Final report

What is the nutritive value of modern crop stubbles?

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Executive summary

Grazing of crop stubbles is an important part of the seasonal feedbase in the mixed farming region of southern Australia, with farmers reporting that sheep spend about 25% of their time grazing stubbles. Feed demand by the sheep enterprise during summer may not be as high as at other times during the year, particularly if young stock can be finished and sold early. However, a good source of feed during summer is essential to maintain the productivity of the sheep enterprise at this time, coinciding with joining and pregnancy. Inadequate nutrition over summer can result in higher mortality, lower lambing rates and lower lifetime productivity of lambs. This project aimed to address the lack of knowledge of the nutritive value of crop stubbles for the main crop species, and the variability in stubble quality. Further, the willingness of young and mature ewes to wheat chaff, a low quality feed, and select higher quality chaff components with or without the provision of supplementary feed was evaluated in an animal house study.

The results of this project confirmed that stubbles and chaff (excluding grains) are primarily a low quality source of forage, with an energy density of ranging from 4-8 MJ ME/kg, and typically around 6 MJ ME/kg for the edible components of chaff. Varietal effects were investigated, but crop type, growing conditions and management (e.g. N) were identified as having the largest drivers of differences in stubble quality. Edible components of barley and lupin chaffs were mostly higher quality than wheat and canola chaffs, however all were below the maintenance requirements of sheep of 7.5-8 MJ ME in feed. Therefore, farmers would need to ensure that sheep have access to other high-quality feed such as spilled grains, supplements or green forage to maintain or grow sheep grazing stubbles and chaff. Even the higher quality chaff components are of relatively low feeding value, and when offered ad libitum will only provide about one third to one half of the daily maintenance requirements of sheep. On average, barley chaff contained 7 times the amount of grains than that of wheat chaff, and of the whole samples that were analysed are the most likely to meet the nutritional requirements of sheep.

The animal house study demonstrated that provision of a supplement is likely to be additive, that is both young and mature sheep offered lupin supplement did not reduce their intake of chaff. However, this may depend on the overall level of feeding as the sheep in this experiment consumed substantially below their maintenance requirement. Both young and mature ewes, with or without lupin supplement, adapted readily to eating the wheat chaffs offered in the animal house experiment, and intake was at a level where this provides a valuable feed resource despite it being of low quality. However, because the overall quality of wheat chaff components is low, and grain is only ~0.5% of dry matter in a chaff sample, selective grazing provided only a marginal improvement in the quality of their feed intake (~1-2% DMD higher eaten than offered), and wheat chaff provided for less than half of maintenance requirements of the ewes. In a stubble paddock, sheep need access to spilled grain and/or graze chaff more selectively to meet their full nutritional requirements.

Farmers consistently stated that the greatest limitations in managing grazing of stubbles was knowledge of the feeding value of stubbles initially, and then when feed has run out. The results of our evaluation of the nutritive value of chaff and stubble following the 2018/2019 harvest highlighted why this is the case. First, stubbles are made up of components that vary widely in nutritive value (e.g. stem, leaf and grains). The finer stem and leaf, and other fine (< 2 mm) components of chaff are about 1 MJ ME/kg higher in nutritive value than the main stem. Further, stubble quality varies widely between paddocks with comparable crops. There was a consistent range of about 5 percentage units of digestibility between the lower and upper quartile of samples, equivalent to 1 MJ ME/kg. The factors responsible for variability in nutritive value seen among chaff samples remain unclear and understanding the G x E x M drivers of stubble quality would help farmers to predict livestock production outcomes more accurately when grazing stubbles.

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1. Background

1.1 Crop stubble as a source of feed on mixed farms

The provision of feed over summer is an important consideration for livestock businesses in the mixed farming region of southern Australia, due to the Mediterranean-type environment and few perennial plants that are suitable forage options. Historically, stubbles have been an important source of feed for mixed farms in the Mediterranean-type climate zones of southern Australia, particularly during ewe mating and early gestation. However, crop stubbles are probably the most difficult feed resource to estimate the feed value for because as little as 10% of biomass are edible components such as grain, leaf and germinated weeds. Further, considerable variability in the feeding value of stubbles is observed between crop species, components of stubbles (stem, leaf and grain) and from one paddock to the next. Combined with the difficulty of monitoring the performance of livestock in extensive grazing systems, this variability makes it difficult for livestock producers to determine precisely when sheep should be moved, or provided supplementary feed. The decision to move livestock from a stubble to other feed sources (often fresh stubbles) is critical because poor timing may result in over or under utilisation of the feed resource, poor livestock performance and welfare outcomes and deterioration in the productive capacity of the land (Pickup and Stafford Smith 1993; Brennan et al. 2006).

1.2 Feeding value of stubbles and chaff

Typically, the bulk of stubble biomass is poorly digestible, and generally inedible, plant stems (straw). Further, the high quality components are also depleted over summer by populations of endemic fauna such as ants, mice and birds (Landau et al. 2000). The edible stubble biomass is also susceptible to nutrient leaching with any summer rain events that occur. This variable and dynamic nature of feed from stubbles makes nutritional outcomes for sheep grazing them highly variable and difficult to predict. As was summed up by a participant of the 1983 symposium on stubble utilisation "Due to the tremendous variability in stubble quality there is a need for a readily available means of identifying the value of stubbles relative to the type of crop that is being grown, the yield of the crop… [and] the soil type" (Arnold 1983). Dispite clearly articulating the problem, there has been little progress and arguably little investment made toward resolving this challenge in the intervening period. Fully characterising stubbles in order to predict their feeding value would require accurate knowledge of the mass and quality of edible stubble components, and the selective grazing behaviour and intake by livestock. These measurements are very difficult to ascertain, even within research projects.

Through enough experience farmers may better understand the feeding value of their stubbles through knowledge of how crop type and growing conditions, soil type, harvesting methods and post-harvest weather jointly affect feed quality of stubbles. There have been previous efforts to investigate and integrate this complexity (e.g. Orsini, 1990; Purser 1983). However, much of the grazing and supplementation recommendations for stubble grazing in Western Australia are based on data collected 40+ years ago (e.g. Arnold 1978, Mitchell, 1979, Pearce 1979, Purser 1983) that was generated from old crop cultivars, and harvested using the machinery of that time. There is also little information available for new (or increasing) crop species such as canola, particulary in lower rainfall areas. Changes in crops that affect stubbles and their feeding value include:

i) Higher yielding, crop varieties (~0.5% yield increase per year; Fischer 2008)
ii) Larger harvesters (~4% wider per year, Fuchs et al. 2015)
iii) Increase in proportion of farm cropped (~2% more land cropped per year in WA from 1980, Bell 2012)
iv) Higher proportion of canola stubbles (~30% more canola harvested per year in WA from 2000, Wilkinson 2017)

v) Increase in the use of chaff carts to collect threshed material at harvest (~15% increase in chaff collected per year during the next 5 years, Walsh 2017)

1.3 Project aims

Despite the changes in the characteristics of stubbles over previous decades, many of the key questions being asked by farmers over this period remain relevant and still need to be addressed, including how the carrying capacity of stubbles can be better estimated to allow greater precision and certainty in livestock management. The aims of our project were to;

i) Identify current stubble grazing practices on mixed cropping and livestock farms.
ii) Evaluate the nutritive value of stubbles and chaff from modern crop species and varieties.
iii) Examine variability in the feed value of chaff piles, the capacity of sheep to select higher quality components, and the requirements for supplementary feeding of sheep grazing chaff.

2. Objectives

Objectives of this project were;

1. Deliver up to date information on the nutritional value of stubbles (and chaff piles) of modern crop cultivars, harvested with modern equipment in both digital and print formats
2. Describe current use of crop stubbles - following engagement with producers - in the mixed farming regions (feedbase decision making, crop species/varieties grazed, typical grazing days, livestock species and classes grazed)
3. Provide improved knowledge of the value and supplementary feeding strategies for grazing chaff piles, identifying the selective grazing of material from chaff piles, and the nutritive value from a diverse range of samples from different crops
4. Facilitate the easy use of the many facets of stubble grazing management, by producing an online integration tool and hard copy communication materials to specify expected grazing days and supplementary feeding requirements for selected scenarios
5. Have submitted a minimum of 1 peer-reviewed scientific publication on the feeding value of modern crop stubbles to ensure the information gathered is available for other users.

3. Methodology

3.1 Producer survey

A survey of mixed crop and livestock farmers was conducted to understand the key features of their stubble management practices and identify priority issues. The survey was conducted using Survey Monkey. A total of 41 farmers participated, and they took a median time of 21 minutes to complete the survey. Their willingness to give up this time is gratefully acknowledged, and the time required may have reduced participation. However, the survey responses were widely source from more than 17 farmer groups in WA and one in SA, which should provide a fair reflection of stubble grazing practices in mixed farming businesses of southern Australia. Some specific farmer feedback we received regarding the project included “An important area of research for a balanced farming system” and “I think it is a very good project to undertake”.

In designing the survey we deliberately chose to use more open ended questions in the survey to avoid limiting responses, although this meant that surveys took longer to complete and were more difficult to analyse. The online survey design and content was reviewed and authorised by our CSIRO human ethics committee (Ethics Clearance 111/18).

To deliver the survey we were supported by the WA Grower Group Alliance and widely by 15 grower groups across Western Australia, and 1 in South Australia. The project scope and the survey was promoted through 2 mail-outs from grower group executive officers in October 2018 and February 2019, and via social media including 4 twitter posts (395 engagements, 20 retweets). The survey was promoted in state wide communications from the WA Livestock Research Council, WA Grower Group Alliance, The Sheep's Back and with assistance from the MLA project manager.

An outline of the questions of the survey is as follows;

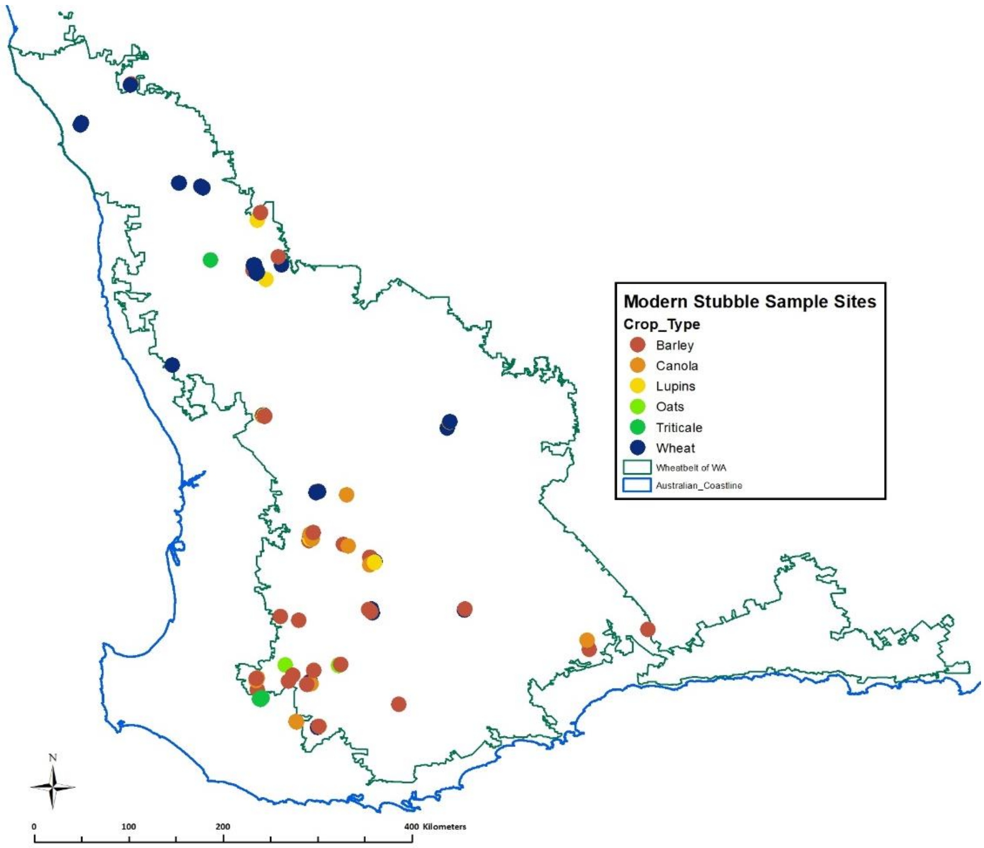
1) Agreement
2) Farm location, size, type
3) Grower group
4) Farm enterprise structure, livestock
5) Farm feedbase
6) Harvest plans
7) Chaff management at harvest
8) Chaff management at harvest
9) Stubble grazing management
10) Livestock performance on stubbles
11) Pests in stubbles
12) Research priorities, limitations of chaff management
13) Use of yield maps
14) Use of yield maps
15) Further project involvement
16) Contact details

Farmers were asked to provide input into future research priorites for stubble management, and were asked to identify current limitations when grazing stubbles or chaff and to outline where they think information is lacking.

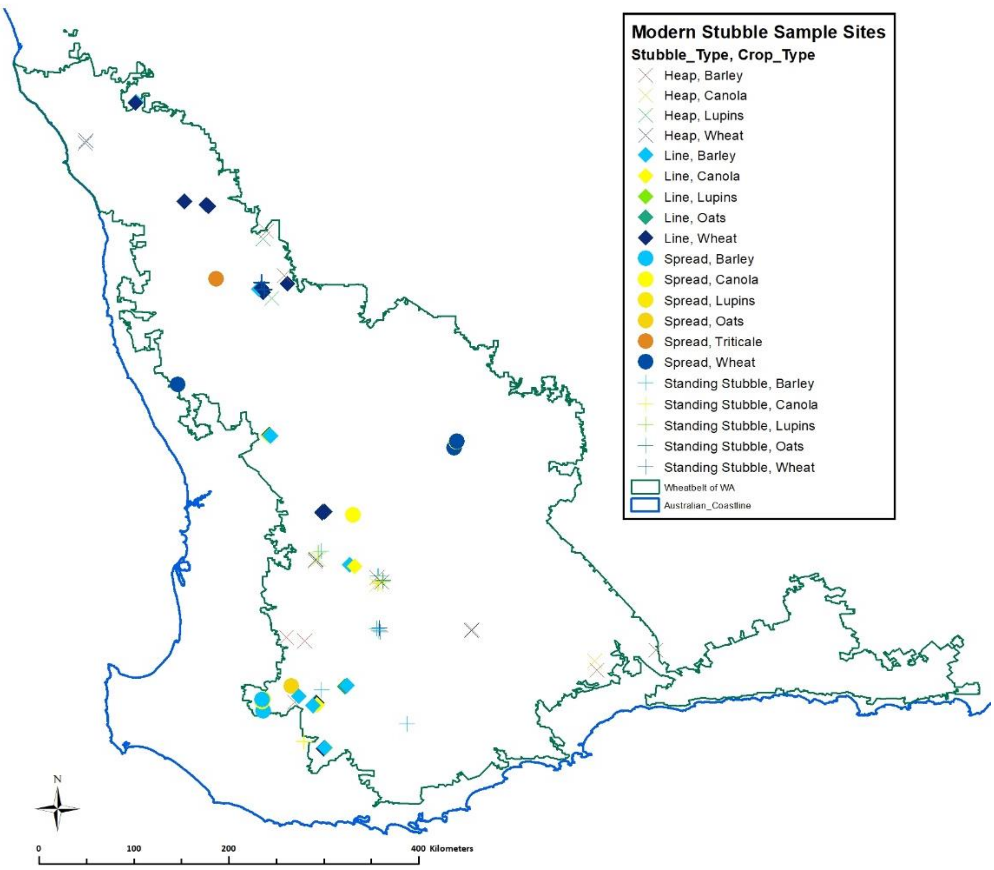
3.2 Chaff and Stubble Nutritive value

3.2.1 Chaff sample survey

Standing stubbles and chaff piles were sampled across the Wheatbelt of Western Australia in coordination with participating farmers (Fig. 1). This was done in order to address the project objective "to provide improved knowledge of the value and supplementary feeding strategies for grazing chaff piles, identifying the selective grazing of material from chaff piles, and the nutritive value from a diverse range of samples from different crops". The standing stubble collections were made during 17-21 December, with CSIRO staff travelling to collect samples quadrats at 8 properties, with an additional farm in the north-eastern Wheatbelt sampled by the Liebe group. The collection sites were generally well distributed, although the central eastern region was under-represented and there were no project samples collected from the far south eastern region. It should be noted that stubbles in different mixed farming regions (such as Vic and NSW) may differ in the composition of stubbles due to their different soils and growing season conditions. At least 4 quadrat samples were collected in each of the standing stubble paddocks sampled, in order to make an assessment of within-paddock variability in nutritive value (Plate 1).



a)



b)

Figure 1. Modern Stubbles project sampling sites in the Wheatbelt of Western Australia, showing a) stubble samples by crop type, and b) stubble samples by crop type and chaff management.

Plate 1. Quadrat sampling of a standing wheat stubble paddock in the Western Australian Wheatbelt.

Harvest dates of standing stubble and chaff samples are reported in Fig. 2. A majority of samples were wheat, barley or canola, however, samples from more than 6 crop types in total are being analysed. There do not appear to be strong trends in harvest dates among crop types, most of the samples were from crops harvested from mid-November to mid-December, which corresponds with the peak harvesting period in Western Australia.

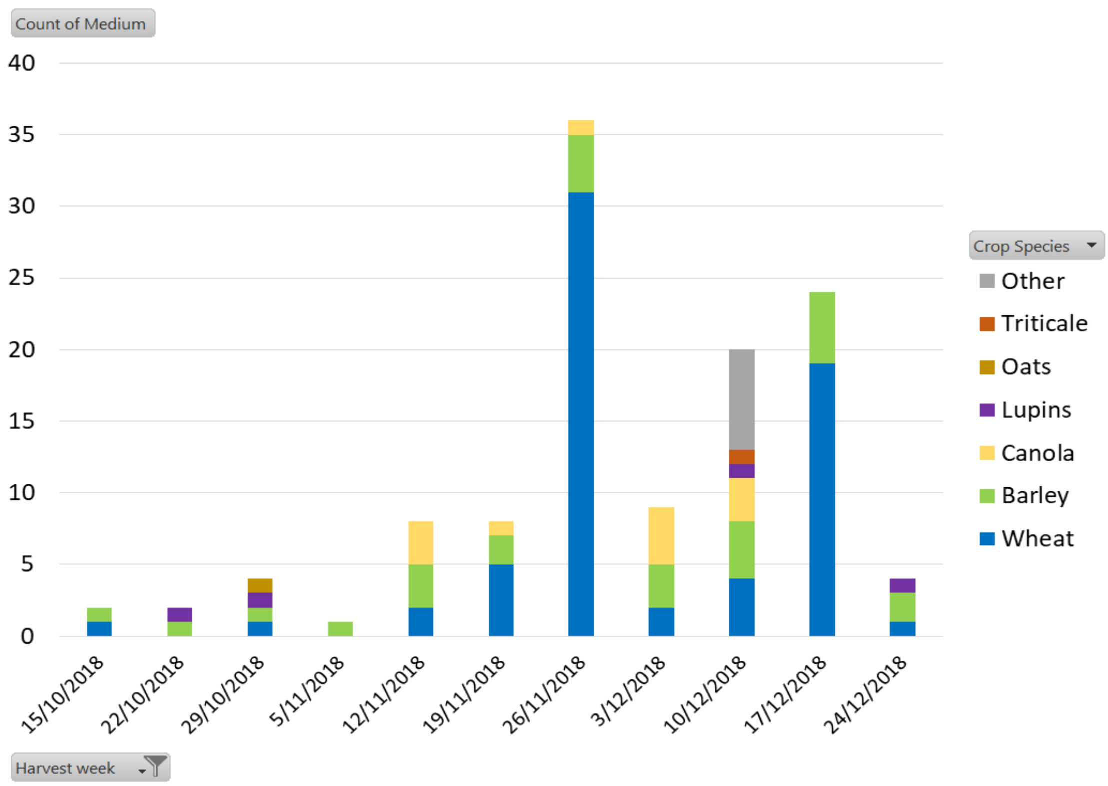


Figure 2. Harvest date of samples provided or collected for nutritive value analyses by crop type.

The project samples are currently being processed, sorted into large, medium, small and seed components (Plate 2), and will be analysed for nutritive value at the Floreat Nutrition Laboratory.

Plate 2. A wheat chaff sample sorted into Large, Medium and Small components, and grain Seeds.

3.2.2 Varietal comparison

The effect of crop variety on nutritive value was explored using samples taken from a varietal trial site at Merredin, in the eastern wheatbelt of Western Australia. To do this, the nitrogen (N) and metabolisable energy (ME) content for the same cultivars (8 wheat and 2 barley) grown in two separate plots at the same location was compared. In addition, an analysis of other project reported nutritive value data was conducted using a linear model-based statistical analysis to identify differences among cultivars.

3.2.3 Sample preparation

Samples were dried at 60 °C for 48 h prior to processing. Samples containing the residue of the soil were thoroughly cleaned using 600 µm laboratory test sieve (Endecotts LTD. London, England). Residues of other plant species or plant material from the previous cropping season were also removed. Then, all samples were sorted, and material was categorised into Large, Medium, Small and Seed (grain) components (e.g. Plate 2). In doing so, a 2 mm stainless steel laboratory test sieve - Endecotts LTD. London, England, was used to separate the Small (fine) plant portion while the Large, Medium and Seed portions were manually separated. All sub-samples were weighed, then dried at 60 °C for a further 24 h and ground using 1 mm diameter grinder (Foss Analytical Co., Ltd.). Fractions were kept separately for individual analysis, where there was sufficient material of each component (Plate 2). Where there was insufficient material of a component for nutritional analyses, only weight data was recorded. Ground material was stored in small screw-top plastic containers and stored for laboratory analysis. The plant material of each sub-group varied according to the type of the crop stubble as outlined in the Table 1. Processing these samples has required a high degree of knowledge, skill and persistence and we thank CSIRO technical officers Andrew Toovey, Doraid Amanoel and Adam Brown for completing this work.

Table 1. A description of components of chaff sorted into Large, Medium, Small and Seed.

Stubble type	Large	Medium	Small	Seed
Wheat, Barley and Triticale	woody stems	fine stem, leaf and leaf sheaths	awn and glume of the spikelet combined with the lower and upper hulls of the kernel	wheat, barley and triticale grains

Canola	woody stems	broken leaf and pods	very fine leaf and stem	canola grains
Lupins	woody stems	broken leaf, fine stems, lupin pods	very fine leaf, stem and hulls	lupin grains
Oats	woody stems	flower, broken leaf and nodes	very fine leaf, stem and hulls	oat grains

In total, 436 field samples were tested through the Floreat Laboratory (Wheat: 187, Barley: 126, Canola: 76, Lupins: 33 and Other: 14; Table 2). Due to the range of practices used to manage chaff at harvest, chaff from a number of sources (associated with harvest method) were identified during collection and these groups were used to improve the reporting of results. The stubble sources, associated with method of chaff management at harvest, were;

i) Heap: Chaff collected directly from a header during harvest that was collected in a chaff cart during harvest, with heaps up to the capacity of the cart left around the paddock. The piles were often unloaded to form a row across the paddock, presumably for ease of management.

ii) Line: Chaff retained in a narrow row, aggregated at the back of the header during harvesting. Material collected was only of the chaff, excluding the stubble underneath.

iii) On Row: A quadrat sample of the chaff line but included other material within the quadrat beneath the chaff such as standing stems.

iv) Off Row: A quadrat sample of the area of stubble between chaff lines including material such as loose chaff and standing stems.

v) Spread: A quadrat sample of stubble taken within a paddock where material was spread from the back of the header at harvest.

Nutritive value analyses were conducted at the Floreat Nutrition Laboratory, using a combination of wet chemistry and Near Infra-red Reflectance Spectroscopy (NIRS) methods.

Table 2. The number of samples for which laboratory analyses were conducted, sorted by chaff components (Large, Medium and Small) of each type of chaff (Heap, Line, Off Row, On Row or Spread) and for each crop (Barley, Canola, Lupins, Oats, Triticale/Oats/Rye and Wheat).

Crop/component	Heap	Line	OffRow	OnRow	Spread	Total
Barley						
Large	11	11	2	15	3	**42**
Medium	11	11	2	15	3	**42**
Small	11	11	2	15	3	**42**
Canola						
Large	2	2	2	12	8	**26**
Medium	2	2	2	12	8	**26**
Small	2	2	2	12	6	**24**
Lupins						
Large	6			5		**11**
Medium	6			5		**11**
Small	6			5		**11**
Oats						
Large				1	1	**2**
Medium				1	1	**2**
Small				1		**1**
Triticale, Oats, Rye						
Large		4				**4**
Medium		5				**5**

Wheat						
Large	5	10	8	42	8	**73**
Medium	5	10	8	42	8	**73**
Small	5	10	8	12	6	**41**
Total	**72**	**78**	**36**	**195**	**55**	**436**

3.3 Chaff feeding – animal house experiment

3.3.1 Experimental design

To investigate the voluntary feed intake and nutritional value of wheat chaff, we conducted an individual pen feeding experiment with Merino sheep. This allowed us to measure feed intake, feed refusals and diet selection of individual sheep from a known diet. A balanced 9 x 9 Latin square experimental design was used to improve the statistical power of the experiment in testing nine wheat chaffs. The treatments are sheep Age (lamb and ewe) and Lupins supplement (+ or -), with the nine wheat chaffs sourced from 3 rainfall (high, medium and low) x 3 region (north, central and south WA wheatbelt) cells. This is a split-plot design with has main treatments, Lupins x Age, allocated as a completely randomised design, and sub-treatments, Chaff, allocated as a Latin square balanced for residual effects (Table 3). Each day 1500 g fresh weight of chaff (~1400 g DM) was offered to each of the sheep, with the + lupin treatment being offered 200 g of lupins in addition.

Table 3. Allocation of Mature ewes (M1-M18) and Young ewes (Y1-Y18) to 2 Lupin (+Lupin and -Lupin) and 9 Chaff treatments (1-9), using a balanced 9x9 Latin square (provided by Jane Speijers, agricultural statistician)

+Lupin	**Mature ewes**									**Young ewes**								
Day	**M1**	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**	**M8**	**M9**	**Y1**	**Y2**	**Y3**	**Y4**	**Y5**	**Y6**	**Y7**	**Y8**	**Y9**
1	1	5	2	6	3	7	4	8	5	9	6	1	7	2	8	3	9	4
2	9	6	1	7	2	8	3	9	4	1	5	2	6	3	7	4	8	5
3	2	4	3	5	4	6	5	7	6	8	7	9	8	1	9	2	1	3
4	8	7	9	8	1	9	2	1	3	2	4	3	5	4	6	5	7	6
5	3	3	4	4	5	5	6	6	7	7	8	8	9	9	1	1	2	2
6	7	8	8	9	9	1	1	2	2	3	3	4	4	5	5	6	6	7
7	4	2	5	3	6	4	7	5	8	6	9	7	1	8	2	9	3	1
8	6	9	7	1	8	2	9	3	1	4	2	5	3	6	4	7	5	8
9	5	1	6	2	7	3	8	4	9	5	1	6	2	7	3	8	4	9
-Lupin																		
Day	**M10**	**M11**	**M12**	**M13**	**M14**	**M15**	**M16**	**M17**	**M18**	**Y10**	**Y11**	**Y12**	**H13**	**Y14**	**Y15**	**Y16**	**Y17**	**Y18**
1	5	6	2	8	9	7	4	1	5	9	4	7	3	1	3	6	2	8
2	1	9	6	3	6	2	8	5	3	4	9	1	5	7	8	2	7	4
3	3	2	7	4	4	1	9	7	1	6	8	2	8	5	5	9	6	3
4	7	4	9	5	2	6	3	3	8	8	6	5	1	2	4	7	1	9
5	8	7	1	9	8	5	6	2	7	2	3	6	4	3	1	4	9	5
6	2	8	4	1	7	9	5	8	4	3	2	3	7	6	9	1	5	6
7	4	1	5	6	3	3	2	6	2	7	5	9	9	8	7	8	4	1
8	6	3	8	7	1	4	1	4	9	5	7	8	2	9	6	5	3	2
9	9	5	3	2	5	8	7	9	6	1	1	4	6	4	2	3	8	7

3.3.2 Animals

In the experiment we used 36 female non-pregnant Merino sheep (ewes), in two cohorts from the same genetic and environmental background i) 18 of 14-month young ewes and ii) 18 of 4-year mature ewes. The mature ewes were an average of 72.6±1.7 kg (mean±SE) and Condition Score 3.6, and the young ewes were 53.4±1.1 kg and Condition Score 2.8 immediately prior to starting treatment chaff diets. Previous farmer surveys have indicated that young ewes and lambs are often the first type of livestock that are offered crop stubbles, and ewes are the largest commercial class of livestock. The ewes were selected from a commercial farm in the wheatbelt of Western Australia (Pingelly), and had been backgrounded on stubbles during the previous summer.

All animals were health checked by an experienced staff member prior to leaving the farm of origin, and were drenched, vaccinated and a lice treatment was applied. The animals were orally drenched (to kill gut parasites) immediately prior to being transported to CSIRO Floreat. Sheep were given an acclimatisation period of 2 weeks both in yard and pen environments prior to commencement of the treatment chaff diets. By gradually introducing the animals to the pen environment for short periods over several days, we were able to ensure that the experimental sheep were calm and familiar with the experimental facilities and procedures. Sheep were offered oaten chaff as a base diet, which was initially supplemented with 100 g/head/day of lupins to meet the protein requirements of the sheep. However, lupin feeding was withdrawn for the 6 days prior to the experimental period to ensure the intake of lupins did not influence results, given lupin supplementation was a treatment factor. All staff caring for animals were trained in low stress stock handling techniques, which were used at all times.

Historically, there have been cases of annual ryegrass toxicity (ARGT) associated with feeding chaff to sheep. As a result, and on advice of the CSIRO's Animal Ethics Committee, a risk management plan was implemented to mitigate the risk of any poisoning, and sheep were observed closely during the experiment for any signs such as irregular behaviour associated with neural toxicity (e.g. tremors, inappetence), particularly when the animals are being handled or moved.

3.3.3 Animals

Chaff for the experiment was sourced from recently harvested stubbles at 9 locations in the wheatbelt of Western Australia. About 100 kg of each of the 9 chaff's was collected to ensure ample material was available for feeding. Each chaff was then sub-sampled and processed for laboratory analysis. Nutritive value results for each chaff are reported, including by fraction, in Table 4.

Table 4. Nutritive value of experimental wheat chaff samples collected from 9 locations in the wheatbelt of Western Australia.

Location	Component	Fraction	Crude Protein	DMD	ADF
Component sample					
Wickepin	large	18.9	3.2	37.0	46.9
	medium	46.8	3.5	42.9	42.9
	small	32.9	6.7	50.1	36.7
Nanson, 50 km NE Geraldton	large	20.7	4.3	39.7	45.0
	medium	46.8	4.0	42.4	41.9
	small	27.6	6.8	49.9	34.7
Eganu, 20 km NE Badgingarra	large	16.7	4.1	39.1	44.9
	medium	55.7	4.9	46.2	40.5
	small	27.3	7.5	51.6	36.3
Perenjori	large	17.8	4.5	42.9	42.8
	medium	42.3	6.2	47.8	39.9
	small	37.6	6.4	45.8	37.8
Lake Grace	large	20.0	3.6	40.7	42.7
	medium	42.2	4.3	44.2	40.9
	small	36.3	5.6	49.9	38.2
Wagin	large	15.2	4.0	38.9	44.3
	medium	58.9	4.8	45.2	40.9
	small	22.8	10.0	50.2	34.7
Darkan	large	15.6	4.6	39.0	43.5
	medium	53.1	4.0	43.9	40.8
	small	26.9	5.5	48.0	38.0
Tangedin, 50 km SE Merredin	large	24.6	5.3	37.6	46.2
	medium	46.6	6.1	45.5	41.5
	small	25.7	10.2	49.0	37.7

Muntadgin, 66 km S Merredin	large	16.2	3.4	37.0	45.6
	medium	40.0	3.3	43.0	42.9
	small	39.3	6.3	51.2	37.9
Total sample					
Wickepin		32.9	4.5	43.4	42.1
Nanson, 50 km NE Geraldton		31.7	5.0	44.0	40.5
Eganu, 20 km NE Badgingarra		33.2	5.5	45.6	40.6
Perenjori		32.6	5.7	45.5	40.2
Lake Grace		32.8	4.5	44.9	40.6
Wagin		32.3	6.3	44.7	40.0
Darkan		31.9	4.7	43.6	40.8
Tangedin, 50 km SE Merredin		32.3	7.2	44.1	41.8
Muntadgin, 66 km S Merredin		31.8	4.4	43.7	42.1

3.3.4 Measurement and statistical analyses

The amount and quality of material eaten by the sheep was measured daily, by collecting daily refusals for weight and nutritive value assessment. The sheep were weighed on arrival (Day -18), Day -7, Day 0, Day 10 and Day 11. Sheep were fasted overnight (15 hours) with access only to water prior to being weighed. Analysis of variance for treatment effects (lupins and age) on intake and intake per unit metabolic liveweight (g DM/kg liveweight$^{0.75}$) were carried out using the R statistical computing environment (R Core Team 2020).Results

4 Results

4.1 Producer survey

4.1.1 Survey responses

Producers who completed the survey were from 16 farmer groups, and 9 groups had a single responder (Fig. 3). The highest rate of responses came from the Southern Dirt and West Midlands groups, which are groups with larger memberships and are in higher rainfall mixed farming areas, where the value of the sheep enterprise was often equal to or higher than cropping. However, the project was also supported by the Liebe and Mingenew-Irwin groups in the northern agricultural region, which is cropping enterprise-dominant. A majority of farmers were willing to be involved further with the project in allowing additional sampling or providing materials for other research (Fig. 4).

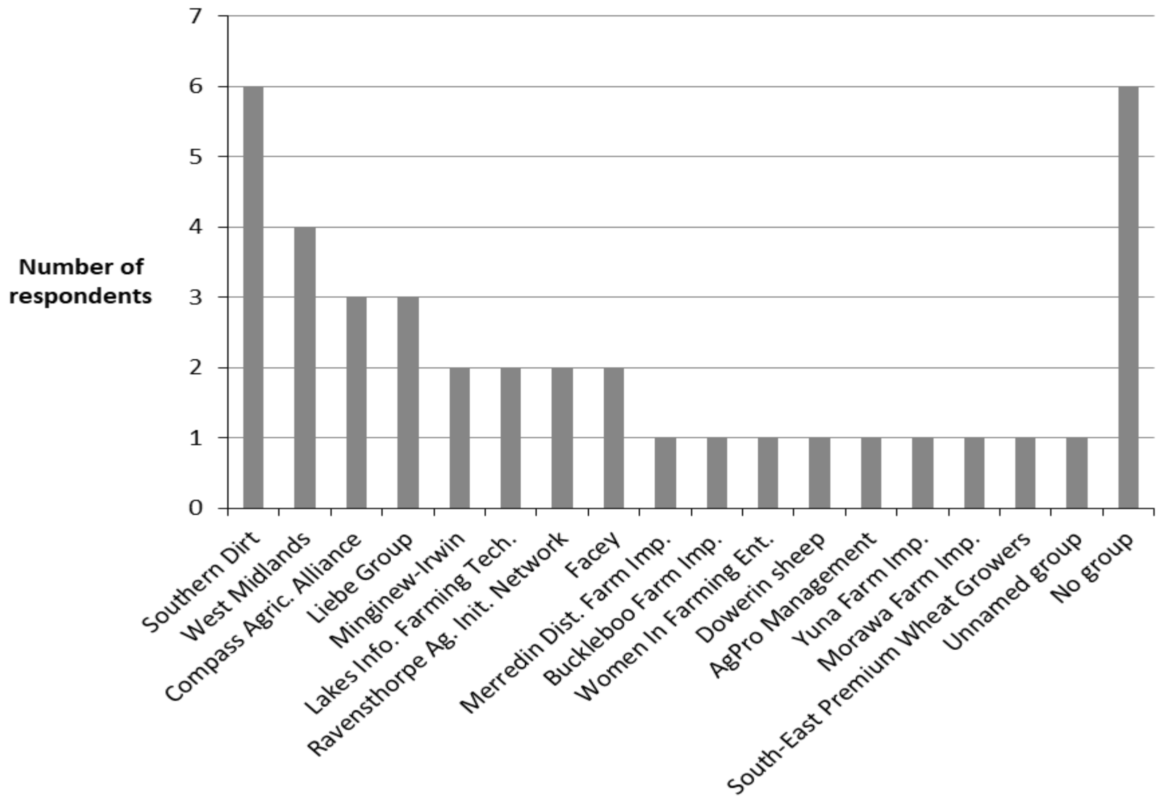


Figure 3. Nominated grower groups of farmers surveyed regarding stubble grazing practices.

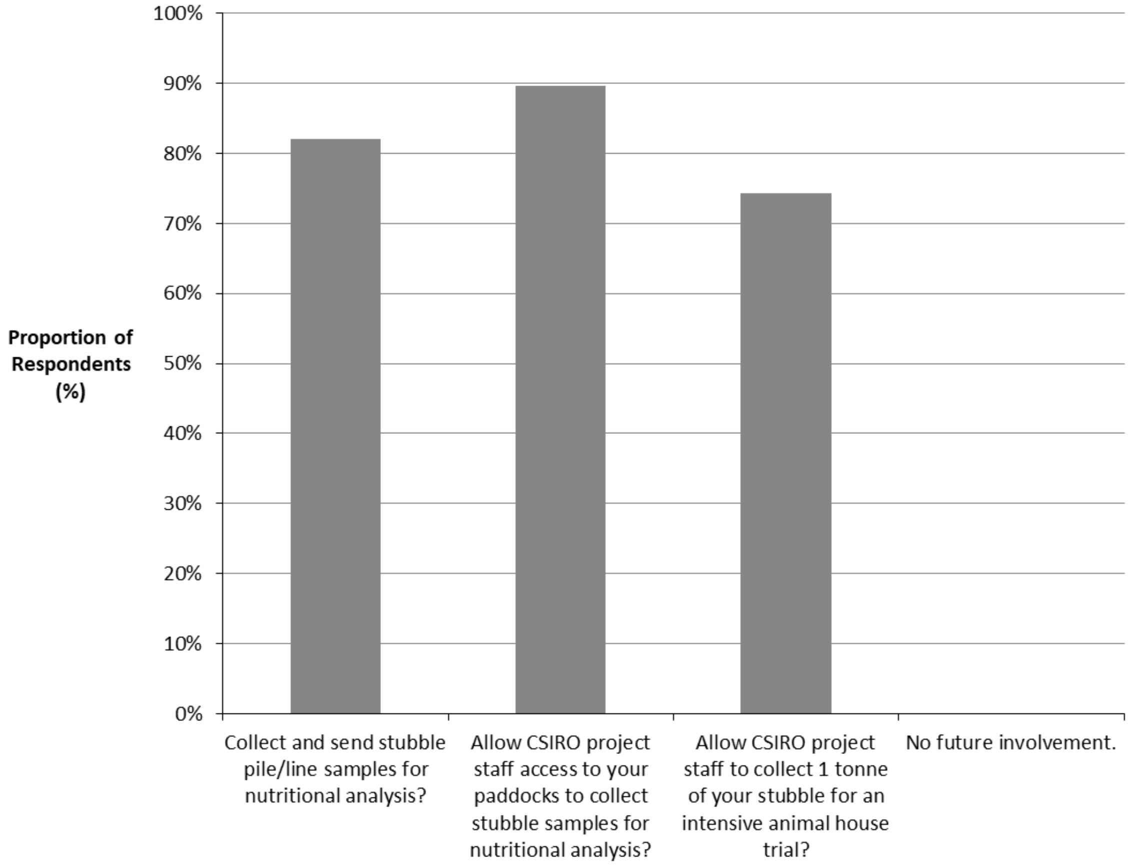


Figure 4. Farmers interest in participating further in the project.

4.1.2 Harvest and grazing management of stubbles

Farmers reported a wide range of stubble/chaff management practices at harvest (Fig. 5). Spreading chaff from the back of the header is most common, with chaff cart piles and chaff wind-rows or lines being the next most common. Other practices included putting chaff through a seed destructor (grinds chaff to a powder), direct baling of chaff and 'crunching' of lupin stubble, which is the use of rolling machinery to break down and flatten standing stubble. Practices for wheat, barley and canola were reasonably consistent, although no baling of canola stubble was reported. Farmers were less likely to use chaff carts with their pulse crops.

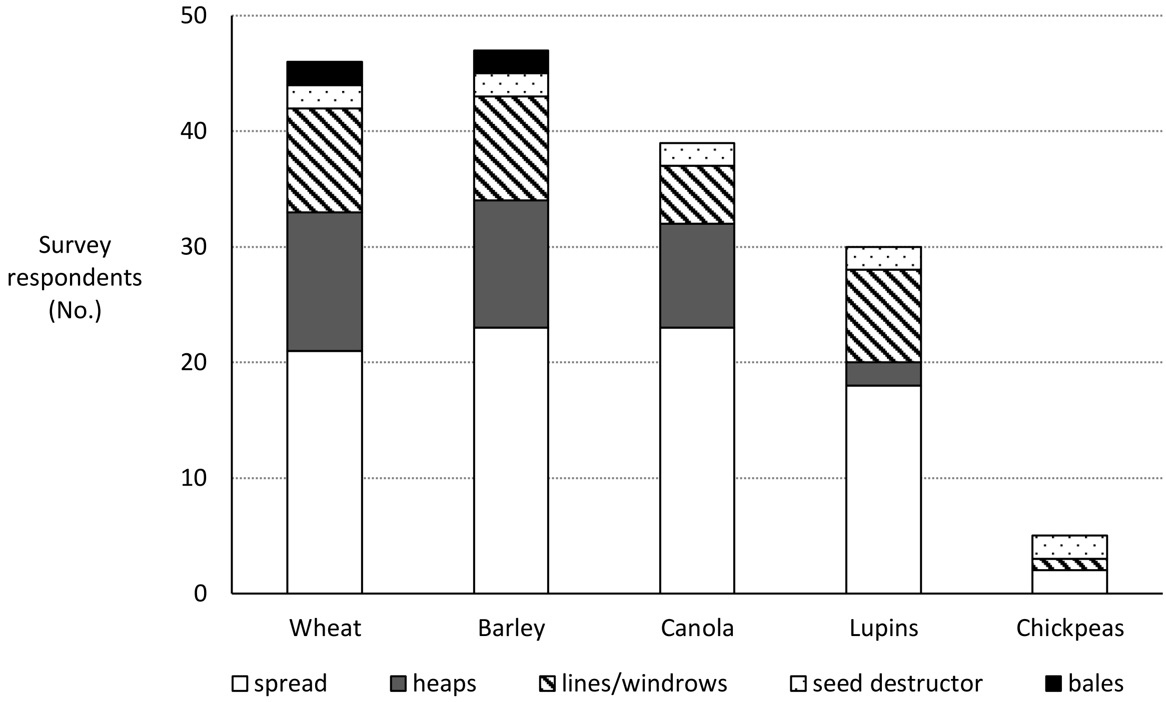


Figure 5. Methods used for chaff and stubble management when harvesting crops.

Seasonal feedbase rotations of the farmers surveyed are reported in Fig. 6. On average, the feedbase was comprised 3 months stubble grazing, 4 months green pastures, 3 months dry pastures, 1.5 month other forage (fodder crops, dual-purpose crops, shrubs) and less than 0.5 months of confinement feeding. Additional farmers estimated 4 months per year of in-paddock supplementary feeding. There was a wide range in time spent on stubbles annually, from 9% to 58%, although only 3 of 41 farmers had stock on stubbles more than 5 months of the year. These farmers did not report providing any in-paddock supplementary feeding of stock.

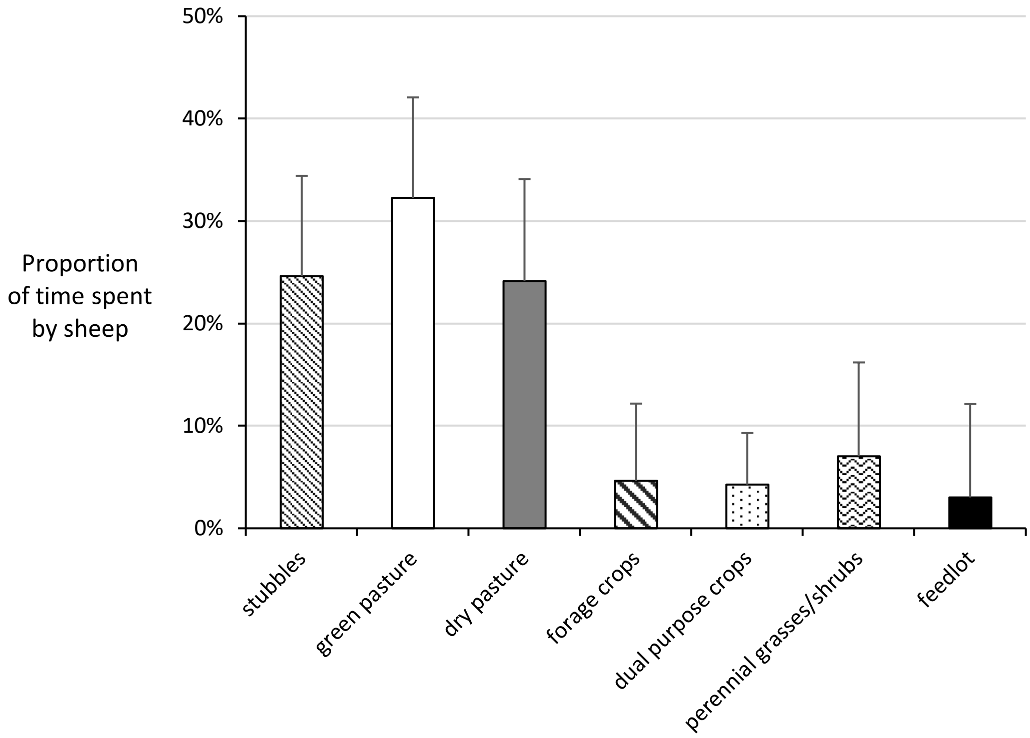


Figure 6. The percentage of time sheep spend grazing by feedbase component in mixed farming enterprises in the Western Australian wheatbelt. Error bars are standard deviation from the mean.

Stubbles are grazed as soon as practically possible after harvest, at this time stubbles are at highest feeding value and as other pastures will have senesced and been depleted by grazing stubbles become an important feed source. Farmers prioritise the value of stubbles and organise their grazing by various flocks according to the performance requirements of livestock. Views expressed by farmers on the relative feeding quality and the intensity of grazing on stubbles of various crop types are summarised in Table 5. In some cases there are clear rules of thumb, for example both lupin and barley stubbles were considered of highest quality. However, farmers had differing views on the feeding quality of wheat, canola and oats. Using a chaff cart to collect canola chaff was considered to improve the value of canola stubble by one farmer. Other than this, little information was provided in relation to chaff pile grazing, which is consistent with other survey data suggesting a lack of knowledge on managing grazing of chaff piles. Results of the differing intensity of grazing stubbles of various crop species were generally consistent, with cereal stubbles grazed heavily while lupin and canola stubbles were grazed lighter except in one case.

Table 5. Perceptions of feed quality and the intensity of grazing on stubble and chaff piles of different crop types.

Stubble type	Feed quality			Grazing intensity	
	High	Medium	Low	Heavy	Light
Wheat stubble	XX	XXXXX	XX	XX	
Barley stubble	XXXXXXXXX	XX		XXX	
Canola stubble	XX	XX	XXX		X
Oat stubble	X		XX		
Lupin/legume stubble	XXXXXXXXXXXXX			X	XXX
Wheat chaff					
Barley chaff					
Canola chaff	X				

Oat chaff		
Lupin/legume chaff		

Field work observations show the utilisation by chaff piles after several weeks of grazing by sheep (Plate 3).

a)  b) 

Plate 3. Chaff piles a) before and b) after grazing by sheep.

Survey results highlighted the prioritisation of stubbles for grazing based on the quality of the stubble and the class of stock. Higher priority stock were allocated to high quality stubbles first, and visa versa. Highest priority stock were lambs, particularly ewe lambs, followed by ewes either prior to or during joining or gestation. One farmer mentioned the use of higher quality stubbles to "build weaners up for summer asap". Older or dry ewes had lower priority and were generally grazed on wheat or canola stubbles.

Soil conservation was mentioned by farmers a number of times. Legume stubbles were mentioned often for light grazing to avoid soil erosion. For example; i) "Less bulk on lupin stubble, lower numbers to reduce erosion", ii) "canola stubble tends to develop wind erosion risk earlier than cereals stubbles", iii) "wheat and barley grazed longer than canola and lupins because of wind erosion", iv) lower numbers [on lupin stubbles] to reduce erosion. In one case increased erosion risk was attributed to plant breeding outcomes "new barley varieties seem to have weak straw that is prone to being knocked over by sheep".

The duration of stubble grazing reported was highly variable (Fig. 7). Across the cohort of farmers surveyed, a wide range of reasons for variability in stubble feeding value were identified, but generally each farmer only offered one or two reasons related to their experiences. One of the main reasons for variable grazing duration was that stubble paddocks may be used to retain stock until seeding, at which time they would be fed supplements once edible material in the stubble is exhausted. Other differences were attributed to i) crop type, ii) summer rain, iii) growing season conditions (e.g., crop yields, frosts), iv) stocking rate, v) harvesting conditions (e.g., header grain losses) and vi) weed burden. For example, barley crop stubbles were reported to last twice as long as canola stubbles. Although this may also be influenced by low ground cover in canola stubbles causing farmers to reduce grazing time to avoid erosion.

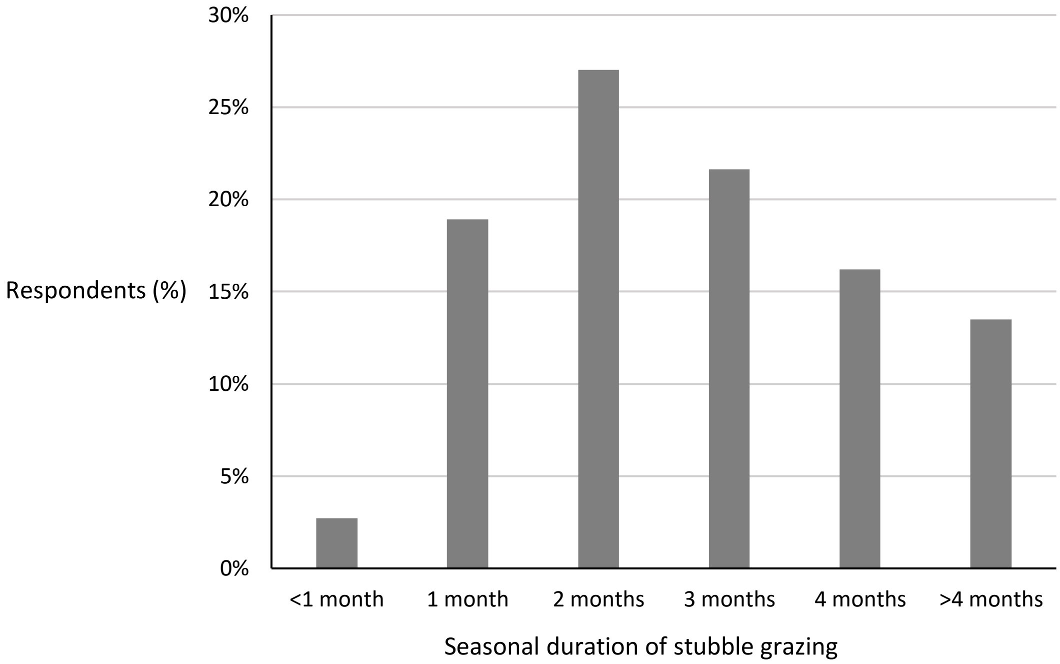


Figure 7. Duration of stubble grazing reported in mixed farms in Western Australia.

A majority of farmers believed that aggregated chaff (piles or lines) were better grazing value for stock compared with traditional spread chaff in standing stubbles (Fig. 8). One farmer thought there was no difference, while almost a quarter said they did not know. This could be as high as 50% of farmers, if we assumed those that didn't answer also did not know.

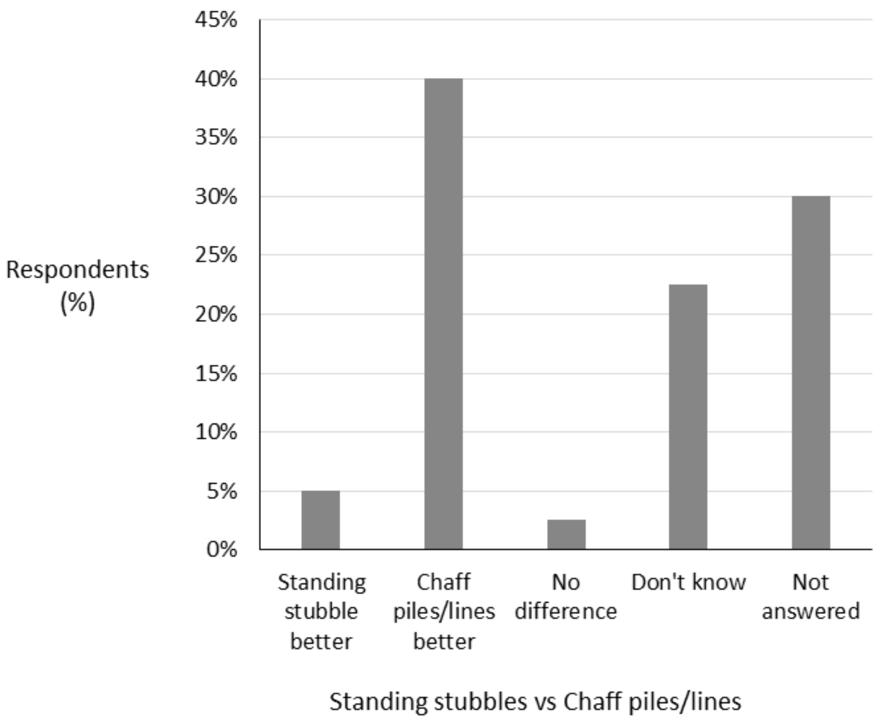


Figure 8. Farmer views on the relative grazing value of standing stubbles with distributed chaff versus chaff aggregated in piles or lines.

Our results showed that a there are a relatively low number of farmers who make quantitative measurements of stock condition while grazing stubbles, with only about one third of farmers measuring weight or condition score of livestock grazing stubbles (Fig. 9). The remainder either used visual assessment or other methods to monitor the performance of livestock grazing stubbles.

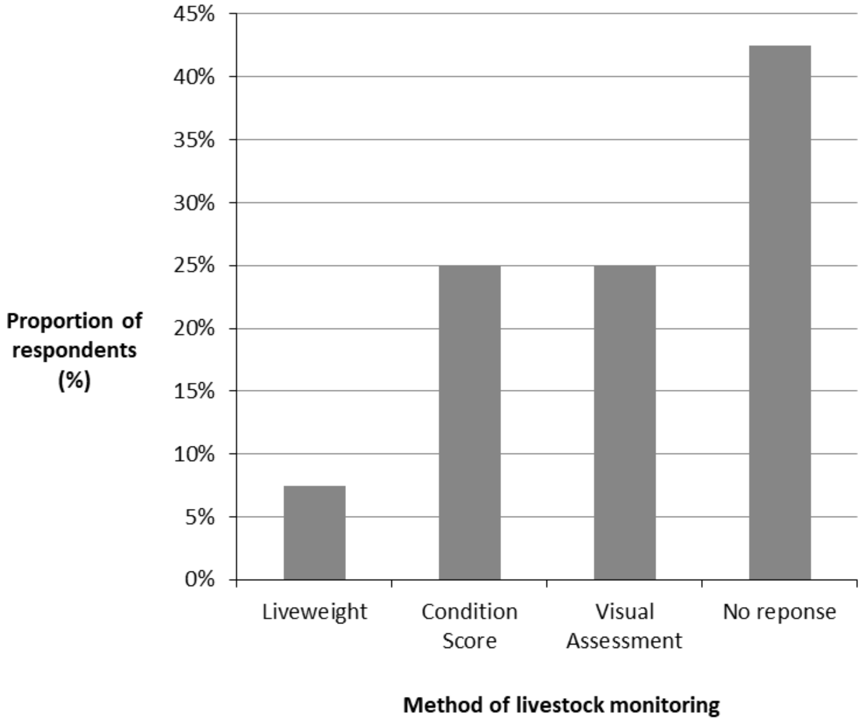


Figure 9. Methods used to monitor livestock performance during stubble grazing.

4.1.3 Future research priorities

Farmers provided a range of feedback in relation to their current limitations to stubble grazing management, and where they found information was lacking. These observations are recorded in Table 6. The need to manage additional machinery during harvest was mentioned several times as a limitation to implementing management practices that might assist grazing stubbles. Correspondingly, other labour intensive activities such as providing water points and monitoring stock objectively were mentioned as obstacles. Another limitation for stubble grazing was soil management, with overgrazing and wind erosion risk noted. The information lacking, corresponding with the objective of this project, was understanding the feed resource. Questions relating to feedbase management were raised consistently such as; How much feed is available? When has feed run out? What are the effects of stubble management and rain on feed quality? and What drives paddock to paddock and year to year variability in the quality of stubbles?

Table 6. Farmer feedback on research priorities for grazing stubbles. Current limitations and areas where information is lacking are identified.

Limitations	Information is lacking
Machinery/infrastructure	*Feed value of stubble*
Capacity to bale chaff to preserve dry feed	When have stubbles run out x 5
Having to tow a chaff cart	Actual feed value of stubble and chaff piles x 3
Cost of machinery for chaff management	Effect of rain on stubble quality
Ability to pick up piles and cart to feedlot	What are the benefits of chaff lining
Provision of water points	Every paddock is different
Time to monitor livestock objectively	What could be put on chaff heaps to increase quality
Other	How much is FOO reduced with a destructor

Wind erosion x 3	*Systems*
Chaff not grazed properly before burning	Grazing and weed seed spread x 2
Stubble doesn't last long	Whole-farm ramifications of various systems
Overgrazing	Any worm problems from sheep grazing around piles
Phomopsis	Work involved in burning stubbles
Headers are too effective	

4.2 Nutritive value of stubbles

4.2.1 Chaff and stubble samples

There were clear differences in the proportion of components (Large, Medium, Small, Seed) depending on the source of chaff, both due to crop type and harvest method. Samples from chaff heaps(Heap) had the lowest proportion of the Large component (main stems), ranging from 8.0 – 12.4%, while OffRow had the highest proportion of Large (40.7-52.0; Fig. 10). The proportion of Small material also tended to highest in Heap for barley and wheat, but was lower in lupins and canola, which had very similar component ratios in Heap material, with a high proportion (approx. 80%) of Medium chaff. The proportion of Seed in chaff samples, i.e. barley heaps (1.8%) and lines (4.3%), was higher than for other crops, however this was not the case for the other sampling classes (OffRow, OnRow and Spread).

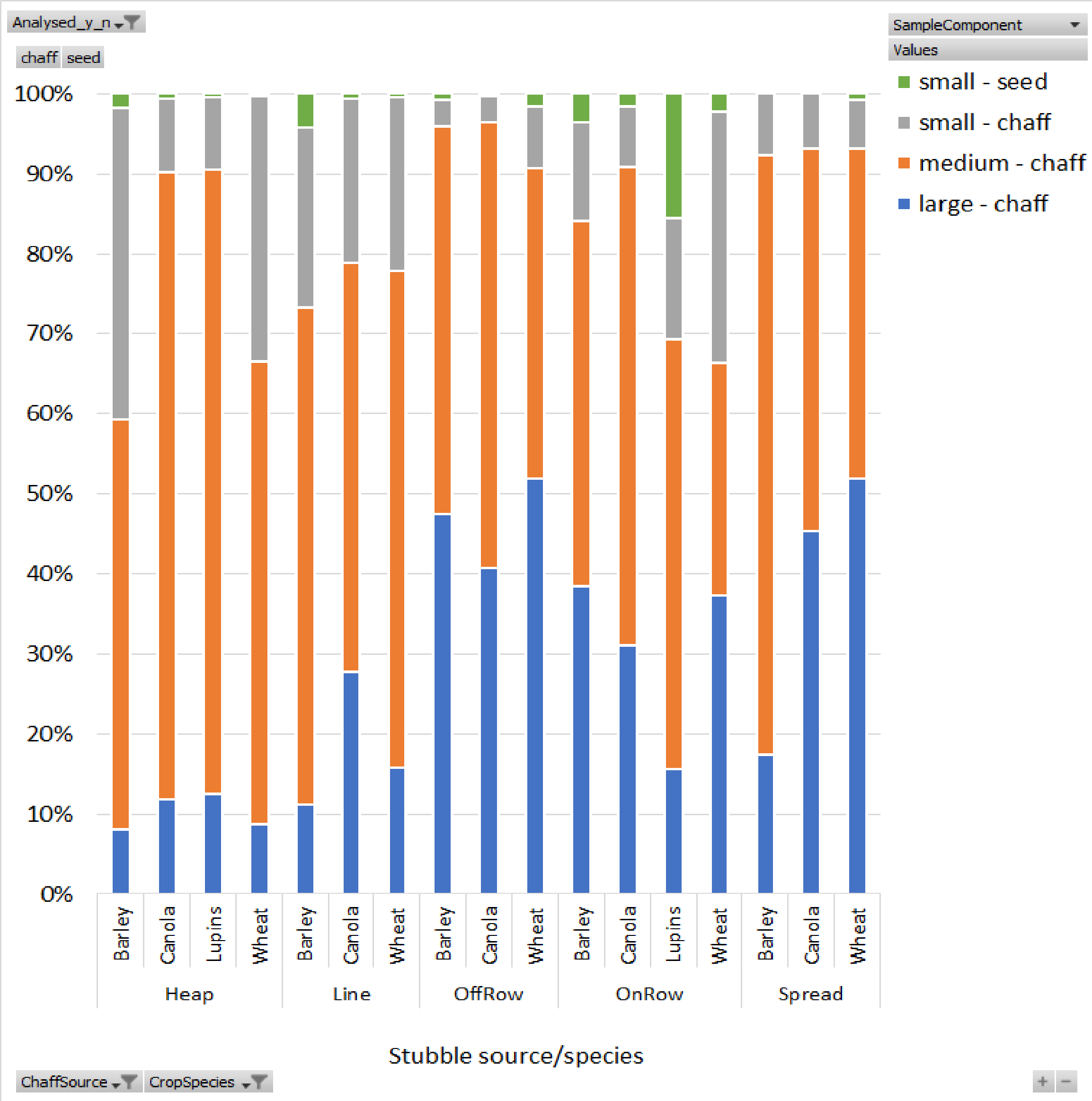


Figure 10. Composition of various stubble sources for 4 grain crops. Proportion of biomass attributed to Large (main stem), Medium, Small and Seed chaff fractions.

Dry matter digestibility (DMD) of the Medium and Small components was markedly higher than Large (main stem). Since the ash content of stubbles is consistent and relatively low, an assessment of DOMD was not included. Combined Small and Medium components were 6.5, 8.3, 9.9 and 14.9 percentage units higher than Large for barley, wheat, canola and lupins, respectively (Fig. 11). Overall, irrespective of the sampling method, DMD (and metabolisable energy calculated from DMD) was reasonably consistent within each species for the Medium component (Table 7, Table 8). There was high variability among the components within species, with about 5% units difference in digestibility between the lower and upper quartiles. This is equivalent to about 1 megajoule (MJ) ME/kg. DMD of the Large and Small components tended to be higher in heaps and lines (header chaff), compared with these components in samples taken using whole biomass quadrat cuts in the field. This difference was approximately 3-6 percent units higher DMD (equivalent to 0.5-1 MJ ME/kg) in Small or Large material in chaff heaps and lines (Table 7, 8). Barley and Lupins tended to be of higher nutritive value across all components compared with Wheat and Canola. Trends and differences in N content among species and components were generally similar to DMD (Table 9).

Table 7. Dry matter digestibility (DMD %) of chaff (Heap, Line) and standing stubble (OnRow, Off Row, Spread) samples, separated into Large, Medium and Small components.

3	Heap	Line	OffRow	OnRow	Spread
Barley					
Large	42.8	40.2	39.9	37.3	
Medium	45.4	46.3	53.5	46.5	43.9
Small	47.2	47.4	46.6	42.7	
Canola					
Large	34.0	32.7	34.0	35.1	31.8
Medium	40.9	38.7	40.0	45.3	43.2
Small	48.3	45.7		41.8	
Lupins					
Large	37.2			33.1	
Medium	46.7			50.1	
Small	44.9			58.4	
Oats					
Large				47.0	40.5
Medium				56.4	
Small					
Triticale, Oats, Rye					
Large		41.7			
Medium		48.1			
Small					
Wheat					
Large	40.5	38.3	31.5	30.3	37.9
Medium	46.5	41.5	44.4	40.9	38.3
Small	49.3	45.5	42.2	42.0	49.5
Total	44.5	42.7	40.1	39.1	39.3

Table 8. Estimate of metabolisable energy content (MJ ME/kg) of chaff (Heap, Line) and standing stubble (OnRow, OffRow, Spread) samples, separated into Large, Medium and Small components.

Crop/component	Heap	Line	OffRow	OnRow	Spread
Barley					
Large	5.7	5.2	5.2	4.7	
Medium	6.1	6.3	7.5	6.3	5.8
Small	6.4	6.4	6.3	5.6	
Canola					
Large	4.1	3.9	4.1	4.3	3.8
Medium	5.3	5.0	5.2	6.1	5.7
Small	6.6	6.1		5.5	
Lupins					
Large	4.7			4.0	
Medium	6.3			6.9	
Small	6.0			8.3	
Oats					
Large				6.4	5.3
Medium				8.0	
Small					
Triticale, Oats, Rye					
Large		5.5			
Medium		6.6			
Small					
Wheat					
Large	5.3	4.9	3.7	3.5	4.8
Medium	6.3	5.4	5.9	5.3	4.9
Small	6.8	6.1	5.6	5.5	6.8
Total	5.9	5.6	5.2	5.0	5.1

Table 9. Crude protein (CP %) of chaff (Heap, Line) and standing stubble (On Row, Off Row, Spread) samples, separated into Large, Medium and Small components.

Crop/component	Heap	Line	OffRow	OnRow	Spread
Barley					
Large	4.4	4.0	3.6	2.8	
Medium	5.3	4.7	5.7	4.6	5.8
Small	6.6	6.2	5.9	4.9	
Canola					
Large	3.7	4.5	2.8	2.7	4.5
Medium	4.6	5.1	2.5	4.0	5.7
Small	5.6	6.4		4.6	
Lupins					
Large	5.5			3.5	
Medium	6.1			6.1	
Small	6.9			9.6	
Oats					
Large				3.4	4.3
Medium				4.5	
Small					
Triticale, Oats,					
Large		5.6			
Medium		5.6			
Small					
Wheat					
Large	4.3	3.3	2.3	1.6	4.8
Medium	4.8	4.1	5.7	3.4	3.6
Small	6.3	4.8	5.3	5.0	5.5
Total	5.5	4.6	4.2	3.4	4.8

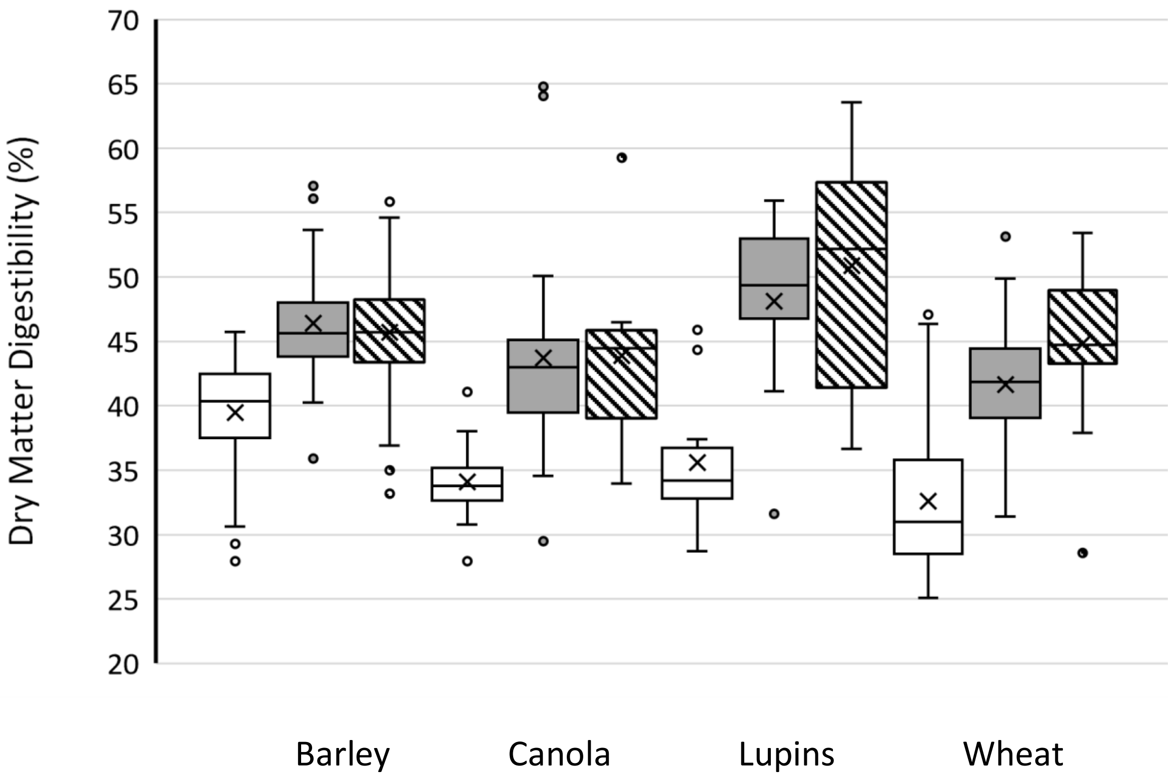


Figure 11. Dry matter digestibility of large (open), medium (grey) and small (diagonal line) components of barley, canola, lupin and wheat chaff collected in the mixed farming region of Western Australia.

Samples were collected from a wide range of commercial grain cultivars, particularly for barley and wheat. This may have been partly the result of our survey sampling method, where farmers may have been more likely to send in different varieties to have them tested. Differences in crop variety produced a large amount of variability in the nutritive value of stubble components (Table 10). However, it is not possible to determine from this study whether these were related to variety, environmental or management factors. This is supported by the large amount of variation within variety that could sometimes be observed. For example, Scepter wheat (Medium particle size) was measured to range from 38.1% to 53.1 % DMD among 6 locations. There is some evidence that there may have been an influence of growing season rainfall in this case, as a negative relationship between nutritive value and growing season rainfall could be observed (Fig. 12). However, specifically designed tests would be needed to adequately test the effects of crop genetics, growing environment and crop/stubble management (GxExM) interactions on forage nutritive value. Similarly, we observed high variability in the proportion of Seed in stubble samples among varieties, but equally it is was not possible to account for possible effects of seasonal and harvesting conditions (Table 11).

Table 10. Dry matter digestibility (DMD %) of barley, canola, lupin and wheat varieties samples, sorted by Large, Medium and Small particle size.

	Heap			Line		
Crop Variety	**Large**	**Medium**	**Small**	**Large**	**Medium**	Small
Barley						
Bass	42.1	47.3	48.5			
Compass					49.9	
Flinders				41.1	46.5	47.0
Granger	45.7	47.4	44.1			
Latrobe	41.1	43.5	45.4		47.2	
Litmus	43.3	42.3	50.0			
Planet					47.9	48.5
Rosalind				36.4	43.3	47.3
Spartacus		49.3	52.5	43.8	45.7	47.7
Canola						
Bonito	34.0	40.9	48.3			
Cobbler				33.6	39.4	
Stingray				31.7	38.0	45.7
Lupins						
Gunyidi	45.9	55.9				
Jennabillup	44.3	53.7	40.6			
Mandellup	37.4	47.9	41.4			
Wheat						
Arrino				40.6	45.3	
Bonnie Rock		41.3	43.2			
Emu Rock				37.6	44.6	
Longsward	37.4	48.3	50.3			
Mace				37.7	39.1	44.7
Ninja				33.9	36.2	
Scepter	39.3	47.5	51.0	39.9	41.4	46.1
Wylie				39.5	43.0	44.3

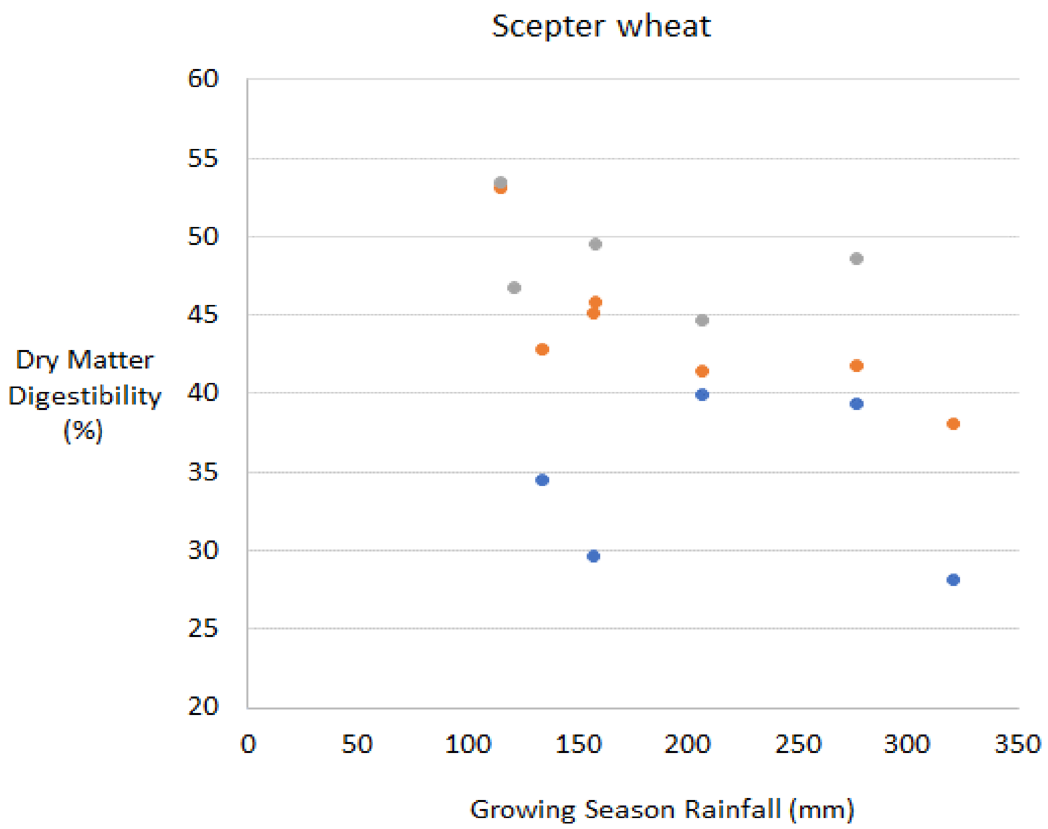


Figure 12. Relationship between dry matter digestibility (DMD %) and Growing Season Rainfall (mm) for Scepter wheat for Large (●), Medium (●) and Small (●) particle size stubble components.

Table 11. Proportion of Seed (%) in barley, canola, lupin and wheat crop samples, by variety and sampling method (Heap, Line, On Row and Spread).

Crop Variety	Heap	Line	On Row	Spread
Barley				
Bass	3.3			0.0
Compass		17.8		
Flinders		2.1		
Granger	0.5			
Latrobe	0.4	7.8		
Litmus	1.1			
Planet		2.0		
Rosalind		1.5		
Spartacus	0.0	2.4		
Canola				
Bonito	0.5			0.0
Cobbler		1.8		
Hyola 404			1.5	
Stingray		0.2		0.0
Lupins				
Gunyidi	0.0			
Jennabillup	0.9			
Mandellup	0.8			
Wheat				
Arrino		0.6		
Bonnie Rock	1.9			
Emu Rock		0.4		
Longsward	0.0			
Mace		0.3		

Ninja		0.5		
Scepter	0.1	0.5	7.8	1.0
Wylie		0.0		

There was a clear positive relationship between crude protein content and dry matter digestibility/ME in the chaff samples, across all components, with the exception of canola (Fig. 13). Overall, stubble and chaff were 1 unit higher in crude protein for every 2 to 3 units of DMD, with a y-axis (DMD) intercept ranging from 18.7 (Medium lupin) to 37.7 (Medium canola). For barley, lupins and wheat, Large and Small components had more closely related protein and energy, compared with Medium. This may suggest that Medium material is more heterogenous, consisting of a wider range of plant components. However, the consistent relationship in Small particle samples across all crops was surprising since non-crop components (e.g. weed seeds) were common. The positive relationship between protein and energy has also been observed in senesced annual legume dry matter (Thomas et al. 2010). No positive trend between digestibility and crude protein existed in canola stems (Fig. 13). The relationship between nutritive value and growing season rainfall was explored, but no trends were apparent (Fig. 14). This is likely due to the complex GxExM interactions likely to be driving stubble nutritive value.

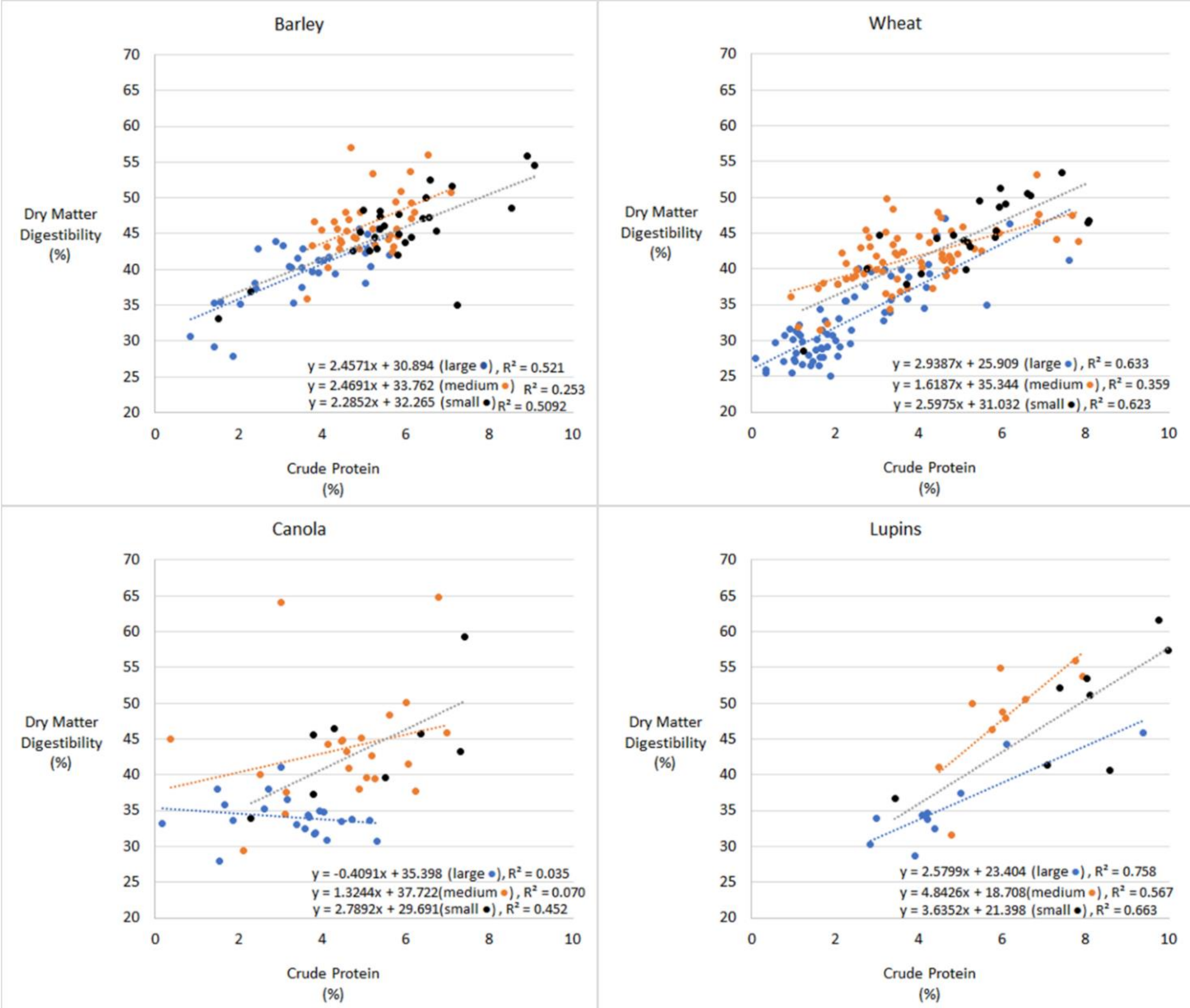


Figure 13. Relationship between DMD and N in chaff among three component fractions and four crop species.

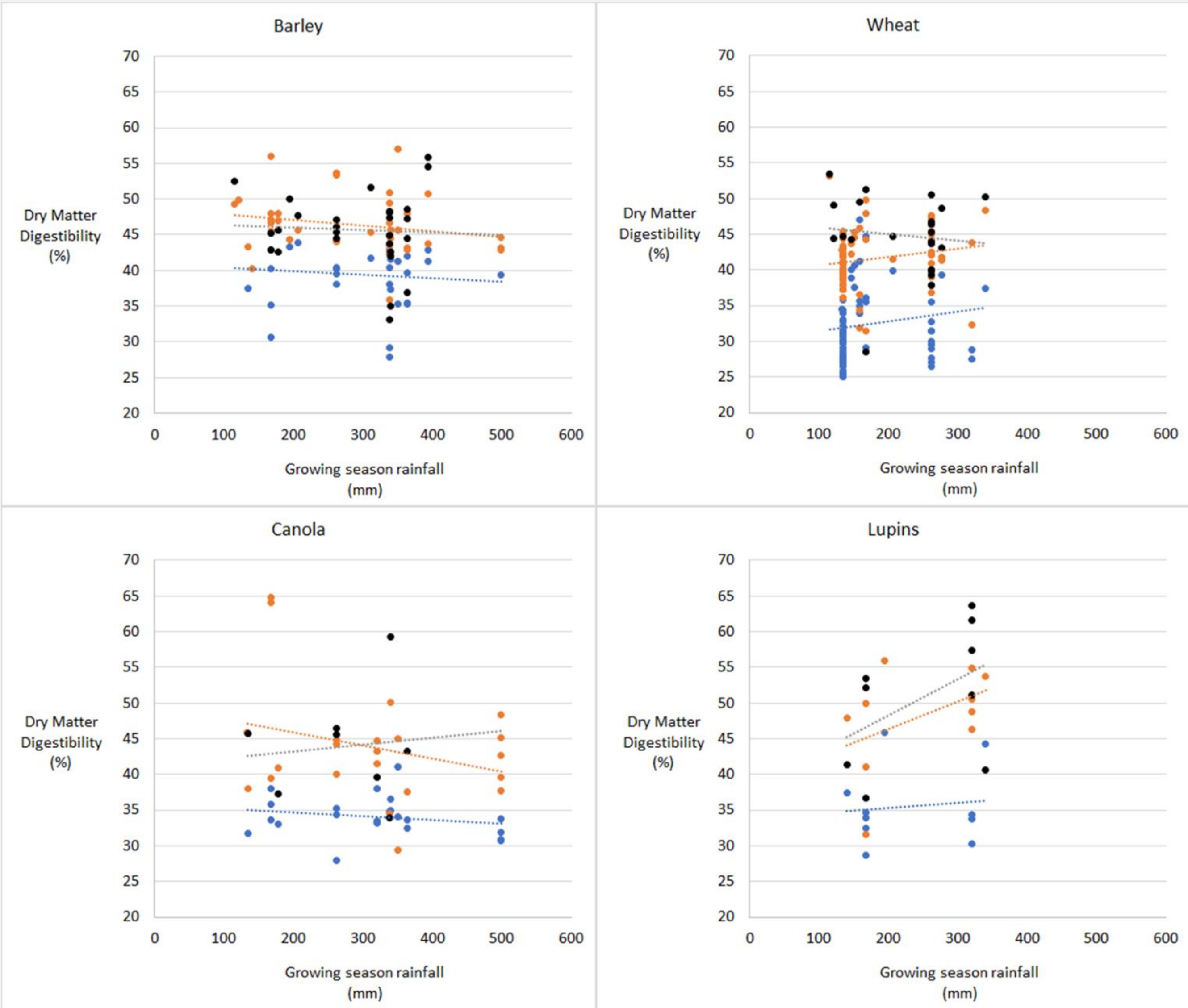


Figure 14. Relationship between rainfall (mm) and dry matter digestibility (%) among three component fractions and four crop species.

In general, the DMD of one component did not predict well the other components (Table 12). The reason that the chemical composition of the main stem does not correlate well with, for example, Medium leaf and stem is not clear but possibly they respond differently to the various environmental and management drivers.

Table 12. Correlation matrix for DMD among stubble components (Large, Medium and Small) for each crop species.

	Large	Medium	Small
Barley			
Large	1		
Medium	0.064	1	
Small	0.209	0.037	1
Wheat			
Large	1		
Medium	0.17	1	
Small	0.319	0.716	1
Canola			
Large	1		
Medium	0.122	1	

Small	0.02	0.341	1
Lupins			
Large	1		
Medium	0.459	1	
Small	0.103	0.252	1

4.2.2 Varietal comparison of nutritive value

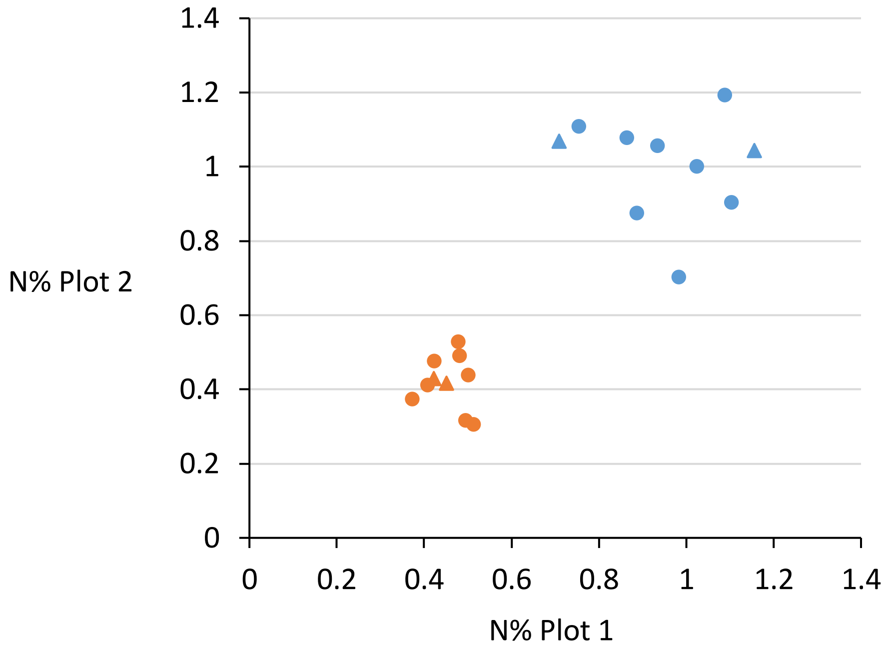
1. Crop variety trial

Our analysis of samples collected from a crop variety trial found no cultivar effects, and a positive relationship between the nutritive value of plots containing 8 wheat and 2 barley cultivars grown at the same location (Fig. 15). This suggests that growing conditions such as soil, environment and management have a greater bearing on the nutritive value of the stem and leaf components of stubble than cultivar differences. There was a positive relationship between nitrogen and metabolisable energy content among the 10 cultivars, which suggests that environmental conditions where stubble nitrogen (N) content is higher will be reflected in higher metabolisable energy content, at a rate of 0.23 MJ ME/kg DM per 0.1% increase in N for the leaf component (Fig. 16).

2. Project sample comparison

We conducted an analysis of previously reported nutritive value data, using a linear model-based statistical analysis, we identified some significant differences among cultivars (e.g. lower N content in Mace wheat, and higher N content in 2 lupin cultivars; Table 13). The average N content of the Medium component of Scepter wheat was 0.82 (ranging from 0.73 to 1.15), which was one of the highest of this component in wheat, remained within 1 standard deviation of the mean for Medium wheat (0.62 ± 0.25). Based on these, we have concluded that effects of growing environment and crop management will likely outweigh cultivar effects in most cases. This also means that there is an opportunity to better understand stubble quality based on growing conditions.

a)



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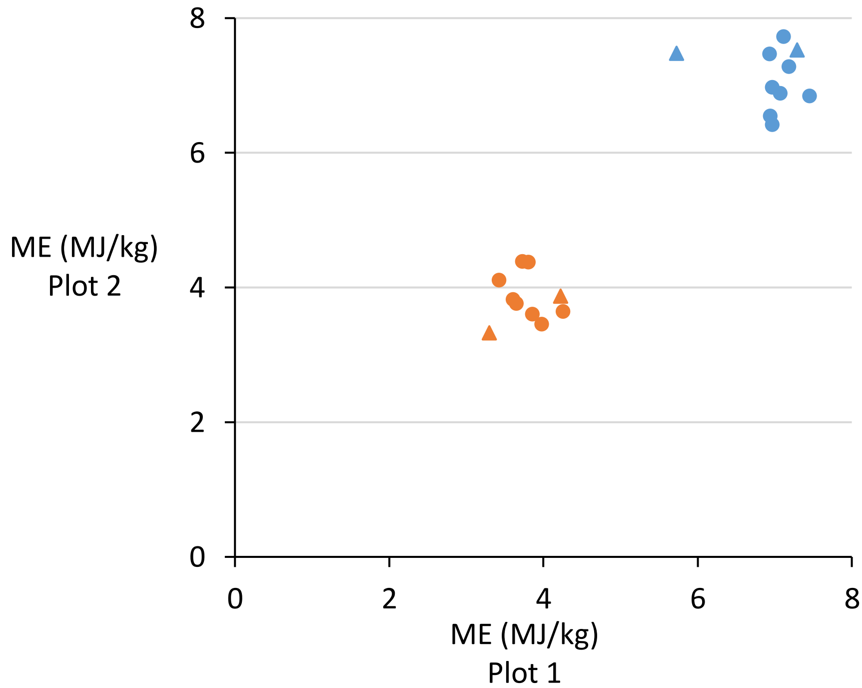

Figure 15. Scatter plots for a) nitrogen (%) and b) metabolisable energy (MJ/kg) content of stubble stem (red) and leaf (blue) in a range of wheat (●) and barley (▲) cultivars.

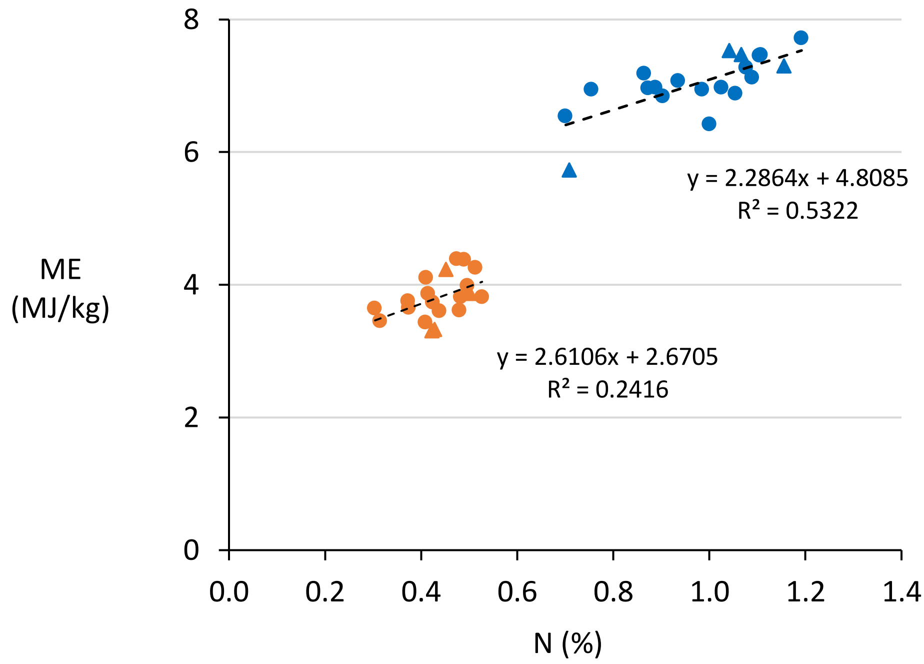

Figure 16. Relationship between nitrogen (%) and metabolisable energy (MJ/kg) content of stubble stem (red) and leaf (blue) in a range of wheat (●) and barley (▲) cultivars (y=ax+b, R^2).

Table 13. Statistical analyses (linear model) of the nutritive value of stubble samples a) varietal comparison of N content in wheat, barley, lupins and canola stubbles, b) species comparison of N content in wheat, barley, lupins and canola stubbles, c) species comparison of ME content in wheat, barley, lupins and canola stubbles and d) species comparison of ME content in stem and leaf components.

a) Varietal Comparision N - ref-CropVariety_Arrino

	Estimate	Std. Error	t value	Pr(>|t|)	
Wheat					
(Intercept)	0.68850	0.13719	5.019	1.64e-06	***
Bonnie Rock	0.07550	0.23762	0.318	0.751183	
Emu Rock	-0.15100	0.19401	-0.778	0.437779	
Longsward	-0.08300	0.19401	-0.428	0.669486	
Mace	-0.33595	0.13932	-2.411	0.017255	*
Ninja	-0.16450	0.19401	-0.848	0.398031	
Scepter	-0.02264	0.14666	-0.154	0.877537	
Wylie	-0.12850	0.16802	-0.765	0.445755	
Barley					
Bass	0.09670	0.15841	0.610	0.542634	
Flinders	0.09363	0.15338	0.610	0.542635	
Granger	0.10100	0.16802	0.601	0.548787	
Latrobe	0.18036	0.15556	1.159	0.248361	
Litmus	-0.04717	0.17711	-0.266	0.790411	
Planet	0.30650	0.23762	1.290	0.199329	
Rosalind	-0.10200	0.16802	-0.607	0.544842	
Spartacus	0.10250	0.17711	0.579	0.563765	

Canola					
Bonito	0.06850	0.16802	0.408	0.684160	
Cobbler	0.14350	0.19401	0.740	0.460824	
Hyola404	-0.08967	0.15841	-0.566	0.572324	
Stingray	0.09223	0.14914	0.618	0.537373	
Lupins					
Gunyidi	0.68300	0.19401	3.520	0.000591	***
Jennabillup	0.43500	0.19401	2.242	0.026611	*
Mandellup	0.19950	0.19401	1.028	0.305687	

b) lm(formula = Nitrogen_pc ~ CropSpecies, data = rawData)
Coefficients: ref-CropSpeciesBarley

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	0.69256	0.03078	22.498	< 2e-16	***
CropSpeciesCanola	-0.06938	0.04911	-1.413	0.15894	
CropSpeciesLupins	0.16954	0.06457	2.626	0.00915	**
CropSpeciesWheat	-0.19735	0.03770	-5.234	3.38e-07	***

c) lm(formula = MetabolisableEnergy_MJkg ~ CropSpecies, data = rawData)
Coefficients: ref-CropSpeciesBarley

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	5.7027	0.1407	40.533	< 2e-16	***
CropSpeciesCanola	-0.7212	0.2245	-3.213	0.00148	**
CropSpeciesLupins	-0.2175	0.2951	-0.737	0.46176	
CropSpeciesWheat	-1.0169	0.1723	-5.901	1.1e-08	***

d) lm(formula = MetabolisableEnergy_MJkg ~ SampleComponent, data = rawData)
Coefficients: ref- SampleComponentlarge

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	4.26489	0.08429	50.60	<2e-16	***
SampleComponentmedium	1.53992	0.11789	13.06	<2e-16	***

*Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*

3. High and low preference chaff comparison

Chaff samples were collected from chaff piles of 2 barley varieties (Bass and Spartacus) from a mixed farm near Pingelly, Western Australia. The livestock producer observed a strong preference by sheep for Spartacus over Bass barley chaff heaps. The results of testing for nutritive value are shown in Table 14. Bass heaps had a high proportion of barley grains, while there was little difference in the ME and crude protein content of the other chaff components. Except that the ME and protein content of the large component (main stem) was substantially higher in Bass compared with Spartacus, however this made up a very small proportion of the chaff. Based on this, it is difficult to understand why sheep may have preferred Spartacus, as a preference for the piles with a high grain content would be expected.

Table 14: Nutritive value and component proportions (Large, Medium, Small and Grain) of Bass and Spartacus barley chaff collected from chaff heaps.

Component/barley variety	ME_MJ/kg	CP_%	NDF_%	Proportion_%
Large				
Bass	6.4	5.0	70.6	5.2%
Spartacus	5.4	3.8	79.7	8.6%
Medium				
Bass	6.9	5.8	70.8	34.4%
Spartacus	6.8	6.0	71.6	35.2%
Small				
Bass	7.5	7.3	68.3	51.4%
Spartacus	6.8	7.2	71.9	53.3%
Grain				
Bass				8.9%
Spartacus				2.9%

4.3 Chaff feeding animal house experiment

4.3.1 Intake

The daily intake by young and mature ewes offered 9 different wheat chaffs, with or without a 200 g/day lupin supplement, are shown in Table 15. The daily intake of wheat chaff was the same for young compared with mature ewes (733 *v* 682 g DM/head/day; P=0.295; Table 15), and there was no overall effect of lupin supplementation on ewe's intake of chaff (P=0.873; Table 15). On a metabolic bodyweight basis, the DM intake of young ewes was 36% higher than mature ewes (37.7 *v* 27.8 g DM/kg liveweight/day; P<0.001). In general, intakes among mature ewes was more variable than that of the young ewes (Standard Deviation 198 *v* 99 g DM/head/day, respectively). This result was unexpected, as the more experienced ewes that would have had more experience grazing chaff and stubbles might be expected to adjust to the new diet more readily.

Chaff intake varied among the 9 chaff's that were offered, ranging from 617 to 857 g DM/head/day, but intake of each chaff across the sheep treatment groups was consistent. Chaff intake did not appear to correspond with selectivity, for example Chaff 1 and 6 were eaten most selectively, but these were relatively low and high intake by sheep, respectively.

Table 15. Dry Matter Digestibility (DMD), Crude Protein (CP) and Intake (g DM/ewe/day) of wheat chaff by young and mature Merino ewes, with (+ lupins) or without (- lupins) a 200 g/day lupin supplement. Values are means ± standard error.

	Chaff nutritive value		Wheat chaff intake (g DM/ewe/day)			
	DMD	CP	Mature ewes		Young ewes	
	(%)	(%)	+ lupins	- lupins	+ lupins	- lupins
Chaff 1	44.2	4.5	613 ± 74	449 ± 91	665 ± 39	554 ± 83
Chaff 2	44.0	5.0	739 ± 124	784 ± 137	784 ± 49	907 ± 36
Chaff 3	46.5	5.5	667 ± 122	837 ± 32	713 ± 66	749 ± 46
Chaff 4	46.1	5.7	743 ± 68	682 ± 34	811 ± 35	755 ± 88
Chaff 5	45.6	4.5	727 ± 73	700 ± 73	787 ± 48	740 ± 68
Chaff 6	45.4	6.3	783 ± 80	718 ± 105	853 ± 52	794 ± 60
Chaff 7	44.3	4.7	517 ± 103	588 ± 104	666 ± 36	619 ± 58
Chaff 8	44.5	7.2	700 ± 97	730 ± 46	716 ± 75	798 ± 79
Chaff 9	45.3	4.4	670 ± 103	613 ± 104	639 ± 88	631 ± 49

Mean	45.1	5.3	684 ± 32	678 ± 30	737 ± 20	727 ± 24

4.3.2 Diet selection

There were significant effects of both sheep class (mature or young ewe; P=0.005) and lupin supplementation (P= 0.006). Young ewes selected a higher digestibility diet that than older ewes, compared with what was offered, as seen with the associated change in the quality of the diet refused of -1.55 *v* -0.79 %units DMD, respectively. Ewes offered lupins were also more selective than those offered chaff by itself (change in diet refused compared with offered -1.54 *v* -0.79 %units DMD for +lupins *v* -lupin groups). It seems feasible that sheep offered lupins stimulated searching through the feed to find lupins resulting in the greater selectivity in the chaff components selected. There was no significant chaff x lupin interaction (P=0.364). The most selective group (young ewes supplemented with lupins) had refusals that were 1.79 %units lower than that of the chaff being offered, meaning they were the most selective cohort (Table 16a). The young ewes were familiar with eating lupins and as they are still growing would have been motivated to increase their protein intake. Overall selectivity also depended on the chaff offered, and varied from 0.4 %units for Chaff 1 and 6 to 2.5 %units for Chaff 2 (Table 16b). The difference in selectivity among the chaffs was not unexpected, since composition of the difference chaffs would be affected by different growing conditions and harvest methods (e.g. header height). The difference in quality between the chaff offered and what was eaten was lower than we expected, given the motivation and ability of sheep to select higher quality components. What may have been lacking is the capacity of sheep to be selective, as their may not have been enough variability among the stubble components. Although the quality of main stems is about 10 % units lower than other stubble components, the main stem generally makes up only a small proportion of wheat chaff (~10%, see Figure 10).

Table 16. Sheep class (Mature or Young ewe) and supplementation (+lupin or -lupin supplement, 200 g/head/day lupins) effects on the digestibility and crude protein content of the chaff refused (not selected) shown as a) aggregated data or b) separated by the 9 sources of wheat chaff offered.

a)

Treatment	Chaff Intake DM (g)	Chaff offered DMD (%)	Chaff refused DMD (%)	Chaff offered CP (%)	Chaff refused CP (%)
Mature Ewe					
-lupin	742	45.1	44.8	5.28	6.10
+lupin	740	45.1	43.8	5.28	5.66
Young Ewe					
-lupin	783	45.1	43.8	5.28	5.81
+lupin	788	45.1	43.3	5.28	5.50
Mean	**763**	**45.1**	**43.9**	**5.28**	**5.77**

1.
2. b)

Treatment and chaff	Chaff Intake DM (g)	Chaff offered DMD (%)	Chaff refused DMD (%)	Chaff offered CP (%)	Chaff refused CP (%)
1	**617**	**44.2**	**43.8**	**4.53**	**4.89**
Mature	**576**	**44.2**	**44.4**	**4.53**	**4.76**
-lupin	494	44.2	45.0	4.53	5.09
+lupin	658	44.2	43.8	4.53	4.44
Young	**658**	**44.2**	**43.2**	**4.53**	**5.01**
-lupin	603	44.2	43.5	4.53	5.27
+lupin	714	44.2	42.8	4.53	4.76
2	**857**	**44.0**	**41.4**	**4.88**	**5.48**

Mature	**818**	**44.0**	**42.1**	**4.88**	**5.62**
-lupin	840	44.0	43.1	4.88	5.59
+lupin	795	44.0	41.1	4.88	5.65
Young	**897**	**44.0**	**40.8**	**4.88**	**5.35**
-lupin	964	44.0	40.0	4.88	5.56
+lupin	830	44.0	41.6	4.88	5.13
3	**790**	**46.5**	**45.3**	**5.47**	**6.14**
Mature	**801**	**46.5**	**45.7**	**5.47**	**6.05**
-lupin	893	46.5	46.7	5.47	6.34
+lupin	709	46.5	44.6	5.47	5.76
Young	**778**	**46.5**	**44.9**	**5.47**	**6.23**
-lupin	799	46.5	44.5	5.47	6.19
+lupin	758	46.5	45.3	5.47	6.28
4	**819**	**46.1**	**45.2**	**5.93**	**6.25**
Mature	**799**	**46.1**	**45.1**	**5.93**	**6.44**
-lupin	789	46.1	45.1	5.93	6.52
+lupin	810	46.1	45.0	5.93	6.35
Young	**840**	**46.1**	**45.2**	**5.93**	**6.06**
-lupin	811	46.1	45.4	5.93	6.35
+lupin	868	46.1	45.1	5.93	5.76
5	**793**	**45.6**	**44.4**	**4.63**	**5.29**
Mature	**770**	**45.6**	**44.8**	**4.63**	**5.59**
-lupin	761	45.6	45.0	4.63	6.08
+lupin	780	45.6	44.5	4.63	5.10
Young	**815**	**45.6**	**44.0**	**4.63**	**5.00**
-lupin	795	45.6	44.5	4.63	4.83
+lupin	836	45.6	43.4	4.63	5.17
6	**853**	**45.4**	**45.0**	**5.93**	**6.11**
Mature	**819**	**45.4**	**45.2**	**5.93**	**6.28**
-lupin	788	45.4	45.9	5.93	6.50
+lupin	850	45.4	44.5	5.93	6.05
Young	**886**	**45.4**	**44.8**	**5.93**	**5.93**
-lupin	855	45.4	45.3	5.93	6.01
+lupin	917	45.4	44.4	5.93	5.86
7	**649**	**44.3**	**43.0**	**4.53**	**5.21**
Mature	**607**	**44.3**	**43.4**	**4.53**	**5.27**
-lupin	649	44.3	42.7	4.53	5.47
+lupin	566	44.3	44.1	4.53	5.07
Young	**691**	**44.3**	**42.6**	**4.53**	**5.15**
-lupin	669	44.3	43.4	4.53	5.32
+lupin	713	44.3	41.9	4.53	4.98
8	**809**	**44.5**	**43.1**	**7.01**	**7.18**
Mature	**791**	**44.5**	**43.8**	**7.01**	**7.29**
-lupin	809	44.5	44.3	7.01	7.46
+lupin	772	44.5	43.3	7.01	7.11
Young	**828**	**44.5**	**42.4**	**7.01**	**7.07**
-lupin	877	44.5	42.3	7.01	7.59
+lupin	779	44.5	42.4	7.01	6.56
9	**683**	**45.3**	**44.2**	**4.58**	**5.38**
Mature	**689**	**45.3**	**44.4**	**4.58**	**5.63**
-lupin	659	45.3	45.2	4.58	5.89
+lupin	719	45.3	43.5	4.58	5.38
Young	**678**	**45.3**	**44.0**	**4.58**	**5.13**
-lupin	674	45.3	45.3	4.58	5.21
+lupin	681	45.3	42.7	4.58	5.05
Mean	**763**	**45.1**	**43.9**	**5.28**	**5.77**

4.3.3 Liveweight gain

The liveweight gain (LWG) of the ewe groups during the period that they were feed the chaff treatment diets are reported in Table 17. However, the results of a statistical analysis found that no significant differences in liveweight gain between sheep class (P=0.432) and the provision or not of the lupin supplement (P=0.114). The numerically higher LWG in supplement fed groups for both mature and young ewes showed a statistical trend, and are consistent with the improved weight gain (or less weight loss) that would be expected. However, the high variability in chaff intake meant that the error was too high to confirm the numerical apparent treatment effects. Other research has demonstrated the value of supplementing stubbles with high protein and energy feeds such as lupins, so the result was most likely just the limitation of high variability in liveweight measurements (can be affected by patterns of drinking and urination etc.) and the short period of the feeding study (as a rule of thumb, at least 4 weeks is needed with treatment group size of 20 make measure treatment effect). Given the very low quality of the diets and associated sheep weight loss, it is unlikely we would have been granted approval to run the study for longer.

Table 17. Liveweight gain (g/head/day) of mature or young ewes offered chaff with or without supplementation of 200 g/head/day of lupins (Lupins).

	Liveweight gain (g/head/day)	
Class	+Lupins	-Lupins
Young ewe	-51	-121
Mature ewe	-81	-176

4.3. Calculation of suggested energy supplementation

Results presented in the previous section highlight that while chaff is a potentially valuable source of summer feed, it's low quality means that supplementary feeding is an essential consideration. The lack of statistical significance in our weight gain results means that these results should be considered with some caution. However, based on numerical trends in liveweight responses, which agree with a comparative assessment with ruminant nutrition modelling, we can calculate that the chaff diets offered should meet maintenance feeding requirements (x-int = 0) of mature ewes at 371 g/head/day and of young ewes at 346 g/head/day using lupins as a supplement (Fig. 17). Lupins was used in this example, as its high protein content and relatively low cost means that it makes an excellent complement for low quality diets such as header chaff. Other pulse grains are likely to have similar complimentarity given that the young ewes are still growing, provision of lupin supplement to achieve at least 50 g/head/day liveweight gain should be considered, which would require an estimated 488 g/head/day of lupins. This level of lupin supplementation is potentially higher than typical in the industry and may exceed protein requirements, which would also result in a higher feeding cost – so this scenario should simply be considered as an estimation of the equivalent amount of energy supplementation to achieve a liveweight gain target.

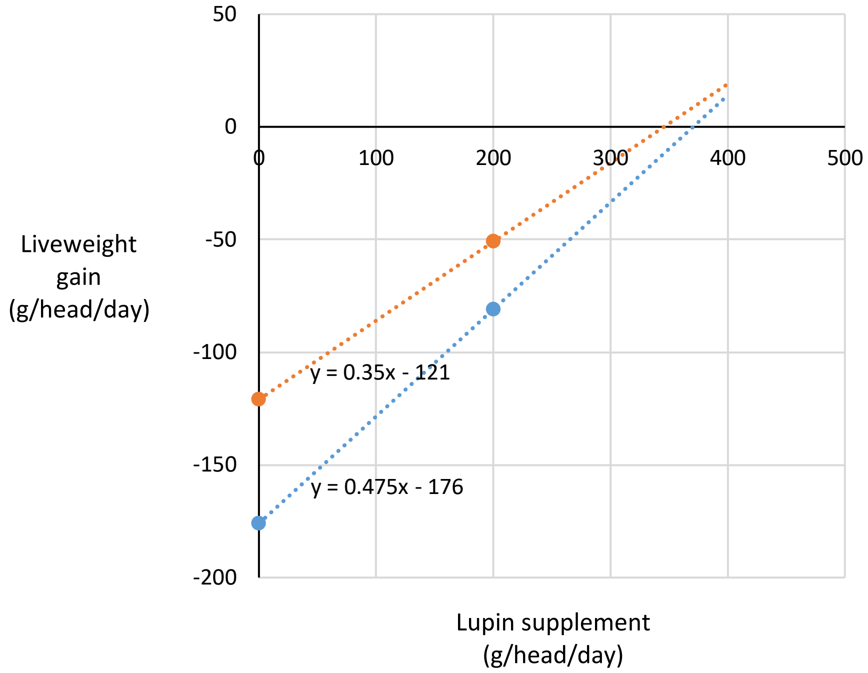

Figure 17. Trends in liveweight gain associated with supplementary feeding of lupins, and an estimate of maintenance level of lupins required based on data from mature (●) and young ewes (●) in a wheat chaff feeding experiment.

5. Discussion

5.1 Stubble management and grazing practices

Farmers identified a lack of quantitative knowledge on the feeding value of stubbles as a major management constraint, and rely on their own observations and experience to guide their feedbase management decisions. When asked what information was lacking, the following quotes reflect the responses; i) When stubbles have run out of value, ii) "Actual feed value of stubble", iii) "Nutritional value of stubbles, how can sheep get the best out of stubbles" and iv) "Need better idea of the feed value of the different stubble types, and across seasons".

A range of factors that were thought to affect stubble feeding value were identified, and have been compiled from survey monkey using the word cloud function (Fig. 18). Some key words identified in the word cloud included season, crop, type, rain and paddock. The survey responses revealed that farmers have more confidence that some factors affect feeding value (e.g. type of crop) compared with others (e.g. seasonal conditions or chaff management at harvest). In general, farmers felt that it was difficult to predict the grazing value of a stubble when making grazing management decisions. One farmer highlighted some of these issues based on their observations and experience stating "Wheat is very poor value. Barley is almost always good as there is always some grain loss, plus the straw is favourable. Canola is quite variable, and I don't know why. Oats can vary a lot [and feed value is] dependant on variety and length of season". On the other hand, there were some farmers who found that wheat stubbles were moderate to high value. These differences may be attributable to locations (hence seasonal conditions), harvesting practices, sheep management practices and whether there are alternative stubbles to allow comparisons (e.g. pulse crops).

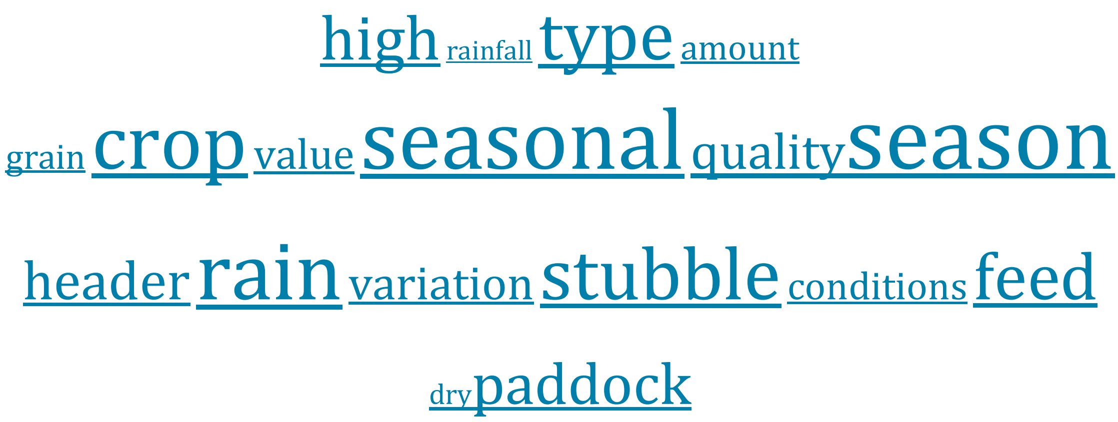

Figure 18. Word cloud association of the limitations to management of grazing of chaff piles or standing stubbles identified by farmers.

Farmers had differing views on the feeding quality of wheat and canola. This may be partly attributed to the different farming systems, for example, farmers who do not grow lupins or barley (high quality stubbles) may consider wheat stubbles to be of higher value and allocated them to priority classes of livestock. In addition, we know that the feeding value of stubbles varies depending on seasonal and harvesting conditions, so experiences when grazing stubbles may differ for this reason. Our stubble sample analyses have helped to inform these hypotheses. Results of the survey showed consistent prioritisation of stubbles for grazing based on the nutritive value of the stubble and the class of stock. Higher priority stock were allocated to high quality stubbles first, and vise versa. Highest priority stock were lambs, particularly ewe lambs, followed by ewes either prior to or during joining or gestation. Older or dry ewes had lower priority and were generally grazed on wheat or canola stubbles, or after a higher priority stock class had been moved from a paddock.

In addition to not being able to predict the feed value of stubbles, generally farmers lacked quantitative information on the performance of animals grazing stubbles and relied on intuition and visual assessments. Only 7% of farmers measured the liveweight of stock, and 25% condition scored. These measurements are also likely to be restricted to priority classes of stock, such as lambs. This result is not surprising as physical measurements are highly labour intensive and require access to facilities and equipment such as yards and weighing scales. In future, cost effective systems of walk-over-weighing and animal wearable sensors may automate collection of this data making it viable for many more farmers to adopt. A 2016 farmer survey for a CSIRO project investigating GPS tracking of stock on stubbles found a similar result, where 8% of farmers measured liveweight and 15% measured condition score of sheep grazing stubbles and indicates reluctance by a majority of livestock farmers to adopt recommended monitoring practices, despite them being heavily promoted in recent times to improve management practices.

Management of chaff and stubbles at harvest was another thing in the forefront of farmer's minds. Many different methods of chaff management were implemented, as reported in Fig. 5. In terms of livestock production, it was generally thought that aggregating chaff in lines, windrows or piles/heaps was advantageous to stock grazing stubbles, although a large proportion stated that they were unsure whether or not this was the case. However, there are also important considerations for cropping. There was a significant concern about the management of stubble trash when seeding the paddock the following year, which resulted in farmers burning stubbles prior to seeding. Concerns about the effects of stubble burning on soil carbon, soil nutrients and the risk of soil erosion are often raised in relation to this issue.

5.2 Nutritive value of stubbles and chaff

5.2.1. Grazing value of stubbles

The results of stubble sampling and measurement of nutritive value highlights the range of genetic x environment x management (GxExM) interactions that exist, creating a high level of variability in nutritive value of stubble and chaff components. There were consistent differences between the 3 stubble components (Large, Medium and Small) analysed. In particular, the Small and Medium components were 6.5, 8.3, 9.9 and 14.9 percentage units higher in dry matter digestibility than Large (main stem) for barley, wheat, canola and lupins, respectively. However, we also found poor correlations between nutritive value characteristics among the components. This suggests effects of environmental and management factors on the various components through different biological mechanisms.

The overall average results are consistent with those previously reported for stubble nutritive value, particularly by Pearce (1979). Our analyses confirm that overall straw and chaff is a low-quality feed, with a typical digestibility range of 40-50% (total aggregated range 31.8-58.4; Table 4), or 5-7 MJ/kg ME. However, the high variability in quality among the samples and components would suggest that the variability that was observed would be of practical importance for livestock production. So, where possible, information on the nutritive value of the stubble or chaff of interest should be quantified when preparing livestock rations. Purser draws attention to the significance of the grain (which was not measured in their study), and also variability in components and the capacity of stock to select. Our results support the conclusion of Purser that “Theoretical calculations and experimental results show that whole crop stubble is less than maintenance for all classes of sheep at all locations”.

Through this project, and other literature, we have identified a range of factors that may contribute to the feeding value of stubbles, and the associated implications in future research (Table 18).

Table 18. Overview of the genetic, environmental and management factors that contribute to the feeding value of stubbles, and implications of these factors in further research.

Factor	Project findings	Implications
Crop type	Evidence supporting the view that barley and lupin chaff is higher quality than canola or lupins	Given high variability, efficient methods to measure nutritive value on-farm could be considered.
Harvest method	Proportion of higher nutritive value chaff components is markedly higher in chaff heaps and lines that that measured in quadrat cuts.	It is likely that the feeding value of stubbles with chaff piles and lines will be higher, as the aggregation of material effectively reduces the animal's constraints to diet selection. Other factors such as harvest height would also influence chaff composition. Management practices that reduce constraints to selection are likely to improve livestock productivity on stubbles. This will likely add to the economic viability of using chaff carts for farmer with cropping and livestock enterprises.
Grain spillage	Grain (seed) content of stubbles depends on harvest method, is highly variable, but tends to be lower and less variable in wheat stubbles compared with other crops.	Grazing livestock on stubbles presents and ideal way to value-add spilled grain and avoid pest problems by leaving grain in paddocks. The amount of grain spillage is highly variable and difficult to quantify without labour-intensive field surveys, and chaff assessment.
Growing season conditions	Weak evidence suggesting that stubble quality is higher with lower GSR. However, this was swamped by variability from other factors.	Samples collected from the same cultivar grown under similar conditions at different sites would help to inform this. If known, this information would be useful help estimate a seasonal outlook for stubbles. Farmers cite large year-to-year differences in the value of stubbles due to season.
Animal production objectives	Based on our nutritive value analyses, stubbles and chaff are mostly below maintenance value once grain has been depleted, unless a high level of supplementation is provided.	Supplementary feeding strategies should be considered to improve the utilisation of stubbles and chaff, particularly after the first 2-3 weeks of grazing. All stubbles will be deficient in protein and energy to meet animal production objectives, after spilled grain is depleted.
Grazing systems	The samples analysed were mostly taken during harvest or immediately after harvest. A gradual deterioration in the value of ungrazed stubbles is expected as soluble chaff components and grain is naturally depleted/decomposed.	Chaff and stubbles may provide a valuable feed source for 2-3 months of the year. However, some of the stubbles will not be grazed for several months after harvest. Effects of standing time on the nutritive value of stubbles and chaff, in relation to harvest method and crop type should be considered.
Capacity for selective grazing	Low ME and N concentration would strongly motivate livestock to select higher nutritive value components	A high capacity of livestock to select to improve their diets from standing stubble has been demonstrated, and likely for chaff, but the true extent of this capacity is unknown. Further field and animal house experiments would be of value to improve this knowledge and test existing ruminant modelling assumptions. Grazing pressure is also important, as sheep will select and eat lower quality components as the higher quality material is depleted. This will result in a continuous reduction in protein and energy intake, and decreasing weight gain, over time while sheep remain in a stubble paddock.

5.2.2 Feeding value of chaff

Our results suggest that, in general, chaff by itself will not meet the energy or protein requirements of livestock, so feeding chaff will require 'topping up' with grains (particularly pulses such as lupins) to get the most out of the feed. Although there are clear trends in the nutritive value of the stubbles sampled that are associated with components and species, the generally low nutritive value of this material does not appear to agree with what some anecdotal evidence would suggest. For example, livestock typically growing as well or better when feeding in paddocks with aggregated chaff (lines or heaps). An important qualification of our results is that we have not accounted for the capacity of livestock to select higher nutritive value components from the available forage. In fact, there are few studies published where the components selected by livestock grazing stubbles has been quantified. Other unpublished research suggests that the value of stubbles may be strongly influenced by the amount of spilled grain. Our data suggests that spilled grain in lupin and barley crop stubbles tend to be considerably higher, although still highly variable, compared with wheat crop stubbles. Therefore, it is quite possible that the combination of higher residue nutritive value, higher grain loss and the capacity of livestock for selective grazing of higher nutritive value components all contribute to multiplying what may otherwise be considered fairly small differences in digestibility that we observed in this study.

Supplementary feeding of a chaff-based diet will depend on the class of sheep or cattle being fed. Fast growing or lactating livestock require feed that is about 4 %units higher in protein than dry mature livestock. If a suitable supplement is not provided, stock will tend to pick out the higher nutritive value chaff components, if they can, resulting in higher wastage of the chaff and the stock are likely to lose weight.

5.2.3 Timing and utilisation of feedbase components for the farms

The heterogeneity of chaff and stubbles, and influence of crop type growth conditions and management (GxExM) presents a significant challenge in understanding the feeding value of this feedbase component. For example, stubbles may be fed in paddocks with chaff evenly distributed by the header, or as lines or chaff piles. This affects the capacity of sheep to select higher nutritive value components. We expect active selection for higher nutritive value components due to the low overall quality of feed.

Somewhat surprisingly, the amount of stubble grazing in crop-dominant businesses is similar to those with a relatively smaller area of stubbles. This indicates that the seasonality of WA's Mediterranean-type climate, and the make-up of individual businesses, drives feedbase rotations more-so than the proportion of cropping. Also, that stubbles are grazed with less intensity in cropping dominant businesses.

5.3 Sheep selection of chaff components

Both young and mature ewes adapted readily to eating the wheat chaffs offered in the animal house experiment, and intake was at a level where this provides a valuable feed resource despite it being of low quality. Young and mature ewes, with or without supplementation, were able to select chaff of higher quality than that offered. However, this provided only a marginal improvement in the quality of their feed intake. While the chaff being accepted and eaten by ewes was an important result, the level of intake provided for less than half of maintenance requirements of the livestock, and the provision of supplementary feed is therefore essential for livestock to meet their energy and protein requirements from wheat chaff. And, this is particularly important for young, growing livestock and mature ewes during gestation. Based on the nutritive value results of other chaff's this is likely to be the case across all chaffs, albeit the overall quality of barley and lupin chaffs were higher than wheat. Further, barley and lupin stubbles were found to have a higher proportion of spilled grain, which would help these stubbles to sustain animal production for a longer period of time. Providing a lupin supplement increased the level of selection for higher quality chaff components and did not result decreased intake of chaff. Therefore, lupins (and potentially other grain legumes, such as peas, beans and vetch), are an ideal supplementary feed when feeding chaff to overcome the low energy and protein content of this feed.

5.4 Stubble grazing calculator

The purpose of the Stubble Grazing Calculator is to provide a method to estimate of the amount of feed available in crop stubbles, and assist managing the grazing duration and supplementation requirements of stock grazing stubbles in order to meet defined production targets. The feed available is expressed as mob days to a liveweight gain target (for example number of days until the sheep in the mob reach maintenance, where liveweight gain = 0). This calculation is based on determining the number of DSE grazing days per hectare, calculated by multiplying the number of days grazed in a paddock by the stocking rate in DSE/ha. DSE grazing days per hectare is standardised for the particular mob based on their energy requirements in relation to a 50 kg wether sheep, approximately 8.9 MJ ME. For the purpose of simplicity we have included standardisation for liveweights and gestation in the Stubble Grazing Calculator, so the mob grazing days can be calculated according to the characteristics of the sheep that are specified. This activity addresses the need for updated information on the management of stubble grazing in the mixed farming region of southern Australia. Building on earlier research (e.g. Orsini and Arnold 1986), the Stubble Grazing Calculator has been built so that the number of days that a stubble paddock can support grazing, for a particular set of grazing conditions, may be estimated. The calculator is informed by a 2018/2019 survey of chaff and standing stubbles across Western Australia and number of stubble grazing experiments (Thomas et al. 2021). A single page interface ('Stubble Grazing Calculator' tab) is used for the calculator, where inputs for scenarios where ewes are grazed on crop stubbles can be entered into fields on the left hand side of the worksheet. Output values (right hand side) provide estimates of the expected number of grazing days before various liveweight change targets are reached. Supplementary feeding (selecting from several grain supplements) is included as a management option in the calculator, and livestock performance is adjusted based on the level and timing of supplementary feeding used in each scenario. The estimated cost of supplementary feeding, and relative proportion of energy gained from the stubble and supplement are reported.

5.4.1 Calculator specifications

The grazing tool incorporates user inputs about the sheep and paddock to be grazed, including the crop type and area of the stubble paddock (ha), the sheep liveweight (kg) and condition score (1-5), so that a standardised stocking rate can be determined. Liveweight gain decreases consistently as stubbles are grazed, due to the depletion of unharvested grains and other edible forage components such as senesced leaf and stem. This gives livestock managers some guidance as to when they could implement a management intervention such as supplementary feeding or moving stock to a new paddock, e.g. when a target rate of weight change is reached.

Estimates of the grazing value of stubbles, in the form of available ME for intake by sheep, were derived from of grazing experiments of mature Merino ewes grazing wheat stubbles (Thomas et al. 2021). In these experiments the liveweight gain of Merino ewes was measured at intervals, and energy intake required to achieve those weight gains was calculated, as the stubble was depleted of foraging value (Fig. 19).

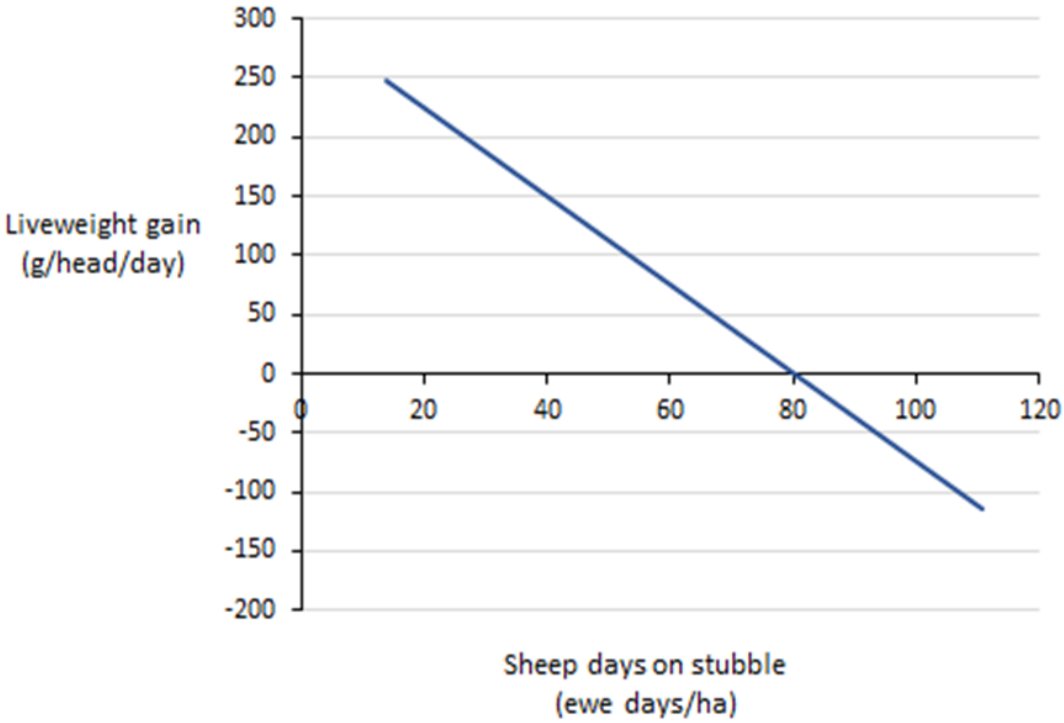

Figure 19. Average change in weight gain for Merino ewes grazing on wheat stubble

For stubble grazing data, a significant relationship was identified between sheep liveweight gain and their initial condition score (Thomas et al. 2021). Specifically, sheep of lower condition gained more weight on stubbles than sheep with higher condition score. Therefore, we have included sheep "condition score" as a factor in the stubble grazing tool and established 4 cohorts of condition. These are sheep CS <2, CS 2-2.75, CS 3-3.75 and CS > 4. The relationship between sheep days on stubble (x) and liveweight gain (b) are shown in Fig. 2, y = ax +b. Initial liveweight gain (b) was set to 300 g/head/day, which approximates the maximum rate of empty body gain for Merino ewes. Higher values have been recorded, but these are likely to be due to higher gut fill (even after fasting) when stock were moved from depleted pastures to fresh stubbles.

Livestock managers grazing stubbles aim to maintain sheep's liveweight (or lose little) during stubble grazing. The process of losing and regaining ewe liveweight is an energetically inefficient process (although a commonly used practice to minimise supplementary feeding costs). Based on the experimental information reported in Fig. 19, we have designed cumulative liveweight gain functions (quadratic) to predict ewe liveweight gained or lost on a given day. For the function $y=ax^2+bx+c$, where x is the number of sheep days on stubbles and y is the change in sheep liveweight from the start of grazing, constant values for each condition score are shown in Table 19.

Table 19. Constant values used in quadratic functions to calculate changes in sheep liveweight under stubble grazing.

Condition	a	b	c
CS < 2.0	-0.0014	0.2985	0
CS 2.0 - 2.75	-0.0019	0.2981	0
CS 3.0 - 3.75	-0.0021	0.2979	0
CS > 3.75	-0.0026	0.2974	0

Supplementary feeding is commonly made available to sheep to support their liveweight maintenance after stubbles (particularly cereal stubbles) become depleted. Many factors are considered in determining the type, amount and timing of supplementary feeding. The calculator offers the option of 3 commonly used supplements (barley, lupins and oats) and the user needs to manually define the supplement cost ($/t). The amount and timing of supplementary feeding can be adjusted dynamically in the stubble grazing calculator, based on formulated adjustments to the quadratic functions described above. To achieve this, stubble grazing has been treated as three chronologically sequential events; i) grazing stubbles unsupplemented, ii) grazing stubbles with supplementation and iii) grazing depleted stubbles, where feed value from the stubble is negligible and the supplement is the sole source of feed.

i) Grazing stubbles unsupplemented

The period prior to any supplementary feeding can be represented using the functions described previously, for x number of sheep days on stubbles.

ii) Grazing stubbles with supplementation

Effects of supplementary feeding on liveweight gain are represented by predictable adjustments to constants in the liveweight gain quadratic function $ax^2 + bx + c$ to take into account both the level of supplementation and the starting date of supplementation (assuming this follows a period of unsupplemented stubble grazing).

The constant b under supplementation (b_s) can be determined by function;

$b_s = b_{ns} + q_l \times e_l$

where;

b_{ns} is the original b constant with no supplementation

q_l is quantity of supplement fed kg/sheep/day

e_l is based on the energetic value to livestock of the supplement. These values were 0.42, 0.32 and 0.275 kg LWG/kg supplement for lupins, barley and oats, respectively.

The constant c under supplementation c_s can be determined by the function;

$c_s = (q_l \times e_l) \times d_s + (q_l \times e_l)$

where;

d_s is the number of sheep days after which supplementary feeding commences

iii) Grazing depleted stubbles with supplementation

A value for liveweight gain (y) per unit of supplementary feed (x) (kg/kg) was determined for each of the supplement types. This is integrated with an assumed value of 0.2 kg/head/day weight loss in ewes grazing depleted stubbles. For example, using a lupin supplement, this is, $y = 0.42\,x - 0.2$.

5.4.2 Calculator testing

Input from industry on the calculator was coordinated during development. In particular, producer demonstration events were held on 25/09/2020 (with DLPS Northern Ag Tour), 26/10/2020 (with WAMFIG) and 10/11/2020 (with WALRC) to gather feedback on the tool. Based on this feedback new versions of the calculator were built, with version 2.11 submitted on 30/11/2020. Version 2.11 was adapted from Version 2.1, with a few of the smaller updates taken from extensions in other further developed versions v2.2, v2.3 and v2.4. Updates added in v2.11 were 1) variable number (not drop down) condition score input and 2) variable number (not drop down) pregnancy input, 3) supplementary feeding output changed to $/ewe/day during period of supplementation, 4) moved weight gain target input field to the top of input box and 5) removed options for barley, lupin and canola stubbles (name now changed to mature ewes on wheat stubbles).

As mentioned previously, presentation of amount of grazing available on a stubble to inform the decision on when to implement a management decision is challenging for two reasons. First, the state of the sheep at the decision point needs to be able to be clearly defined and described in a way that can be easily understood. Second, for sheep to maintain weight while grazing a stubble the initially rapid weight gain of sheep when they enter a fresh stubble that has a lot of high quality components, such as spilled grains, is later offset by an extended period of weight loss. An illustration of what this looks like based on field data from the AWI Increasing Wool Sheep project is shown in Figure 20. In the stubble grazing calculator we initially identified the number of grazing days to when the ewes would return to their initial liveweight. However, because farmers may want to intervene earlier, for example provide supplementary feeding to reduce the rate of liveweight loss particularly in pregnant ewes. The effects of these potentially large cycles of boom and bust in the nutrition of pregnant ewes on stubbles is something that may warrant further attention.

Figure 20. Mean liveweight of a Merino ewe flock grazing a wheat stubble over time.

5.5 Summary of project objectives

1. Deliver up to date information on the nutritional value of stubbles (and chaff piles) of modern crop cultivars, harvested with modern equipment in both digital and print formats

Up to date information on the nutritional value of stubbles was gathered and delivered in presentations, industry publications and research articles in both digital and print formats. This material is outlined in Appendix 1.

2. Describe current use of crop stubbles - following engagement with producers - in the mixed farming regions (feedbase decision making, crop species/varieties grazed, typical grazing days, livestock species and classes grazed)
A grower survey was conducted with 41 participating farmers from 16 grower groups. From this we were able to better understand the utilisation of crop stubble on mixed farms and the characteristics of crop species and varieties of stubbles grazed. Data was gathered on how crop stubbles integrate with the overall feedbase in the mixed farming region.

3. Provide improved knowledge of the value and supplementary feeding strategies for grazing chaff piles, identifying the selective grazing of material from chaff piles, and the nutritive value from a diverse range of samples from different crops
A total of 436 stubble samples were sorted, ground and analysed through CSIRO's Floreat Nutrition Laboratory. Samples were taken from standing stubbles and chaff from a range of crops primarily wheat, barley, canola and lupins. The digestibility, crude protein, fibre, ash, moisture and estimated metabolisable energy content of samples was determined. An animal house study was successfully completed to determine intake and the level of selective grazing for a range of wheat chaff's.

4. Facilitate the easy use of the many facets of stubble grazing management, by producing an online integration tool and hard copy communication materials to specify expected grazing days and supplementary feeding requirements for selected scenarios
In consultation with farmers and advisors, an excel-based stubble grazing calculator was developed, with a number of improvements implemented in successive versions. In coordination with MLA's communications team, a stubble grazing booklet for farmers was published. https://www.mla.com.au/globalassets/mla-corporate/news-and-events/images/new-featured-image/thumbnail/20mla-modern-stubbles-booklet_web.pdf

5. Have submitted a minimum of 1 peer-reviewed scientific publication on the feeding value of modern crop stubbles to ensure the information gathered is available for other users
A peer reviewed journal paper was published;
Thomas DT, Toovey AF, Hulm E and Mata G (2021) The value of stubbles and chaff from grain crops as a source of summer feed for sheep. Animal Production Science 61, 256-264.

6 Conclusions/recommendations

6.1 Stubble management and grazing practices

Farmers are still seeking to understand more about chaff piles, relative inexperience but some indications that they may increase the feed value of stubbles, particularly in canola. There was uncertainty regarding how much feeding value can be increased by aggregating chaff, compared with distributed chaff in standing stubbles.

Recommendations:

- Further field studies comparing grazing of stubbles with and without chaff aggregated in chaff piles. Measure livestock performance, and the selective grazing of spilled grain and chaff in these paddocks. In particular, barley, lupin and canola stubbles should be investigated, and existing data from grazing trials needs to be analysed and published.
- Extension around consistent use of terminology when discussing grazing stubbles. For example, sheep grazing days and MJ ME/ha to indicate feed value

6.2 Nutritive value of stubbles and chaff

The nutritive value of chaff and stubble components was evaluated across a wide range of crop species and cultivars, and chaff management methods at harvest. We found that chaff heaps and lines contained a higher proportion of higher quality components (about 90% Medium and Small), compared with the average of material measured in quadrats which was as low as 50% Medium and Small components. In addition, the aggregation of the material into chaff and lines may provide livestock a greater capacity to select its preferred diet (grains and high-quality chaff), compared with grazing chaff components spread in the field. The energy and protein content of chaff components (except grains) are well below the maintenance requirements of sheep, so supplementary feeding may be needed when unharvested grain is depleted. The strong positive relationship between N and ME indicates that the energy content is related to the nitrogen nutrition of crops. Both N and ME are key factors influencing the nutritional value of stubbles for livestock. Effects of crop cultivar were small compared with effects of crop growing conditions. Therefore, more attention should be given to understanding growing season effects on stubble quality.

Recommendations:

- Development of tools to enable farmers to rapidly assess stubble quality, such as in-field NIRS feed quality assessment
- Further measurement of the quantity and intake of unharvested grains in stubbles and chaff, across a range of crop species
- A large-scale GxExM experiment to understand the factors driving nutritive value of chaff and stubbles in different seasons, soils and crop management conditions.

6.3 Sheep selection of chaff components

Young (and lighter) ewes ate an amount of chaff that was similar to mature ewes, individual intakes of young ewes were less variable suggesting this cohort adjusted to eating the wheat chaff more quickly than older ewes. This meant that on a metabolic bodyweight basis, the DM intake of young ewes was 36% higher than mature ewes (37.7 v 27.8 g DM/kg liveweight/day). Both mature and young ewes, with and without lupins, selected a higher quality diet. However, the younger ewes and those supplemented lupins selected a significantly higher quality diet. Selectivity by sheep (or the difference in quality between that offered and selected) varied widely among the wheat chaff's offered. However, selectivity did not correspond with the overall level of intake i.e. there were cases of higher selectivity in diets with high and low intake. However, even the higher quality chaff components are of relatively low feeding value and when offered ad libitum will only provide about one third to one half of the daily maintenance requirements of sheep. Therefore, farmers need to ensure that sheep have access to other high-quality feed such as spilled grains, supplements or green forage to maintain or grow sheep on wheat chaff or standing wheat stubbles. This may not be the case for barley chaff, where the proportion of spilled grain was generally much higher. The intake of wheat chaff was not affected by the provision of lupin supplement. Therefore, provision of lupins is an excellent option to improve the nutrition of ewes offered chaff diets.

Recommendations:

- Selective grazing behaviour of livestock offered chaff and stubbles for other crop species should be considered.
- Selective grazing behaviour to be assessed *in situ*, to compare diet selection and livestock performance as compared with the results of the animal house study.

6.4 Stubble grazing calculator

The Modern Stubbles Calculator successfully integrated research on stubbles to provide a practical decision support tool for grazing stubbles. Currently it has been validated via grazing studies for adult ewes grazing on wheat stubbles, and outputs from scenarios outside this should be viewed cautiously.

- All classes of sheep, with or without supplementation, were able to select chaff of higher quality than that offered. However, this provides only a marginal improvement in the quality of their feed intake.
- While it was encouraging that the chaff was readily eaten, provision of supplementary feed is essential for livestock to meet their energy and protein requirements from wheat chaff. And, this is particularly important for young, growing livestock and mature ewes during gestation.
- Providing a lupin supplement increased the level of selection for higher quality chaff components and did not result decreased intake of chaff. Therefore, lupins (and potentially other grain legumes, such as peas, beans and vetch), are an ideal supplementary feed when feeding chaff.

Recommendations:

- Validation of the Stubble Grazing Calculator, via Producer Demonstration Sites in collaboration with farmer groups to test how well the calculator can predict the feeding value of stubbles in terms of the number of mob grazing days to reach a liveweight change target. A range of livestock classes and crop types (i.e. additional to mature ewes on wheat stubbles) could be tested.

7 Key messages

- The greatest limitation of farmers in managing grazing of stubbles was knowledge of the feeding value of stubbles initially, and then when feed has run out.
- The high variability of in the nutritive value of stubbles, from paddock to paddock, means that predicting feeding value remains difficult. Further research is needed so that the GxExM drivers of stubble quality can be determined. On-farm testing of chaff quality testing is possible, and our data can be used as a reference for a comparative assessment of the nutritive value of a particular chaff relative to the results of this project.
- Wheat chaff alone provided less than half of the maintenance requirements of ewes. By comparison, barley chaff contained 7 times the amount of spilled grain, on average, and other barley chaff components were of higher feeding value. For nine field experiments, wheat stubbles varied from 50 and 100 sheep grazing days/ha at the point ewes started losing weight.
- Sheep can consume a higher quality diet through selective grazing, but the overall low quality of stubble and chaff means that farmers need to ensure higher quality feeds are also available, e.g., spilled grains, green pick and providing supplementary feed to meet nutritional requirements.
- Offering a 200 g/day lupin supplement improved the ewe’s energy intake additively, i.e., did not affect the amount of chaff eaten.
- This research provides information that will inform the management of nutrition of ewes during this critical time of ewe nutrition, ewe joining and pregnancy.

Inadequate nutrition at this time can result in the loss of lifetime productivity of the lambs, lower lamb birthweights, higher ewe and lamb mortality, and lower lambing and weaning rates.

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10 Appendix

10.1 Appendix 1: Summary of research outputs

Date	Activity	Attendees	Notes/Link
10/03/2020	What is your stubble worth? (GRDC regional updates, Swan Hill)	95	https://groundcover.grdc.com.au/story/6659606/victorian-grain-business-updates-to-explore-productivity-issues-with-the-aim-of-boosting-profits/
11/03/2020	What is your stubble worth? (GRDC regional updates, Bendigo)	90	https://groundcover.grdc.com.au/story/6659606/victorian-grain-business-updates-to-explore-productivity-issues-with-the-aim-of-boosting-profits/
22/09/2020	MLA special meeting: Presentation of the Stubble Grazing Calculator	10	
23/09/2020	Northern Ag Feedbase tour – Day 1, Dongara	20	
24/09/2020	Northern Ag Feedbase tour – Day 2, Northampton	20	
25/09/2020	Northern Ag Feedbase tour – Day 3, Badgingarra	5	
26/10/2020	WA Mediterranean Farming Improvement Group, regular meeting: Presentation of the Stubble Grazing Calculator	23	
10/11/2020	WA Livestock Research Council – virtual breakfast chat: presentation of the Stubble Grazing Calculator	10	
11/2020	Booklet: Grazing Modern Stubbles		Modern Stubbles project team https://www.mla.com.au/globalassets/mla-corporate/news-and-events/images/new-featured-image/thumbnail/20mla-modern-stubbles-booklet_web.pdf
26/11/2020	ECOS: Precision crop stubble grazing to benefit farmers in vulnerable times		Darius Culvenor, CSIRO ECOS article https://ecos.csiro.au/precision-crop-stubble-grazing/close-stubble/
27/11/2020	MLA Friday Feedback: Five tips for grazing sheep on stubbles		Breanna Wardle, MLA Friday Feedback

			https://www.mla.com.au/news-and-events/industry-news/five-tips-for-grazing-sheep-on-stubbles/?utm_campaign=Social&utm_content=1607147640&utm_medium=social&utm_source=facebook
12/2020	Ovine Observer: Precision crop stubble grazing to benefit farmers in vulnerable times		Zoe Chatfield, Wheatbelt NRM https://www.agric.wa.gov.au/newsletters/ovineobserver/ovine-observer-issue-number-91-december-2020-1?page=0%2C1
12/2020	Beyond the Bale: Grazing Sheep on Modern Stubbles		https://www.wool.com/about-awi/media-resources/news/grazing-sheep-on-modern-stubbles/ https://www.wool.com/land/pastures/stubbles/ https://www.wool.com/globalassets/wool/about-awi/media-resources/publications/beyond-the-bale/beyond-the-bale-december-2020.pdf
24/12/2020	Podcast: AWI The Yarn: The nutritional value of crop stubbles		Ellie Bigwood, AWI https://www.wool.com/about-awi/media-resources/the-yarn-podcast/the-yarn-episode-158/
02/02/2021	AAAS Conference: The value of stubbles and chaff from grain crops as a source of summer feed for sheep Special Issue Journal Paper, Animal Production Science		Australian Association of Animal Sciences conference, Fremantle, Western Australia and Online https://www.publish.csiro.au/AN/fulltext/AN20127
23/02/2021	GRDC Grains Research Updates, Perth: The value of stubbles and chaff from grain crops as a source of summer feed for sheep		http://www.giwa.org.au/2021researchupdates

10.2 Appendix 2: Feedbase, as a proportion of time spend by livestock, reported by 41 mixed cropping and livestock farmers in Western Australia