 4 replicates)*

## Grain production – 2020/21

The yield of grain from subplots is shown in Figure 47. Yields from Felina 32 and Ferimon 12 were disappointing, but the yields from Canda (ToS 1 only), Joey and X-59 were promising, although the variability between replicates was high.

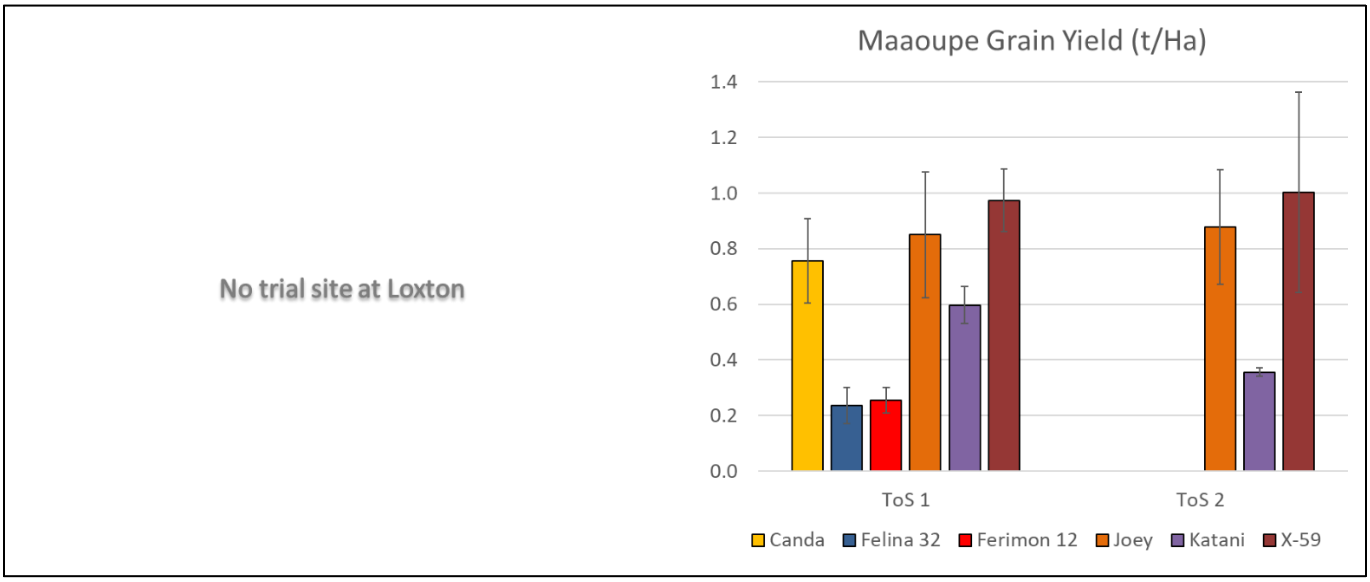


*Figure 47 Average grain yield – 2020/21 (error bars are SE across 4 replicates)*

Figure 48 shows harvest index for each treatment. The low yield of Ferimon 12 and Felina 32 above is reflected in this figure, indicating that the cause of the low yields is poor harvest index, not poor establishment and growth of the crop.

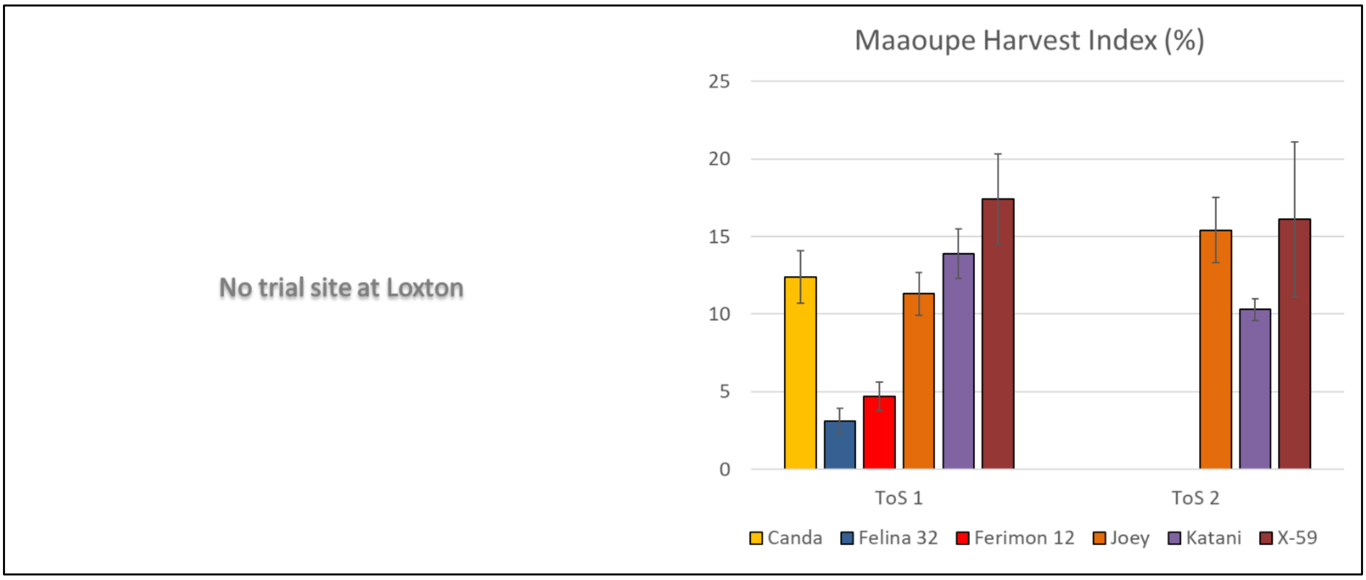


*Figure 48 Average harvest index (grain as a percentage of total dry matter) – 2020/21 (error bars are SE across 4 replicates)*

Water use efficiency, or yield per volume of water applied (kg/ML), is displayed in Figure 49. For Joey and X-59 water use efficiency was higher in ToS 2, due to the lower water application (Figure 42).

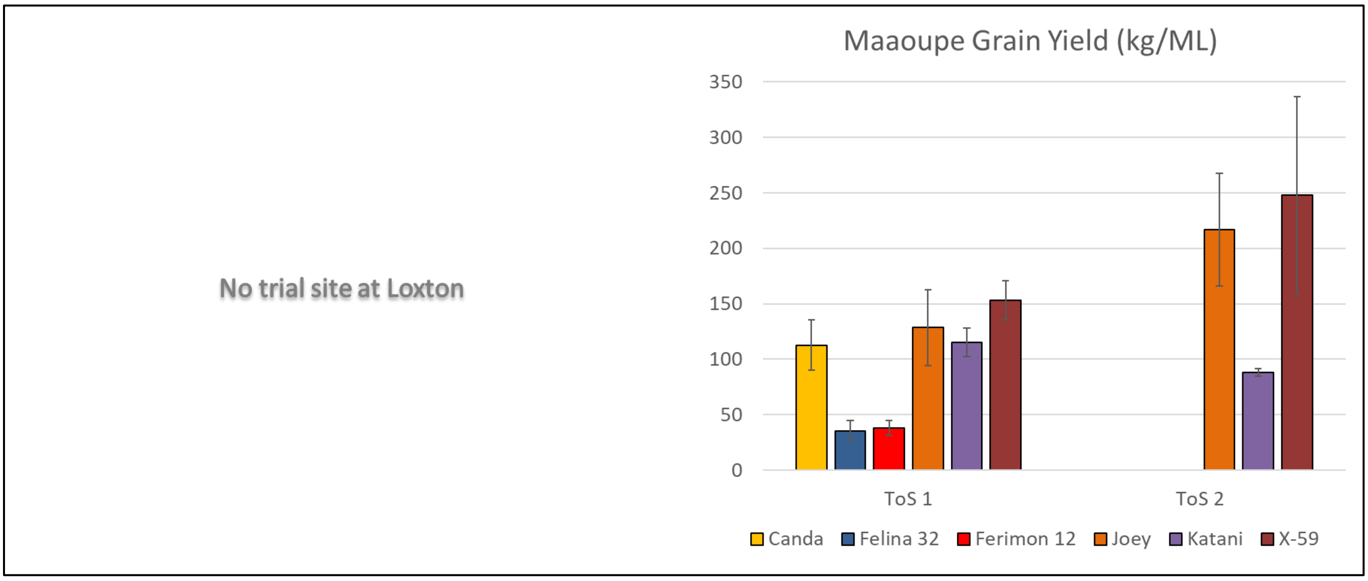


*Figure 49 Average grain yield per volume of water applied – 2020/21 (error bars are SE across 4 replicates)*

Figure 50 presents average grain weight, expressed as the weight of 100 grains. Results are similar across varieties, with the exception that Joey produced significantly smaller grains than Katani. Grain size in ToS 2 was significantly higher than in ToS 1.

Bulk density (Figure 51) is a measure of the weight of seed in a given volume, expressed as kilograms per hectolitre (kg/hL). Low bulk density of grain is usually associated with poor quality. In hemp low bulk density may indicate the presence of shrivelled hearts within a fully developed shell.

Statistical analysis indicated that bulk density in ToS 2 was significantly higher overall than in ToS 1, suggesting that grain fill was more compete in ToS 2. Some varietal differences were found, but consistent patterns were difficult to uncover with half of the varieties missing in ToS 2.

No trial site at Loxton

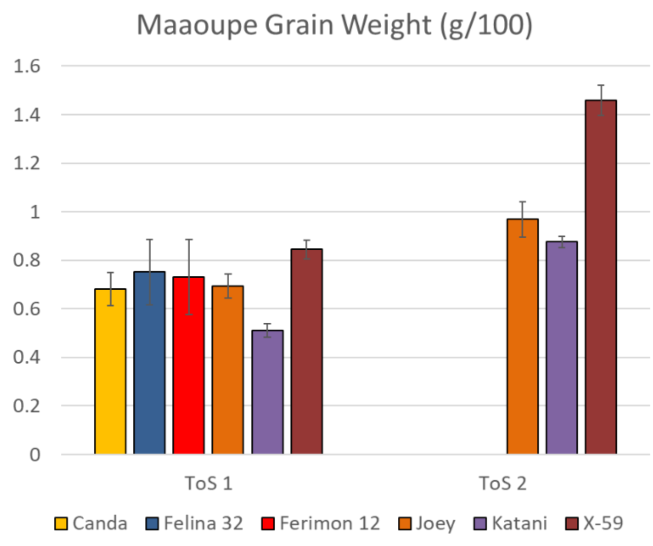


*Figure 50 Average weight of 100 grains – 2020/21 (error bars are SE across 4 replicates)*

No trial site at Loxton

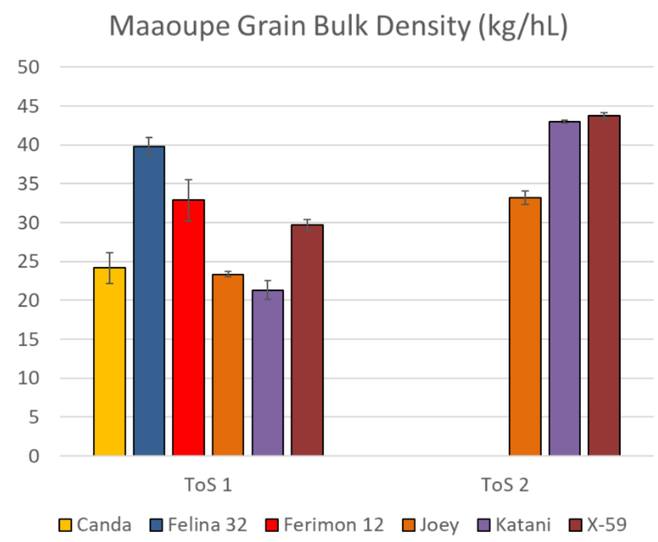


*Figure 51 Average bulk density of grain sample – 2020/21 (error bars are SE across 4 replicates)*

# Inter-Seasonal Comparisons

The discussion above has treated each season separately, comparing performance between the varieties selected for trialling in that season. However, there were two varieties which were common across seasons at the respective sites:

- Han NE was trialled at Loxton in all three seasons (2017/18 to 2019/20), and it was included in the first two seasons in the Limestone Coast (2017/18 at Kybybolite and 2018/19 at Maaoupe).
- Ferimon 12 was trialled in the Limestone Coast in every season (2017/18 at Kybybolite and 2018/19 to 2020/21 at Maaoupe), as well as the first two seasons at Loxton (2017/18 & 2018/19).

This offers the opportunity to compare the performance of these two varieties across multiple seasons, to understand the annual variability in performance of an individual variety as a result of seasonal conditions. The graphs below compare the performance of a November planted and a December planted treatment of the two varieties across all sites where they were grown. Data for Loxton are displayed in blue and data for Kybybolite and Maaoupe are displayed in red. Year is signified by pattern.

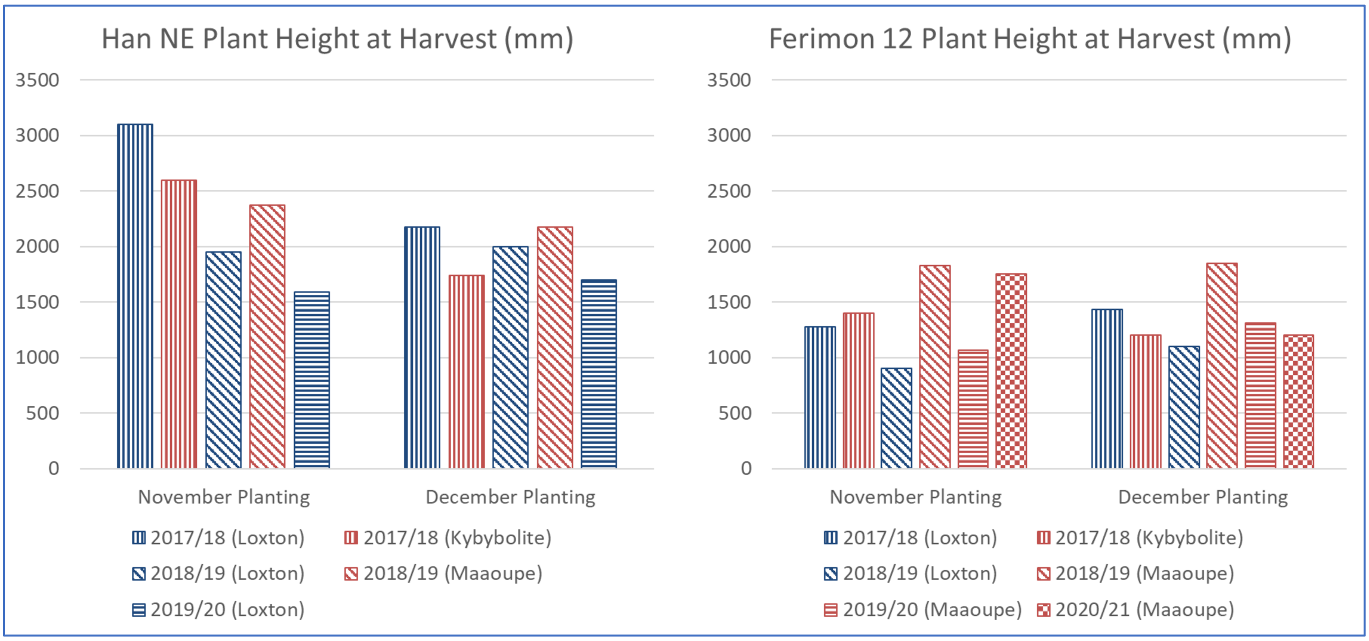


*Figure 52 Average plant height at harvest for Han NE (L) and Ferimon 12 (R) across multiple years and two regions*

Figure 52 displays plant height at harvest for the two varieties at the two locations. When analysed as the complete data set, year was significant, with 2017/18 producing taller plants at harvest than 2019/20, with the other two years being intermediate and not significantly different.

Analysis of just 2017/18 and 2018/19 data allowed analysis of interactions. At both trial sites Han NE (L) was taller than Ferimon 12 (R). However, Han Ne (L) showed no significant difference in height between the two trial sites, whereas Ferimon 12 (R) was taller in the Limestone Coast (Kybybolite and Maaoupe, red bars) than in the Murraylands  (Loxton, blue bars).

Yield of grain is displayed in Figure 53. Analysis of all data together indicates that there was no significant difference in yield across years, most likely due to the variability within the data set. Anecdotal evidence indicated that yields in commercial crops in the Limestone Coast region in 2019/20 were lower than the previous season, indicating that seasonal conditions play a role in yield.

Analysis of interactions in the 2017/18 and 2018/19 data indicated that there was no difference in yield between the two varieties in the Limestone Coast (red bars), whereas within the Murraylands  (blue bars) Han NE outyielded Ferimon 12.

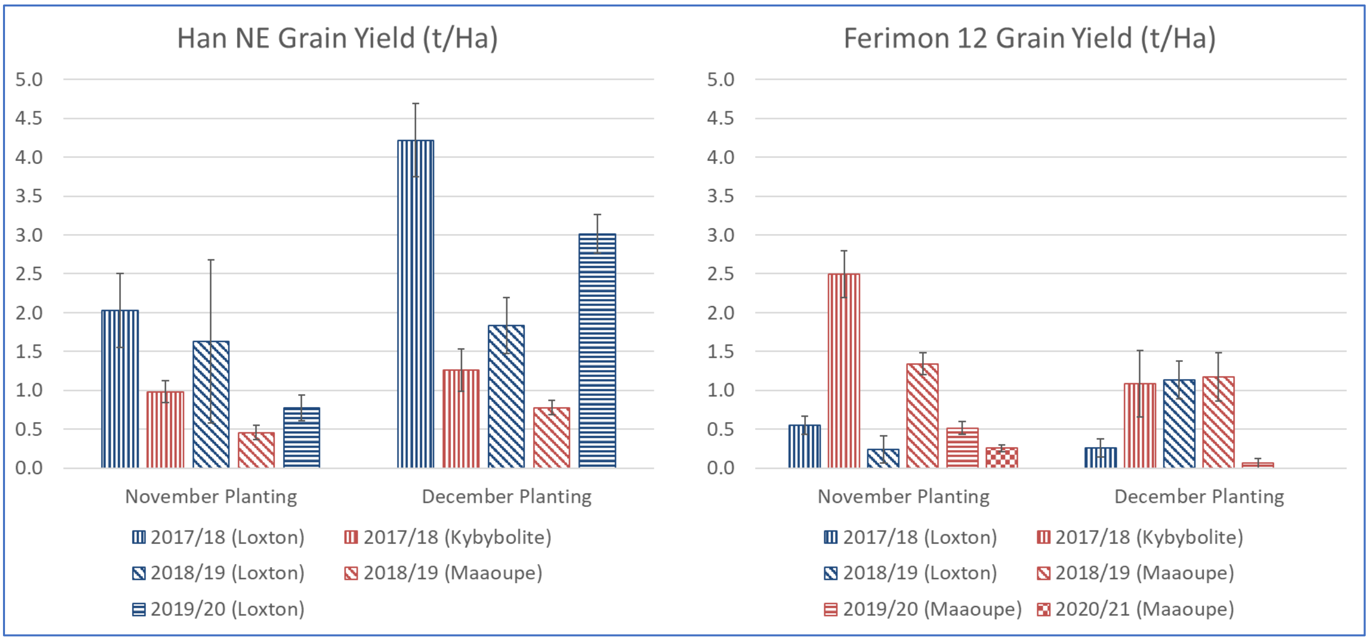


*Figure 53 Average grain yield for Han NE (L) and Ferimon 12 (R) across multiple years and two regions (error bars are SE across 4 replicates)*

Comparing varieties across regions, Han NE (L) recorded a better yield in the Murraylands (blue bars) than the Limestone Coast (red bars), while Ferimon 12 (R) performed better in the Limestone Coast (red bars) than the Murraylands (blue bars). Combined with the crop height data above (Figure 52) this strongly suggests that Han NE is better adapted to Murraylands conditions, and Ferimon 12 is better adapted to Limestone Coast conditions.

Harvest index

Yield per volume of applied water (Figure 54) is similar to yield per hectare (Figure 53), but because applied water varies from year to year, and between the two regions, the results can be quite different. Evaluated across the complete data set, 2017/18 produced higher yield per applied water volume than any of the other seasons.

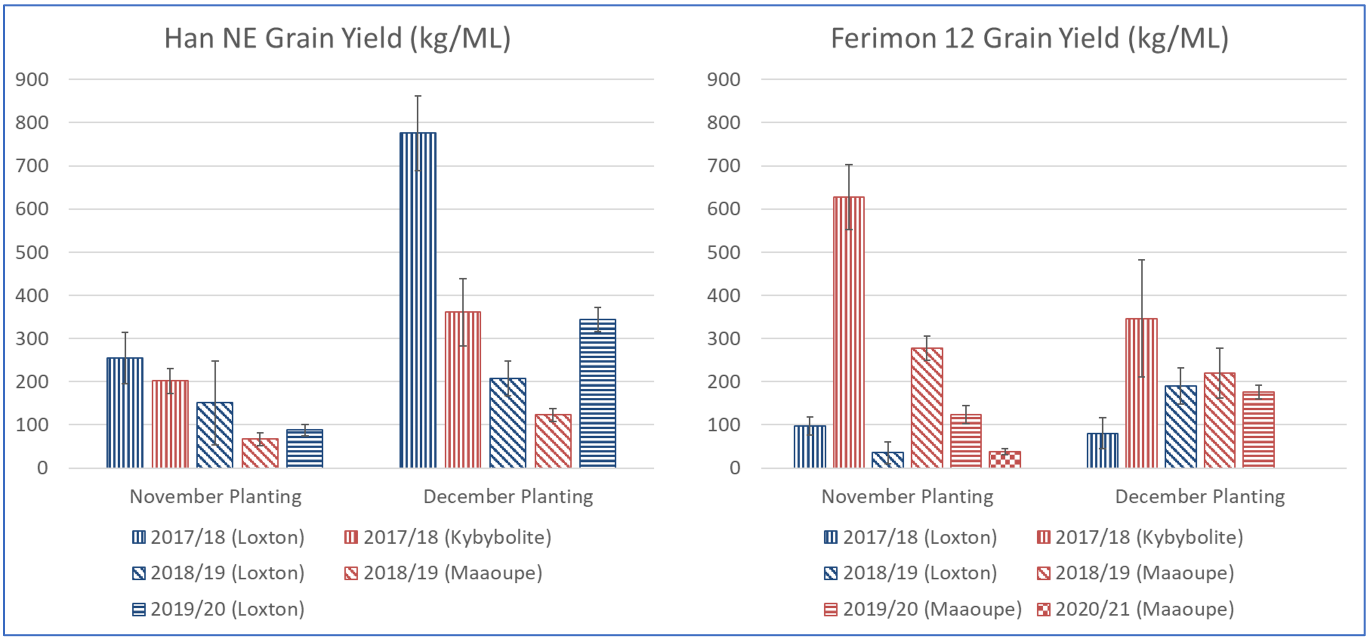


*Figure 54 Average grain yield per volume of water applied for Han NE (L) and Ferimon 12 (R) across multiple years and two regions (error bars are SE across 4 replicates)*

Interactions were again evident in the 2017/18 and 2018/19 data set. Ferimon 12 (R) was the best performer in the Limestone Coast (red bars) and the Limestone Coast was the best location for Ferimon 12, while Han NE (L) performed the best in the Murraylands (blue bars) and the Murraylands was the best location to grow Han NE, mirroring the pattern emerging from crop height (Figure 52) and yield (Figure 53).

Grain weight, a measure of quality, shows similar trends to the above, but with some variation. Analysing the whole data set reveals that 2017/18 produced larger grain size than 2020/21, and Han NE produced larger grain size than Ferimon 12 overall. However, analysis of the 2017/18 and 2018/19 data indicated that the Limestone Coast produced larger grain size than the Murraylands .

In addition, there were significant interactions in the 2017/18 and 2018/19 data set. While Han NE produced the largest seed in both the Limestone Coast (red bars) and Murraylands (blue bars), grain size was not significantly different in Han NE (L) between the Limestone Coast and Murraylands regions, whereas grain size from Ferimon 12 (R) produced significantly larger grains in the Limestone Coast region than in the Murraylands . This would support the conclusion above that Ferimon is better adapted to the Limestone Coast region than to the Murraylands .

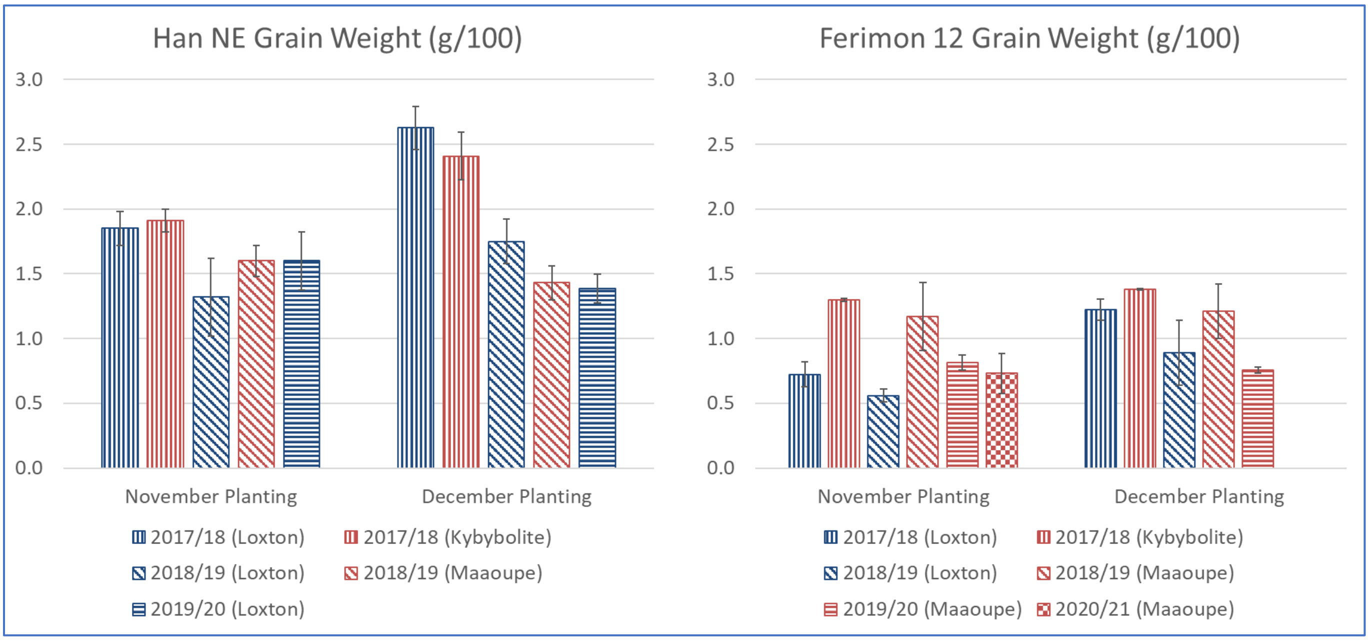


*Figure 55 Average weight of 100 grains for Han NE (L) and Ferimon 12 (R) across multiple years and two regions (error bars are SE across 4 replicates)*

# Additional agronomic observations

As noted above, water salinity was a concern at the Kybybolite site in 2017/18. In early sown crops the winter rainfall stored in  the soil, as well as regular rainfall events, diluted the effect of the saline irrigation water (2,000 ppm / 3600 EC units), resulting in little impact on the crop. Rainfall contributes fresh water to the soil, directly diluting irrigation water, and also assists in leaching salt from the rootzone.

However, in later plantings when the bulk of crop water use was sourced from irrigation water in the absence of rainfall, clear salt burn symptoms were evident in the young crop (Figure 56), and significant plant death was apparent. This resulted in low plant density in the later ToS treatments compared to earlier ToS (Figure 56). Interestingly, more mature plants (taller than around 20 cm) did not show the same impact from salt as younger plants, suggesting an ability for hemp to grow out of susceptibility to salt impacts.

*Figure 56 Salt burn symptoms at Kybybolite in 2017/18*

Hemp is also reported to be susceptible to waterlogging (Amaducci et al., 2015), and observations at Kybybolite in 2017/18 support this conclusion. An intense rainfall event three weeks after sowing of the first ToS treatment at Kybybolite exceeded the intake rate of the heavy clay soil at the site, resulting in runoff accumulating in one of the trial plots. This caused waterlogging in this plot, and resulted in significant plant death. Free draining soil is highly recommended for hemp growing, to avoid this potential issue.

Another issue identified at the trial sites was weed control. There are no herbicides registered for use on hemp, and only a small number for which permits have been granted. Furthermore, there is almost no information on how these herbicides impact on hemp plants. At the trial sites the best weed control was achieved through smothering of weeds by the hemp canopy. This mechanism failed when plant density was low, and was somewhat less effective in the less leafy varieties such as ECO_50GC and Ferimon 12, which were more upright and allowed much more light to penetrate to the soil. This was particularly a problem at Loxton, where caltrop (*Tribulus terrestris* L.) became a major problem in both seasons. Higher plant density was targeted in 2018/19, following the recommendations of Amaducci et al. (2015).

Sand drift into the planting furrows was a problem at Loxton in both seasons. Due to rotary hoeing the soil before planting, and the set-up of the seeder used, the furrows created during sowing were quite deep (>50 mm), and in the soft sandy soil at Loxton there was a clear tendency for sand to accumulate in the bottom of the furrows when wind blew sand drift into the trial site, burying the seeds and seedlings. Hemp seed should be sown quite shallow (<25 mm), and care is needed to avoid seed being buried too deep.

In sandy soil it is recommended that special care is taking with the type of seeding machinery and the setup of the machinery for sowing. Working the soil prior to seeding is still recommended (see comments immediately below regarding weed control). However, a key outcome of the sowing operation should be to sow seed at the recommended depth, and minimise the depth of furrows which may accumulate additional soil due to sand drift. This can be accomplished by a combination of tine selection, good seeding depth control, and the use of press wheels or rollers to settle the soil behind the tines.

In an effort to avoid this problem outlined above, the ground was not rotary hoed prior to sowing ToS 4 in the Loxton trial in 2018/19. As a result the small weeds present at sowing were not killed during the sowing process, and these grew larger before the hemp seedlings emerged, to the point that they smothered the hemp seedlings and dramatically reduced the establishment of the trial plots. This draws attention to the necessity to adequately control weeds prior to sowing. If the hemp seedlings can establish with minimal competition they will outcompete most weeds at later growth stages, but they are susceptible to competition at the very earliest stages of establishment.

At Maaoupe in 2018/19 there were some minor pest and disease issues. In November 2018 a period of humid weather (rain on 8 of the first 10 days of the month) led to the development of mildew-like symptoms in the ToS 1 plots. The initial inclination was to treat the disease, but the problem resolved itself before any action was required. Due to the rapid growth of hemp, once the weather cleared up and the mildew stopped spreading the hemp plants quickly grew new, healthy leaves, and the old, affected leaves were shaded out and dropped onto the ground. There was no obvious long term impact on the crop from this early issue.

In January 2019, immediately prior to harvest of some of the TOS 1 treatments, *Helicoverpa* spp. larvae were found eating the grain in the flower heads of some plants at Maaoupe. The level of damage was not severe, and given that harvest was carried out within a week of the discovery of the larvae, chemical treatment was not possible. Larvae and damage were not noticed in the later harvested treatments, so it doesn’t appear that this infestation was ongoing through the whole season. Insecticide residues in hemp grain could be a major issue, and treatment is not recommended apart from exceptional circumstances.

# Conclusion

The first season of trials at Loxton and Kybybolite Research Centres indicated that industrial hemp can successfully grow under South Australian conditions, when grown as an irrigated summer crop. The subsequent three seasons of trials at Loxton Research Centre and Maaoupe reinforced this conclusion.

Over four seasons the trials have compared a total of 19 different industrial hemp varieties, sown across a range of different sowing times, from late October to mid-January. Performance of the varieties varied between the Murraylands (Loxton trial site) and the Limestone Coast (Kybybolite and Maaoupe trial sites), and between the different sowing times. It is becoming clear that the day-length insensitive varieties are proving more successful for grain production in the Limestone Coast region. There is less clarity regarding the best varieties for the Murraylands region.

Despite the promising performance of Han NE across three seasons, and similarly good performance of Han FNQ in 2019/20, these varieties should be used with caution in South Australia. The base THC levels of these varieties are relatively high, and variation in THC production due to climatic or other influences has the potential to push the THC levels above 1.0%, leading to destruction of the crop under licence conditions.

Some other key agronomic factors contributing to a successful industrial hemp crop include planting in free draining soil to avoid waterlogging, controlling weeds at sowing and achieving a high plant density (>50 plants/$m^2$) to help smother weeds which emerge after sowing.

This report will be further updated with the results of grain and stem analyses from the 2019/20 and 2020/21 seasons.

The work begun in this project will now continue under the Industrial Hemp Variety Trials (IHVT) program, a partnership between AgriFutures Australia and state government bodies from across Australia, including the South Australian Department of Primary Industries and Regions (PIRSA). Future results from the IHVT will be published under separate cover, in partnership with AgriFutures Australia.

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