final report

Project code: B.PAS.0304

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Date published: June 2013

ISBN: 9781925045109

PUBLISHED BY
Meat & Livestock Australia Limited
Locked Bag 991
NORTH SYDNEY NSW 2059

Tedera seed increase

Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government to support the research and development detailed in this publication.

Abstract

In spring 2011, two sites were established with seven accessions of the perennial forage legume tedera (*Bituminaria bituminosa* var. *albomarginata* and var. *crassiuscula*) for seed production. A total of 1.4 ha were sown at Dandaragan and at Medina, 6300 seedlings were transplanted in 21 rows of 100 m each, with a row spacing of 1.8 m. Large commercial scale harvesting methods were evaluated at Dandaragan in December 2012. The best harvesting method was cut and swath with a trial-plot canola swather and harvest with a trial-plot grain harvester. This harvesting method allowed clean seed production of 216 kg/ha, which is a commercially viable seed yield with conventional harvesting machinery. It will also allow the production of tedera seed to be scaled up at a multiplication rate of 21.6 (harvest 216 kg/ha and sown at 10 kg/ha), similar to the existing values for wheat of 25 (harvest 2000 kg/ha and sown at 80 kg/ha). This result was obtained with accession T4, which was the only accession harvested entirely in this way. At Medina, small scale manual harvesting methods were used, applicable only for experimental purposes. A total of 138 kg of clean seed was produced by this project and will be used to sow 9 ha (90 kg seeds required) for grazing trials to be conducted from 2014 to 2016.

Executive summary

Tedera (*Bituminaria bituminosa* var *albomarginata* and var. *crassiuscula*) originates from the Canary Islands, where it is a component of native pastures grazed by livestock or has been cut and carried as hay for dairy goats (Ventura *et al.* 2000). Tedera has potential as a new domesticated perennial legume due to its ability to produce edible dry matter all year round, retain green leaf over summer and autumn with minimal leaf shedding, tolerate extreme drought and is adapted to a range of soil and environmental conditions (Real *et al.* 2008; Real and Verbyla 2010). Over the period 2005 to 2009, tedera has been productive when established at five locations in south Western Australia with growing season rainfall varying from 330-600 mm, and a range of soil types (Real *et al.* 2008; Real and Verbyla 2010). In addition, tedera has demonstrated very good tolerance of, and recovery from, grazing and its nutritive value is comparable to that of lucerne (Ventura *et al.* 2000; Sternberg *et al.* 2006; Oldham *et al.* 2013a; Oldham *et al.* 2013b). Preliminary modelling results based on small scale trials reveal the potential of tedera to improve the profitability of permanent pastures and mixed cereal/livestock systems (Finlayson *et al.* 2012). The main contribution of tedera occurs during summer and autumn, replacing the need for supplementary feeding. However, benefits of tedera for animal production must be clearly demonstrated in grazing trials where animals are grazing tedera all year round. This project was established to multiply seed of tedera to enable grazing studies to be progressed.

Two sites located at J.A.V. Brown & Sons at Dandaragan and DAFWA's intensive industries research station at Medina were established with 7 accessions of tedera (T4, T27, T31, T42, T43, T48 and T52). At Dandaragan, in September 2011, 1.4 ha was sown with seeds at a rate of 10 kg/ha using a cone-seeder at a sowing depth of 2.5 cm and a row spacing of 55cm. At Medina, in December 2011, 900 seedlings of each accession were transplanted at 30 cm spacing in 3 x 100 m rows per accession

At Dandaragan, two commercial scale harvesting options were tested;

- single harvest with a conventional harvester on dry tedera,
- multiple pass harvest on green tedera.

At Medina, two experimental harvesting techniques were used for small scale applications;

- hand-harvest from the plants and
- collection of mature seeds dropped onto weed-stop matting that was laid on the ground for this purpose.

Prior to this research, the feasibility of commercial scale tedera seed production was one of the most important unanswered questions. The achievement of 216 kg/ha using a conventional trial-plot grain harvester after swathing with a canola trial-plot swather, is a major step towards domestication of this species. This technology can be scaled up to large machines used for harvesting canola and wheat without any need for specialised machinery. Seednet/Landmark, our seed production partners, regard the clean seed yield of 216 kg/ha as a commercially viable yield from this experimental accession. This is a yield that will allow tedera seed to reach farmers at a price similar to other alternative forage options so that farmers will be able to select tedera based on merit of the species and not be discouraged by price. It will also

allow the production of tedera seed to be scaled up at a multiplication rate of at least 20x (harvest 216 kg/ha and sown at 10 kg/ha = 21.6x), similar to that for wheat (harvest 2000 kg/ha and sown at 80 kg/ha = 25x). This level of seed production and the agronomic characteristics of tedera, make it comparable to the most successful legumes in southern Australia (sub-clover, lucerne, white clover) as per the study of Revell *et al.* (2013). Revell *et al.* (2013) examined the development and use of exotic annual and perennial legumes in southern Australia and assessed their impact on productivity against their scale of application, ease of seed production and requirements for agronomic management, to determine critical factors for cultivar success.

The multiple pass harvester was able to harvest mature seeds without damaging immature seeds, flowers and leaves, but yields were not high enough to justify its use as the preferred seed harvesting method. However, conventional grain harvesters would require minimal modification to be turned into effective multiple harvesters as per our prototype. In some situations it might actually be the easiest way to harvest if farmers are satisfied with harvesting a smaller proportion of the available seed without the effort and expense of cutting and swathing or desiccating the crop, which might subsequently be used by grazing animals.

At Medina, the small scale experimental methods of harvesting were very time consuming and labour demanding, and are therefore only suitable for the early stages of seed increase when quantities are small. Accession T52 was the best seed producer at Medina (14.4 kg harvested from the plants and 11.0 kg from the ground).

The total seed harvested during 2012/13 was 138 kg. The tedera seed harvested during 2012/13 will provide the 90 kg of seed required to sow 9 ha (8 ha at Cherylton Farm, Kojonup and 1 ha at J.A.V. Brown & Sons Farm at Dandaragan) at 10 kg seed/ha proposed in the MLA application B.PBE.0027 for the tedera grazing trials.

Several options are discussed for ways to improve the seed production of tedera and include optimizing the grazing management before flowering, using breeding lines with high seed potential, attention to pest control, using the right harvesting methodology and selecting machinery settings tailored for the particular “future” cultivar.

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1. Background

The introduction of new forage legumes for grazing by livestock in Mediterranean-type climates of southern Australia has followed three distinct stages. The first stage since the early 1900's was focussed on subterranean-clover (*Trifolium subterraneum* L.) and annual medics (Nichols *et al.* 2012). After 1990 the focus changed to aerial seeded annual legumes such as French serradella (*Ornithopus sativus* Brot; (Loi *et al.* 2005)) and most recently since 2000, research has predominantly focused on perennial legumes such as tedera (*Bituminaria bituminosa* (L.) C.H. Stirt. var. *albomarginata* and var. c*rassiuscula*; (Ewing and Dolling 2003; Loi *et al.* 2005; Nichols *et al.* 2007; Real and Verbyla 2010; Real *et al.* 2011; Nichols *et al.* 2012). All these stages overlap and there is currently active research on the three groups of species (Nichols *et al.* 2012). The collection of genetic diversity and its evaluation for productivity and persistence within a livestock based farming system is central to the process of domestication of forage legumes (Francis 1991).

Tedera originates from the Canary Islands, where it is a component of native pastures grazed by livestock or has been cut and carried as hay for dairy goats (Ventura *et al.* 2000). Tedera has potential as a new domesticated perennial legume due to its ability to produce edible dry matter all year round, retain green leaf over summer and autumn with minimal leaf shedding, tolerate extreme drought and is adapted to a range of soil and environmental conditions (Real *et al.* 2008; Real and Verbyla 2010). The climate and natural ecology of the Canary Islands and Mediterranean-type climates of southern Australia are similar. Over the period 2005 to 2009, tedera has been productive when established at five locations in south Western Australia with growing season rainfall varying from 330-600 mm, and a range of soil types (Real *et al.* 2008; Real and Verbyla 2010). In addition, tedera has demonstrated very good tolerance of, and recovery from, grazing and its nutritive value is comparable to that of lucerne (Ventura *et al.* 2000; Sternberg *et al.* 2006; Oldham *et al.* 2013a; Oldham *et al.* 2013b). When the production data from these preliminary, small-scale studies is used in bio-economic models, the results reveal the potential of tedera to improve the profitability of permanent pastures and mixed cereal/livestock systems (Finlayson *et al.* 2012). The main contribution of tedera is during summer and autumn, replacing the need for supplementary feeding. However, benefits of tedera for animal production must be clearly demonstrated in grazing trials where animals are grazing tedera all year round. This project increased seed of tedera to enable grazing studies to be progressed.

2. Project objectives

By March 2013 to have collected at least 200kg of seed to enable animal production studies to be sown in winter/spring 2013.

3. Methodology

a. Sites establishment

Two sites located at Dandaragan and Medina were established with 7 accessions of tedera (T4, T27, T31, T42, T43, T48 and T52).

Site 1 - J.A.V. Brown & Sons at Dandaragan: DAFWA researchers and Landmark agronomists searched for several weeks for sites near Perth with appropriate soil and infrastructure. We were looking for a farm with access to irrigation to supplement rainfall and ensure high seed production. Most farmers near Perth with irrigation facilities are horticultural farmers and nematodes are one of their main problems when they grow potatoes and/or carrots. We rejected sites with high infestations of root-knot nematodes. The Dandaragan site (120 km north of Perth) in a 400 mm annual rainfall zone fulfilled the requirements of being close to Perth, uniform site, access to irrigation and with low levels of nematodes. The site's soil is a brown sand over loamy sand ($pH_{(CaCl2)}$ 5.0) and was supplemented with 150 kg/ha of super/potash fertiliser prior to seeding. In September 2011, 1.4 ha was sown with seeds at a rate of 10 kg/ha using a cone-seeder at a sowing depth of 2.5 cm and a row spacing of 55 cm. Post-emergent weeds were controlled with an application of Broadstrike® herbicide at 40 g/ha. The site was irrigated 1 to 2 times per month (10-20 mm per application) over the 2011/12 summer. Photos 1a. to 1d. show the tedera site from sowing in September 2011 to April 2012.

Photos 1a. - 7th September 2011; 1b. - 1st December 2011; 1c. - 6th Feb 2012 and 1d. - 10th April 2012

Site 2 - Medina: A second seed production site was established at DAFWA's intensive industries research station Medina (35 km south of Perth). Medina's annual rainfall is about 800 mm and the soil is a Spearwood loam with a $pH_{(CaCl2)}$ 7.4. With 50 g per accession (350 g in total) we produced 6300 seedlings in trays in October 2011. In December 2011, 900 seedlings of each accession were transplanted at 30 cm spacing in 3 x 100 m rows per accession and a row spacing of 1.8 m (with plastic cover to control weeds – Photos 2a. and 2b. The site was irrigated over the 2011/12 summer.

Photos 2a. - 18th January 2012 and 2b. - 20th March 2012

b. Winter and spring management

At Dandaragan, in April/May 2012 the seven accessions were grazed for 21 days and then allowed to grow un-disturbed for seed production. This site was not irrigated until November just before the peak of flowering when we noticed flower abortion in some of the accessions. Four accessions out of the seven had varying degrees of flower abortion, probably as a mechanism to conserve water in a perennial and drought tolerant plant that does not rely on seed production for survival. While this may have been rectified with earlier irrigation, it was an important observation for future cultivar selection work. Early flowers were damaged by populations of native budworm (*Heliothus punctigera*) which were subsequently controlled with insecticide Dominex® @ 100 mL/ha).

The site at Medina was irrigated weekly from establishment. Early flowers were also damaged by populations of native budworm which were subsequently controlled with the same insecticide.

c. Harvesting

At Dandaragan, two commercial scale harvesting options were tested;

- single harvest with a conventional harvester on dry tedera.
- multiple pass harvest on green tedera.

At Medina, two experimental harvesting techniques were used for small scale applications;

- hand-harvest from the plants.
- collection of mature seeds dropped onto weed-stop matting that was laid on the ground for this purpose.

1.1.1 Dandaragan - single harvest

Options for single harvest include the use of a conventional grain harvester after either swathing or application of a desiccant herbicide. Swathing or application of a desiccant herbicide is needed because tedera is a perennial species that remains green and a conventional harvester works with dry material. In a perennial species with indeterminate flowering, timing of harvesting is essential to harvest when the amount of mature seeds is at a maximum (Sandral *et al.* 2010). Since the seven accessions have different flowering patterns and access to a contract harvester was limited, we decided to target just one of the accessions (T4) which had minimal flower abortion. We expected the optimum timing for a single harvest operation to be approximately 27-28 days after the peak of flowering, which was on the 8th November for accession T4 (Photo 3). Even though the single harvest was timed to harvest at the peak of mature seed production, additional seeds produced in the prior weeks will also contribute to the overall yield. In our case, a wind storm on the 28th, 29th and 30th of November with strong winds (>45 km/hr) caused widespread damage to crops in the region, and also affected our tedera seed crop. Most mature seeds at the time of the wind storm were knocked to the ground. Fortunately, the immature seeds that were about 20 days old (since peak of flowering) were strongly attached and remained on the plants.

Photo 3: Peak of flowering of T4 - 8th Nov 2012

On the 3rd December, we took two quadrat samples (50 cm x 50 cm) for each of accessions T4 and T31 from the best seed production areas (not random) to measure maximum potential seed yield. Mature seeds were hand-picked and then processed to evaluate potential yield per hectare at a single point in time.

On the 5th Dec, 27 days after the peak of flowering T4 and a section of T27 were cut and swathed with a canola trial-plot swather from the DAFWA Mount Barker Research station (Photos 4a. and 4b.). The intention was to harvest 5 days after the cut and swath, but we were delayed by a rainfall event of 7.2 mm on the planned harvesting day (10th December) and subsequent rainfall events on the 13th and 14th December of 2.0 mm and 2.6 mm, respectively. Finally, we were able to harvest on the 18th December under non-ideal conditions due to light rain and high humidity. The optimum/ideal condition is a sunny and hot day to have the swath "crunchy" to thresh with minimal seed losses. Unfortunately, we had little flexibility with dates due to prior commitments of the contracted harvester which was also running behind schedule due to the December rains. The grain harvester that we used was a Haldrup machine which belongs to Kaylx Agriculture, a harvesting service provider organized by Landmark/Seednet (Photos 4c. and 4d.).

Photos 4a.- Cutting T4 on the 5th Dec.; 4b. - Close up of cutting T4; 4c. - Harvesting T4 and 4d. - Close up of harvesting T4

Different harvesting settings were tried on accession T27 which was cut and swathed on the 5th December for this purpose. After experimenting with the small area of T27, it was decided to use the following settings;

1. 12 mm concave/drum space (same as for wheat),
2. cleaning fan at 450 rpm,
3. drum speed at 400 rpm,
4. top and bottom sieves at 10 mm.

To pick up the swathed material, the harvester was picking material with the front fingers close to the ground and in that process was also cutting green material un-cut by the canola plot swather. The settings selected allowed all material to flow

through the machine easily without blockages on a very humid day. Harvester settings will need to be fine-tuned in subsequent harvesting operations with good weather conditions and with a dry swath, to have a better threshed and cleaned sample in the header-box.

1.1.2 Dandaragan - multiple pass harvester

The multiple pass harvester developed by DAFWA and Rural Industries Research and Development Corporation (project PRJ-003760 - Commercial seed technology for *Bituminaria bituminosa* var. *albomarginata)* was utilized to harvest mature seeds, while leaving most of the immature seeds, flowers and leaves un-damaged on the plants. Photo 5 is an example of the multiple harvester working.

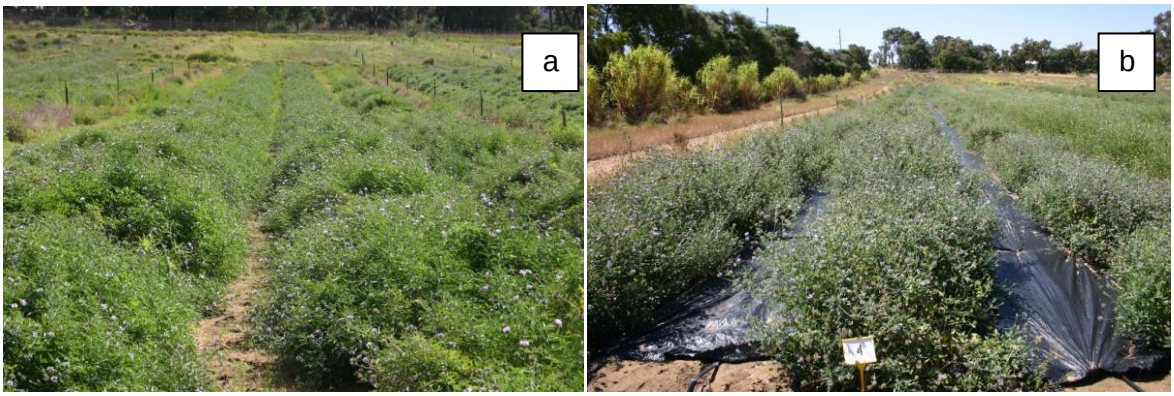
The use of this harvester allowed harvesting of accessions that flowered early and those that re-flowered after the losses from early flower abortion by collecting seeds produced at different times. There were a total of five harvest events conducted with this machine, between the 19th November 2012 and the 23rd January 2013.

Photo 5: Multiple pass harvester

1.1.3 Medina - small scale experimental harvesting

In October 2012, the irrigation system was changed from overhead sprinkler irrigation to drip-tape irrigation with a capacity for supplying 3.2 mm/hour over the area. Weed stop matting was laid on top of the irrigation drip-tapes in-between the rows (Photos 6a. and 6b.). The seven accessions were hand-harvested by shaking the plants into a plastic tub to collect the seeds every 3 to 4 weeks during late spring 2012 and early summer 2013. Seeds that dropped to the ground (together with old

leaves) were swept from the weed stop matting and placed in wool bags for subsequent threshing and cleaning.



Photos 6a. - 19 September 2012 and 6b. - 8 November 2012

d. Seed lots

A total of 24 seed lots were harvested from the two sites and harvesting methods:

Dandaragan
- 2 accessions (T4 and T27) - conventional grain harvester
- 7 accessions - multiple pass harvester

Medina
- 7 accessions - hand-harvested
- 7 accessions - collected from the ground seeds
- 1 mix of accessions – collected from the ground from mixing the rows in-between two accessions (T4/T27 + T27/T31 + T31/T42 + T42/T43 + T43/T48 + T48/T52).

e. Seed processing

All seed lots were taken to DAFWA South Perth and were threshed with a small scale experimental thresher (L. & T. Venebles Pty. Ltd.). The threshed material was further processed with a Clipper machine that uses air, an oscillating screen and sieves to separate the seeds from other plant material. The top screen was round R12 and the bottom screen was slot 1/17 x ½. Seeds from the clipper machine were graded by weight with a gravity table (Westrup LA-K).

f. Germination tests

A study conducted by Beard (2009) reported no differences in germination percentage when seeds were germinated at constant temperatures from 10°C to 30°C (5°C increments), alternating temperatures (20°C/10°C, 26°C/13°C or 35°C/20°C) and either with 12 hours of light/darkness or 24 hours of darkness. The option of 15°C and darkness was chosen for the germination tests as is common practise for several crop species at DAFWA's AGWEST Plant Laboratories. A random sample of 300 seeds was selected from each of the 26 seed lots and separated into six replicates using the seed counter – CONTADOR machine form Pfeuffer. Each replicate of 50 seeds were placed into Petri dishes laid with wet filter paper and allowed to germinate for 21 days with weekly counts of germinated seeds and a final count of hard seeds.

4. Results

a. Dandaragan - single harvest

The potential seed yield from a single hand harvest of accessions T4 and T31 in 50 cm x 50 cm quadrats is presented in Table 1.

Table 1: Seed yield potential for a single harvest of T4 and T31

	T4	T31	Mean
Number of inflorescences	158	228	192
Seed yield (g/quadrat)	24.4	28.4	26.4
Seed yield (kg/ha)	976	1139	**1058**

The replicate and accession effects were not significant for number of inflorescences and seed yield. The maximum seed yield that could potentially be harvested from either accession of tedera in a single operation is about 1 tonne/ha.

Seed yield results obtained by the conventional grain harvester from tedera accession T4 are summarized in Table 2:

Table 2: Seed yield of T4 harvested with a conventional grain harvester

	T4
Length harvested (m)	398
Width harvested (m)	1.7
Area harvested (m^2)	677
Seeds from header box (kg)	33.3
Total clean seed (kg)	14.4
Clean Seed Yield (kg/ha)	216

Given the climatic conditions with the strong wind storm that knocked older mature seeds to the ground, rainfall events that delayed the harvesting of the cut and swath material for an extra 8 days and the non-ideal conditions on the day of harvest, the harvest was considered very successful. The average seed yield was 216 kg/ha of clean and good quality seed with 81.4% germination rate. Seednet/Landmark, the company with commercial rights for tedera and whose staff collaborated in this harvesting process, does not foresee seed production as a limiting factor for tedera.

b. Dandaragan - multiple pass harvester

There were five harvest dates in total; two accessions had four harvests (T27 and T42), two accessions had 3 harvests (T43 and T48), two accessions had two harvests (T4 and T31) and one accession had only one harvest (T52). The amounts harvested varied from 0.24 kg for T43 to 3.22 kg for T52. The multiple pass harvester was able to harvest mature seeds and leave most immature seeds, flowers and leaves un-damaged on the plants, however, seed yields were lower than expected. Another limitation was that some green (moist) immature seeds were collected in the harvest sample, and the sample required oven drying before

cleaning. Only accessions T4 and T27 were harvested by the conventional harvester and the multiple harvester. Almost all the area of accession T4 was harvested by the conventional harvester, therefore yield comparisons with multiple pass harvesting were not possible. Roughly equal areas of accession T27 were harvested with each method. In this case, the conventional harvester achieved ten times more seed from 8.7 kg to 0.9 kg for the sum of four passes with the multiple harvester (Table 3).

c. Medina - small scale experimental harvesting

The small scale experimental methods of harvesting used at Medina were time consuming and labour demanding, and are therefore only suitable for the early stages of seed increase when quantities are small. Hand-harvested seed production and seeds collected from the weed-stop matting are presented in Table 3. Accession T52 was the best seed producer at Medina (14.4 kg harvested from the plants and 11.0 kg from the ground) and T31 was the poorest for both harvesting methods (1.27 kg for hand harvest and 0.18 kg for ground collection).

d. Seed production results

The quantities of clean seed are presented in Table 3. The total seed harvested during 2012/13 was 138 kg. It is important to note that only one accession (T4) out of the seven accessions was harvested at Dandaragan with the conventional harvester at the right time. Accession T27 was also harvested with the purpose of adjusting the harvester settings, but this was an opportunistic harvest because it was very late and most of the seeds had already dropped.

Table 3: Estimate of clean seed quantities (kg) harvested at Medina and Dandaragan

	T4	T27	T31	T42	T43	T48	T52	Mix	Total Clean Seed
Medina hand harvest	3.64	10.08	1.27	7.80	3.28	9.03	14.40		49.50
Medina collected from the ground	3.7	8.52	0.18	3.96	3.32	3.18	11.04	7.95	41.85
Dandaragan Single Harvester	14.40	8.68							23.08
Dandaragan Multiple Harvester	0.24	0.88	1.26	2.54	0.24	1.44	3.22		9.82
First grade from re-threshed and re-processed seeds								13.7	13.72
Total clean seed	21.98	28.16	2.71	14.30	6.84	13.65	28.66	21.67	138.0

e. Thousand seed weight and germination results

The thousand seed weight (TSW), germinated seeds in 7, 14 and 21 days (G), hard seeds (H) and total germinable seeds (TG) results are presented in Table 4.

Table 4. Thousand seed weight (TSW), germinated seeds in 7, 14 and 21 days (G), hard seeds (H) and total germinable seeds (TG) results for 26 seed lots of tedera

		Accession	TSW (g)	7 days G (%)	14 days G (%)	21 days G (%)	H (%)	TG (%)
Dandaragan	Conventional harvester	T4	25.8	29.8	31.5	32.5	48.8	81.4
		T27	24.1	30.1	32.3	32.3	54.6	87.0
	Multiple harvester	T4	27.6	28.0	30.5	32.4	58.6	90.9
		T27	25.9	19.8	20.9	20.9	66.9	87.7
		T31	26.3	25.3	26.2	26.2	68.9	95.1
		T42	24.8	29.5	35.0	35.3	58.7	94.1
		T43	23.1	41.8	47.7	48.3	41.6	89.9
		T48	23.9	26.7	30.7	31.3	61.8	93.2
		T52	27.5	43.8	52.1	53.1	44.0	97.1
Medina	Hand harvest	T4	25.2	18.3	25.9	27.3	59.1	86.3
		T27	26.7	37.9	38.7	39.0	50.6	89.6
		T31	23.4	32.5	35.6	36.3	54.5	90.7
		T42	21.6	29.5	36.3	40.0	48.3	88.3
		T43	22.4	28.0	35.9	38.8	48.4	87.2
		T48	23.8	23.7	32.7	33.7	54.7	88.4
		T52	23.3	31.5	43.7	46.4	30.5	76.8
	Ground collection	T4	24.7	25.5	29.0	29.5	47.8	77.3
		T27	26.5	44.1	47.4	47.4	29.6	77.0
		T31	23.8	19.2	21.5	21.9	39.1	61.0
		T42	21.0	51.5	64.5	65.0	17.2	82.2
		T43	20.9	38.5	45.4	45.4	15.1	60.5
		T48	22.0	27.8	31.1	31.1	28.4	59.5
		T52	24.1	35.8	39.9	40.3	23.2	63.5
		Mix	24.0	34.1	38.2	38.2	35.7	73.8
Reprocessed	From Clipper (top sieve)	Mix	28.0	24.7	27.4	27.8	15.4	43.2
	From Gravity table	Mix	24.0	35.7	41.0	41.3	29.7	71.0
Grand Mean			24.4	30.5	35.3	37.0	43.5	80.5
LSD (5%)			0.95	8.43	9.01	8.80	9.38	6.63

There were significant differences among the 26 seed lots for the six variables presented in Table 4. The TSW varied from 20.9 g to 28.0 g with a grand mean of 24.4 g The germinated seeds (G) for 7, 14 and 21 days, hard seed (H) and total germinable seed (TG) had a grand mean of 30.5%., 35.3%, 37.0%, 43.5% and 80.5% respectively.

5. Discussion

The 138 kg of tedera seed harvested during 2012/13 will provide the 90 kg of seed required to sow 9 ha. The 8 ha at Kojonup will be sown with a mix of the seven accessions and the 1 ha at J.A.V. Brown & Sons Farm at Dandaragan) will be sown with the seven accessions in separate area (not mixed) at 10 kg seed/ha proposed for future tedera grazing trials.

Prior to this research, the potential seed production per hectare from tedera harvested in a way that can be used at a commercial scale, was an important unanswered question. The achievement of 216 kg/ha using a conventional grain harvester after swathing with a canola swather, is a major step towards domestication of this species. This technology can be scaled up to large machines used for harvesting canola and wheat without any need for specialised machinery. Seednet/Landmark, our seed production partners, regard the clean seed yield of 216 kg/ha as a commercially viable yield for this experimental accession. This is a yield that will allow tedera seed to reach farmers at a price similar to other alternative forage options so that farmers will be able to select tedera based on merit of the species and not be discouraged by price. It will also allow the production of tedera seed to be scaled up at a multiplication rate of at least 20x (harvest 216 kg/ha and sown at 10 kg/ha = 21.6x), similar to that for wheat (harvest 2000 kg/ha and sown at 80 kg/ha = 25x). This level of seed production and the agronomic characteristics of tedera, make it comparable to the most successful legumes in southern Australia (sub-clover, lucerne, white clover) as per the study of Revell *et al.* (2013). Revell *et al.* (2013) examined the development and use of exotic annual and perennial legumes in southern Australia and assessed their impact on productivity against their scale of application, ease of seed production and requirements for agronomic management, to determine critical factors for cultivar success.

The multiple pass harvester was able to harvest mature seeds without damaging immature seeds, flowers and leaves, but yields were not high enough to justify its use as the preferred seed harvesting method. Another limitation was that some green (moist) immature seeds were collected in the harvest sample, and the sample required oven drying before cleaning. However, conventional grain harvesters would require minimal modification to be turned into effective multiple harvesters as per our prototype. In some situations it might actually be the easiest way to harvest if farmers are satisfied with harvesting a smaller proportion of the available seed without the effort and expense of cutting and swathing or desiccating the crop, which might subsequently be used by grazing animals.

The seed production potential of tedera sown as a sward in a single harvest of about 1 tonne/ha is the first report of this kind in the literature. In Spain, Correal *et al.* (2008) studied the production of individual tedera plants and obtained a maximum of 175 g/plant and an average of 50g/plant in a single harvest. The plants used in this study were spaced in a 2 m x 2 m grid, therefore production per ha is not possible to be estimated with accuracy. In a similar study in 2012 (Correal pers. comm.) an average of 120g of seed/plant

was harvested, with plants also sown in a grid of 2m x 2m, and seeds were allowed to drop and then be swept-up from weed-stop matting for cleaning. In Argentina, Terenti (2008) studied the seed production potential of tedera transplanted in a grid 0.5 m x 0.5 m (simulating a full sward) in three consecutive years from 2005/6 to 2007/8. Seeds were hand-harvested over a period of 10 days and seed yields were 191 kg/ha, 323 kg/ha and 417 kg/ha for each year respectively. These hand harvesting methods are only applicable for early stages of seed increase and/or for breeding purposes, not for large scale seed production.

Tedera seeds require a period of three months post-harvest to produce high levels of germination (Beard 2009). The 26 seeds lots had a grand mean of germinable seed of 80.5% with 43.5% of hard seed. These 26 seed lots were not scarified which is better for long term storage in a cool room. The 90 kg of seeds to be sown in 2013 will be scarified to increase the readily germinable seed percentage. Our aim is to get 50% of readily germinable seed and 30% of hard seed in the mixed seed lot. The hard seeds will germinate at different times as a safeguard against possible droughts, weed infestations and/or insects attacks.

a. Options to improve seed production

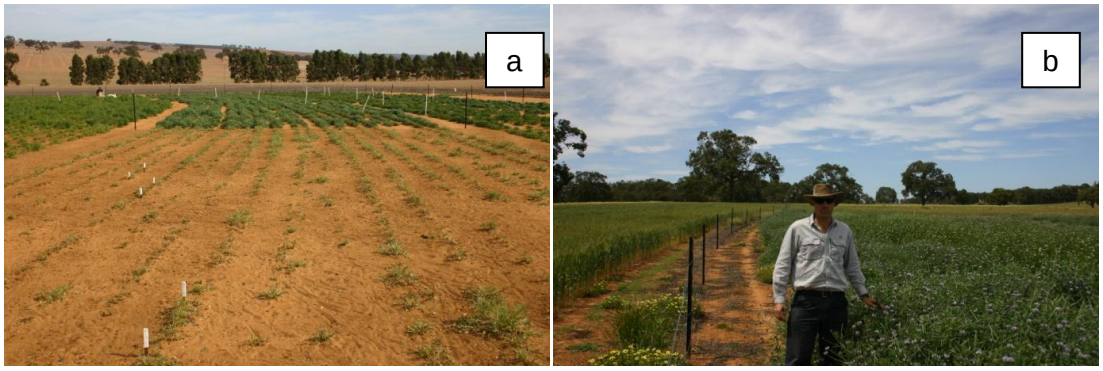
Seed production levels of 216 kg/ha are suitable for this experimental line, however, our aim is to produce 300-400 kg/ha. To improve seed production, new cultivars with high seed yield potential will be utilized, appropriate grazing management will be applied before flowering, the right seed producing conditions and harvesting methods will be sought as described below.

1.1.4 Breeding lines

The seed increase was conducted on seven accessions of contrasting types of tedera. In the breeding program we have 65 accessions of tedera from which we have selected 28 elite parent plants out of nearly 10,000 spaced plants based on forage and seed production and conducted crosses to combine desirable attributes. Some individual parent plants can produce 1000 seeds/plant with minimal flower abortion and some produce only just a few seeds with high levels of abortion. New cultivars to be released will be from the top seed producers as seed production is a key breeding objective. Detailed studies of seed production under different water regimes will be conducted under controlled experimental conditions during spring 2013 with elite breeding lines.

1.1.5 Grazing management before flowering

Dandaragan was heavily grazed in April/May 2012 and was not defoliated again prior to harvest. Photo 7a. illustrates the level of grazing when sheep were moved from replicate 2 to replicate 3. At the end of the grazing in May, the entire site was looking like the foreground of Photo 7a.



Photos 7a. – Grazing in May 2012 and 7b. – accumulated growth from winter and spring.

At flowering in November at Dandaragan, tedera had accumulated 7 to 10 t/ha of lush green dry matter (Photo 7b.) producing a sward with a very high water demand at a time of the year when the days were becoming longer and hotter. Under these circumstances, flower abortion is one of the mechanisms to remove un-necessary water use in a perennial plant. This mechanism is fully described for soybean (Hufstetler *et al.* 2007; Salem *et al.* 2007; Walden-Coleman *et al.* 2013), a close relative of tedera (Pazos-Navarro *et al.* 2012). Hence, grazing in late winter is a management option to be explored in future seed production trials, with the aim of reaching flowering with a much reduced forage mass and a better water balance for the time of the year.

1.1.6 Right conditions for seed production

There is no ideal uniform condition to maximise seed production potential for all the accessions at the same time. For example, evaluation at Medina under continuous irrigation suits some of the accessions very well. Accessions like T52 flourished, but accession T31 that is very drought tolerant, did not grow well under irrigation. Conversely, accession T52 had large levels of flower abortion at Dandaragan and almost all the spring flush of flowers were lost. The only harvest of T52 at Dandaragan was on the 23 January with the multiple pass harvester, collecting seeds produced by a secondary flush of flowers. Therefore, the best seed production environment will depend on which breeding lines are released commercially. Attention to pest control during flowering will also be critical for successful seed production.

1.1.7 Harvesting method for commercial seed production of tedera

Single harvesting technology can be improved by either using a good swather that will be able to cut close to the ground so that the harvester does not cut green material or by using a desiccant that will not affect seed quality. Some accessions with mature seeds along the canopy profile will be suited to cut and swath and others with mature seeds mainly at the top of the canopy will be better suited to a combination of spraying with a desiccant as well as cut and swath. A good dry swath on a good day will allow us to optimize the harvesting process reducing losses over the back of the harvester.

6. Conclusions

- Enough seed was produced to sow grazing trials in 2013.
- Tedera has a high seed production potential but will require attention to management to achieve maximum yields.
- Tedera can be easily harvested in a single operation using a conventional grain harvester with minimal changes to machinery settings from that when harvesting cereals.
- Some accessions of tedera are very well suited to cut and swath and then harvest. Others will be more suited to spraying with a desiccant herbicide and then direct harvesting when dry.
- These sites have been invaluable for gaining practical insights into the strategies required for commercial seed production of tedera.
- All this new knowledge will be used for selecting plants with optimum seed production characteristics from the breeding program.

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