Exploring the potential for native grass production in the Northern Tablelands of NSW: a case study.

Native Grasses for Grains working paper

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Contents

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Introduction

Since the 1980s there has been a growing interest in production of native grasses both for ecological purposes and for productive purposes in farming (Waters *et al.* 1997; Reseigh *et al.* 2008; Hancock *et al.* 2020). Native grasses require less fertiliser and are adapted to low rainfall and interest in natives will intensify as climate change drives transformation of agricultural land. Native grass production can be viewed as part of regenerative agriculture that aims to maintain agricultural productivity as well as promote ecosystem functioning. Non-native grasses have been shown to be a threat to biodiversity while the role that native grasslands have in restoring biodiversity has been recognised (Godfree *et al.* 2017; Dorrough *et al.* 2008). On farm native grass production allows multiple outputs (vertical stacking): pasture cropping, cattle production, native grass seeds, increased biodiversity, improved soil structure and carbon storage (Godfree *et al.* 2017; Seis 2020). There is also an interest in producing native grass seed for developing and commercialising Indigenous food for human consumption (Pascoe 2014; Lee & Courtenay 2016; Vernon 2019). Historically, bread made from grass grain was produced in the Indigenous grain belt known as Tindale's Arc (Tindale 1974) of which the Gomeroi country is part. While Australia's native food industry is growing there is currently low (about 1%) Indigenous representation in the supply chain (Mitchell & Becker 2019). Whilst value adding to the food grade is challenging, opportunity still exists for Indigenous business in grass seed sales to the revegetation and rehabilitation markets. There is consequently great potential for programs to promote Indigenous involvement and related literature suggests the need for economic viability is a key consideration (Gorman *et al.* 2020). On-farm native grass production can be connected to local Indigenous native grass enterprises and exploring this connection, along with the potential farm management and marketing possibilities, motivates this research.

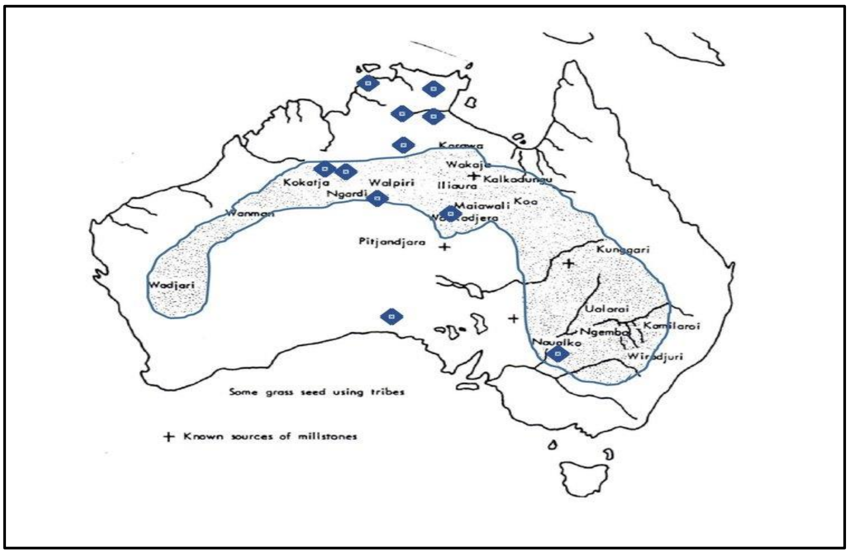

Fig. 1. Map of 'Tindale's Arc' in Chivers, Warrick & Evans (2015).

If it can be demonstrated to farmers through research and extension that native grass production can be profitable, and if native seed markets function well, they are likely to enter production (Loch *et al.* 1996). There is a range of management options for native grass, including cool burning, grazing, monoculture or pasture cropping. Grazing uses cattle to manage the biomass/weeds in winter. Cool burning is an Indigenous practice to manage the biomass. Monoculture is unlikely to be the best option environmentally as it would require more cultivation and result in less biodiversity but probably has a higher yield. Monoculture operations will be similar to those of sorghum production (Drew Penberthy, Narrabri agronomist, pers. comm.). Pasture cropping involves sowing a winter crop into summer growing native perennial grass. This practice has already been adopted by some farms, and the latest data available from the ABS indicate 205,000 ha nationwide are under pasture cropping which is practised on 1,837 farms for 2016-2017 (ABS 2017). The distribution by state is presented in Table 1 below. Total percentage of cropping area under pasture cropping in Australia is 1% so the practice is not widespread. Furthermore, it is not known how many of these farms use pure native pasture mixes as opposed to pure exotic pastures or an exotic/native mix.

Table 1. Pasture cropping in Australia (Source: ABS Cat No 4627.0, 2017)

Location	Estimated area (ha)	% total area cropped	No. of farms
NSW	56,923	1	694
VIC	53,720	2	589
QLD	11,958	0.5	139
SA	62,187	2	234
WA	18,235	0.2	116
TAS	1,479	1	62
NT	227	1	3
Total	205,000	1	1837

There is also a range of marketing/sales alternatives for the seed as there are many existing and potential sub-markets for seed (Reseigh *et al.* 2008). The alternatives considered here are sales of unthreshed seed for the native revegetation and mine rehabilitation markets, and sales for human consumption including to Indigenous harvesters for food production enterprises. The latter may arise from government or otherwise funded local Indigenous social enterprises. Several analyses point to the potential improved Indigenous welfare outcomes and savings from repurposing government expenditure which could be used as start-up capital for viable business and employment opportunities based on country (Sangha *et al.* 2019; Campbell 2016).

If native grass production can be shown to be profitably included in a farm plan, adoption depends on a range of farmer characteristics and characteristics of the native grass production itself. Adoption is more likely if native grass production is perceived to be relatively advantageous to alternatives. The path to adoption is a learning process for the farmer who acquires information about these relative merits (Pannell 2012). Information required comes from research in agricultural science and economic analysis. In terms of the latter, linear programming (LP) is a well-established framework for evaluating the possibility of new activities in a whole-farm context (Alford *et al.* 2004; Kaiser, & Messer 2011). The approach allows for the determination of an optimal mix of farm activities to maximise total farm gross margins for a given set of farm resources on a representative farm. LP can be used to model the choice of production of native grasses by different methods, can allow for different marketing/sales alternatives and can also link to Indigenous enterprises.

This paper is part of the University of Sydney's cross disciplinary project, Grasses for Grains, which aims to bring farmers and Indigenous communities together to develop opportunities for the use of native grass seed. The research was centred on the land, plants and people of the Gomeroi country near Narrabri, NSW. The project was designed to investigate the marketing chain from "paddock to plate". It includes research on agronomic aspects of production, value adding, nutritional and food properties, marketing to consumers, socio-cultural and environmental sustainability and the farming systems context of production. It is the farming context which is explored in this paper. The objective here is to build a model of a representative farm in the Northern Tablelands of NSW to explore the potential for native grass production, including links to local Indigenous enterprises. Results indicate across a range of yields, prices and rotations that native grass production can enter a farm plan and also link to Indigenous enterprises.

This paper is organised as follows. The basic LP structure is presented below followed by a description of the representative farm including specification of farm resources and activities. Results are presented and a discussion and conclusion follow.

A representative model of a Narrabri farm

The region

Narrabri is part of the diverse agricultural area of the New England and North West region of NSW. Grazing on improved/modified pastures occupies 40% of the region. In terms of gross value of production, cotton, cattle and wheat contribute about 67% of the total value (ABARES 2016). Narrabri itself lies within the Indigenous grain belt which extends beyond the wheat-sheep belt. Within the Indigenous grain belt there is a large assortment of native food plants that can be produced across a range of soil qualities (Ampt & Pattison 2017). Some recent research into farming systems in the Narrabri area has been motivated by a range of agronomic factors affecting farm productivity: increasing resistance to herbicides, soil-borne pathogens and declining soil fertility (Baird & Lonergan 2018). This suggests that potential mitigation benefits might arise from a regenerative agriculture approach that includes native pasture production. These have been identified as ecosystem benefits of reduced need for pesticides, fertilisers, improved soil carbon and water holding capacity -drought resilience (Seis 2015; White 2013).

The representative farm model

A standard LP model representation is:

Maximise $TGM = \sum_{j=1}^{m} c_j x_j$

Subject to $\sum_{j=1}^{m} a_{ij} x_j \leq b_i$

Where:

TGM= total gross margin

x_j = level of the jth activity (j=1, …, m)

c_j = Individual gross margin of the *jth* activity

b_i = constraining amount of the *ith* resource (i=1, . . ., n)

a_{ij} = amount of the *ith* resource required or produced by the *jth* activity

all $x_j \geq 0$

Risk is unaccounted for in this model. Variants that incorporate risk could be estimated including quadratic programming and sequential risk stochastic programming (DSSP). In this farming system it is assumed there is enough water to plant various dryland crops - arguable given the recent experience with drought this century and an alternative is to use a DSSP model. This representation could allow for tactical decision making based on the realisation of available water at different points in the production process. The information requirements are quite stringent for these types of models to be built. In particular, there is a lack of historical data on variation of native seed prices and yields, hence a basic LP has been estimated. The idea in this modelling exercise is to make the model as parsimonious as possible given that many of the data elements are conservative estimates, while still allowing examination of the basic farm plan potential. The model was constructed in Microsoft Excel and the Solver platform was used for the optimisation and sensitivity analysis.

The representative farm

The farm has a mix of arable, nonarable and hilly timbered land. The land is suited to cropping and livestock enterprises. The farm is not irrigated and out of drought is well-watered by dams and access to bore water. In terms of infrastructure, there are is a machinery shed and a workshop, an aerated silo grain storage, a weighbridge and cattle yards with crush and loading ramp. Farm equipment includes a header, planter, and vacuum harvesters. The farm LP model is based upon a single production period (year). The productive life of native pasture is about 20 years, with establishment often taking a couple of years. Hence, the model represents an average year over 20 years. Seasonal time units are used. Farm activities include a range of introduced pasture and cropping activities, pure native grass production and native grass seed sales.

Prices and costs

Annualised gross margins (GM) for the native grass production activities are calculated as annuities over a 20-year period (3% discount rate) as in Petersen *et al.* (2003). The retail price of grass seed is high. Reseigh *et al.* (2008) report a range for Kangaroo Grass of $700-900/kg, Bluegrass $300-400/kg and Wallaby Grass $95-200/kg. Current retail prices in NSW are slightly lower (Mitchell Grass is $147/kg, Queensland Bluegrass $175 -various online retail sources). The retail price of seed assumed in this analysis is $150/kg and the seeding rate is 10kg/ha. This would be an average price across four grasses that constitute the native grass mix on the farm proposed below. This cost is added to the cost of 2 vacuum harvesters/ha (with an assumed $15/ha operating cost). An average mark-up of 218% from the farmgate price of seed to the retail price is reported in Reseigh *et al.* (2008) and attributed to information asymmetries about seed quality and level of supply. Accordingly, farmgate prices are discounted in the model. In terms of prices for the cropping activities, the approach adopted is that of Baird & Lonergan (2018): prices are the median 8-year values from ABARES (2020) over 2012-2020. These prices are used to update the NSW DPI GM data. Other DPI cost data have been updated for inflation using the RBA Inflation Calculator (2020). Sensitivity analyses are conducted on various prices in the results below.

Farm activities

A standard range of arable land activities for the Narrabri region (wheat, cattle fattening, cotton, chickpeas, lucerne) are included in the model. These are listed in Table 2 below.

Table 2. Arable land activities (name and GM budget unit are in brackets)

Activity name	Description	GM	Yield	Data source
Dryland wheat (DW, 1ha)	No till. Nitrogen fertiliser is applied to the crop and it is sprayed for weeds and diseases. Contract harvest.	$507/ha	2.6t/ha	NSW DPI GM budgets Dryland wheat, 2012.
Fatten weaner cattle (FWS, 100 hd).	Beef production data are separated out from lucerne pasture production in this budget. Feed production costs are deducted as they are included separately under the native and improved lucerne pasture activities.	$47359/100hd		NSW DPI GM budgets Dryland Lucerne: weaner cattle or trade steers, 2010-11.
Improved pasture: lucerne (IMP, 1 ha).	The pasture is managed with fertiliser and herbicide. Pasture provides feed for the cattle; in seasonal livestock months of feed (LSM). Data are separated out from cattle fattening in this budget.	$(258)/ha		NSW DPI GM budgets Dryland Lucerne: weaner cattle or trade steers 2010-11.
Dryland Cotton (COT, 1ha).	Crop is fertilised and sprayed for sprayed with insecticide & herbicide. Contract harvest.	$1083/ha	3.8 bales/ha	NSW DPI GM budgets Dryland Cotton NW NSW, 2012-13.
Chickpeas (CP, 1 ha).	No till. Crop is fertilised and sprayed with insecticide, fungicide & herbicide. Contract harvest.	$528/ha	1.3t/ha	Data: NSW DPI GM Chickpeas NW NSW, 2012.
Seasonal labour hire activities (LH_i)		$(40)/hr		

Native grass activities are described in Table 3. The native pasture is a mix of Queensland Bluegrass (*Dichanthium sericeum*), Mitchell Grass (*Astrebla* spp.) and Native Millet (*Panicum decompositum*). Native grass production encompasses 5 separate intermediate activities that represent different management techniques: cool burning, pasture cropping (faba beans), grazing, monoculture (Native Millet), and Kangaroo Grass (*Themeda australis*) on hilly nonarable land.

Cool burning is expected to generate a slightly higher yield, and monoculture is also expected to have a higher yield due to intensive management practices. Crop yields from pasture cropping have been found to be about 65% of conventional cropping yields (Millar & Badgery 2009). Also, yields are likely to below district average in Northern NSW based on historical average mean rainfall and associated available soil water (Lodge & McCormick 2010). For these reasons and because an average year over 20 is modelled and establishment may take a while, a yield that is 55% that of conventional crop yield is assumed. The crop is not fertilised and seed is harvested during the Feb - April period. Hand-held commercial outdoor vacuum cleaners are used to harvest the seed.

Table 3. Nonarable land activities.

Activity name	Description	GM	Yield	Data source
Native grass seed production managed by cool burning (NG_{CB}, 1 ha).	Pasture management is cool burning in June. State and local government permits required. The crop is not grazed.	$(129)/ha	0.2t/ha	Angela Pattison, agricultural scientist, pers. comm. Callum Craigie, land management trainee, pers. comm.
Native grass seed production managed by grazing. (NG_{G}, 1 ha).	Grass is grazed by beef cattle. Grass growth is minimal over Winter, at a maximum in the Summer period.	$(129)/ha	0.15 t/ha.	Angela Pattison, agricultural scientist, pers. comm.
Native grass seed production - pasture cropping. (NG_{PC}, 1 ha).	Pasture is not grazed. Faba beans are cropped. Grass seed crop is harvested Feb- April. A yield penalty for faba bean has been applied (from 1.8t to 1t/ha). Faba bean sowing rate 60kg/ha. Faba beans contract harvested.	$(310)/ha	Grass seed 0.08t/ha. Faba bean 1t/ha	Angela Pattison, agricultural scientist, pers. comm. and DPI GM budget Dryland Faba Beans NW NSW Winter 2012
Native grass seed production monoculture (NG_{M}, 1 ha).	Assumed higher seed yield 0.25/t ha. The pasture is crash grazed after the seed is harvested. Production activities are as for dryland sorghum: fertilise, spray for herbicide and insecticide.	$(326)/ha	0.25t/ha	NSW DPI GM budgets No-till Sorghum NW NSW, 2012-13. (Drew Penberthy, Narrabri agronomist, pers. comm.).
Native grass seed Kangaroo grass (NG_{KG}, 1 ha).	Kangaroo grass on hilly nonarable land	$129/ha	0.07t/ha	Data: NSW DPI GM Chickpeas NW NSW, 2012.
Unimproved pasture (UP, 1ha)	Mix of native and improved pastures. No fertiliser.	$0/ha		Pasture growth data for LSM from NSW DPI (2004).

To add flexibility and the potential to connect with Indigenous enterprises, farm or local Indigenous labour can be used for harvesting. Hence, there are 2 separate blocks of activities in the model for native grass production activities that attach to 2 different sources of labour for harvest. The Indigenous harvest activity block uses on farm resources (land and labour) for management practices other than harvest. Indigenous harvesters are not paid by the farm for their harvest labour and make a payment of $10/kg of unthreshed seed they take from the farm. Hence, seed harvested is an input used in a business activity owned and run by local Indigenous workers producing and selling products made from native grass seed for their own profit. The TGM on the harvest and sales activities of the Indigenous business should be large enough to more than cover the cost of Indigenous labour for harvest. Profitability, and well managed value chains complete with contractual arrangements are key for establishment and ongoing success in such enterprises (Gorman *et al.* 2020). As part of the Grasses for Grains project, discussions about business enterprises were conducted with the Narrabri and Wee Waa Local Aboriginal Land Councils (LALCs). It was recognised that a business may start as a social enterprise but should transition to become economically profitable. Several models could serve as options for communities to collaborate and strengthen their enterprises and share knowledge for early stage business development. Collaboration between communities with a potential for a co-managed reserve to produce native grasses, or run as a partnership with one LALC involved in production and harvest and the other responsible for processing, packaging and filling orders are among suggestions (Rebecca Cross, social geographer, pers. comm.). A potential small Indigenous enterprise based on harvesting native seed from local farms and retailing to the revegetation and rehabilitation markets is described in the Appendix. Other promising examples can be found in native seed farming and native plant food production. An Indigenous owned and operated native seed farm on the Geoff Wedlock Innovation Park in Western Australia has been established to supply seeds for the mining industry's land rehabilitation needs. This is run by the Midwest Employment and Economic Development Aboriginal Corporation and it has the potential to be a prototype for native seed production to replace dwindling wild harvest supply (Curtin University 2018).

In the model, outputs from the native grass activities are transferred by a series of resource pool constraints that make the product available for a range of marketing/sales activities (presented in Table 4) as well as feed for cattle. Seed production from these activities appears in unthreshed seed pool constraints. Faba beans from pasture cropping are also transferred to sales via a pool constraint.

Table 4. Native grass seed marketing activities

Activity name	Description	GM	Data source
Unthreshed seed sale (NG_{RVGS}, kg)	Sales to the revegetation/rehabilitation market unthreshed. Assume a farmgate price that is 35% of the retail price (based on Reseigh *et al.* 2008).	$50/kg	Angela Pattison, agricultural scientist, pers. comm. Callum Craigie, land management trainee, pers. comm.
Threshed seed sale (NG_{THS}, kg)	Threshed seed sold for human consumption.	**$9/kg**	The price is assumed about the same as for substitute products (chia or quinoa seeds) plus differentiation premium.
Unthreshed seed sale to local Indigenous harvesters (NG_{OTH}, 1kg).	Seed is sold to harvesters for further value adding in an Indigenous social enterprise.	**$10/kg**	Price assumed that links to Indigenous enterprise in the appendix.
Sales of faba beans from pasture cropping (FB_S, 1 ha).	Faba bean crop is not fertilised or sprayed. Contract harvest. Yield 1t /ha (Assumed yield discounted from 1.8t/ha (DPI data)) at $450/t.	**$429/ha**	NSW DPI GM budgets Dryland Faba Beans NW NSW (no till).2012

Transfer activities

Seasonal feed transfer activities are included to allow for carry-over of unconsumed pasture from season to season. The transfer activities allow for deterioration of pasture between seasons using discount weights suggested in Rickards & Passmore (1977). A threshing activity uses seed from the unthreshed seed pool and generates threshed seed for sale to the human consumption market. Seed is threshed by on farm labour. Hand threshing of 2 kilos unthreshed seeds takes one hour of labour and yields 150g seeds (Callum Craigie, trainee land manager, pers. comm.). It is assumed threshing takes place straight after harvest.

Land and labour constraints

Land is modelled as 3 types: 1000 arable, 750 non-arable, 100 hilly non-arable. The soils are predominately chocolate vertosols (Baird and Lonergan 2018). Labour is seasonal in the model. There are two farm staff working 40 hours per week. Indigenous labour availability is capped at 400 hours (10 people for 40 hours) in Autumn (harvest season).

Feed constraints

Seasonal feed production and requirements of feed for the cattle are calculated based on energy requirements expressed in livestock months (LSM) as in Rickards & Passmore (1977) and presented in Table 5. Native grasses are classified as "medium" quality feed and lucerne as "good" quality feed. Cattle feed requirements are the energy requirements for maintenance and growth. It is assumed that nutritional requirements (protein, vitamins and minerals) are adequately met in terms of the quality of the feed available. LSM requirements are calculated for "medium" quality feed with a grazing exercise allowance of 35%. The pool constraints allow pasture LSM supply to match cattle LSM demand. Monthly dry matter production data (kg/DM/ha) for lucerne and native grass production in the NW Slopes of NSW are taken from Murphy *et al.* (2010). Monthly dry matter production data (kg/DM/ha) for unimproved pasture are from NSW DPI (2004). Monthly data are aggregated to seasonal values. A loss of 15% from trampling and fouling is assumed.

Table 5. Feed pool constraints (LSMs per unit of activity)

	Lucerne (1ha)	Native pasture mix (1ha)	Kangaroo Grass (1ha)	Unimproved pasture (1ha)	Weaner fattening (100 hd)
LSM Su	-165.48	-56.8	-28.4	-111.14	
LSM Au	-72.12	-26.39	-13.195	-49.2525	2040
LSM W	-63.88	-3.34	-1.67	-33.6125	2160
LSM Sp	-142.54	-24.39	-12.195	-83.4668	2130

Threshold constraints

Although prices for native grass seeds are currently high, it is known that demand in native seed markets is inconsistent and that seed markets suffer from a range of market failures (Coggan *et al*. 2009). Because the pasture cropping activity is quite lucrative and the nonarable land is only used for generating indirect income from cattle or income from native grass seeds and faba beans, there is potential to use all nonarable land for native grass income earning activity. However, this yields quite large and possibly non-marketable or storable amounts of seed. Reported yearly native seeds sales from pasture cropping at Winona farm near Gulgong are 1t from 121 ha (Seis 2015). To prevent solutions of potentially unmarketable quantities, threshold constraints are included in the model for arbitrary amounts of unthreshed seed (10t) and threshed seed sold to Indigenous harvesters (5t). Cattle fattening is relatively lucrative, and to avoid impractical outcomes of large cattle fattening numbers this activity was capped at 200 head. This also reflects the reality that large numbers of cattle stock may not be available.

Rotations

Two rotation are included. On nonarable land, native grass pasture cropping is rotated with grass seed production (cool burning, monoculture or grazing). Wheat, cotton, chickpea, long fallow, lucerne are rotated on arable land.

Results

The TGM value of the optimal farm plan is $1.0133m. All the arable land is used to produce on average 200 ha each of cotton, chickpeas, dryland wheat, lucerne and long fallow. There is plentiful supply of lucerne to fatten 200 head of weaner steers without any carryover between seasons. There is surplus feed production raising the potential for hay production (not modelled). A total of 112 ha of native grass pasture is produced (56 ha is produced using cool burning and harvested by on farm labour and 56 ha is pasture cropped native grass harvested by Indigenous labour). Threshold constraints are binding: 10t of unthreshed native grass seed is sold (harvested with on farm labour) and 5t of unthreshed seed is sold to Indigenous harvesters. The surplus of unthreshed seed above the threshold harvested from cool burned pasture is threshed on farm yielding 61kg of threshed native grass seed for the domestic human consumption market. All on farm labour available in Autumn is used (due largely to threshing requirements). The seed harvested by the Indigenous workers generates $50k for the farm and this assumes enough market demand for seed. It is not possible to know the size of the market for unthreshed seed and information on that market potential is presented in the discussion section below. The total pasture cropping activity produces 56t of faba beans for sale. About 637 ha of nonarable land are left idle in this plan. This suggests a change in the rotation that requires lucerne, (so cattle would instead be fed on unimproved or native pasture) or the potential for conservation set aside.

If lucerne is excluded from the rotation on arable land, the TGM increases slightly to $1.171m. All the arable land is used to produce on average 250 ha each of cotton, chickpeas, dryland wheat, and long fallow. 200 weaner steers are fattened on unimproved pasture (209ha) and 2401 LSMs of feed are carried over from Autumn to Winter. Native pasture production increases slightly to 120 ha (60 ha cool burned using on farm labour and 60 ha pasture cropped using Indigenous harvesting). Unthreshed seed sales results are the same as above, and the increased area under native pasture results in 60t of faba bean sales and 134kg of threshed seed for the human consumption market. In total 329 ha of nonarable land are used.

In sum, the results indicate that across rotations with and without lucerne, native grass production would be included in an optimal farm plan. Excluding lucerne from the crop rotation generates a farm plan where the cattle are fed on a mix of unimproved pasture and native grass with some fodder carried over from Autumn to Winter. The increased TGM when lucerne is excluded comes as a combination of reduced cost from feeding the cattle on unimproved and native pasture and higher earnings on arable land devoted to more cropping. The sensitivity analysis below is conducted on the model with lucerne included as from an agronomic viewpoint it is recommended for weed control (Drew Penberthy, Narrabri agronomist, pers. comm.). In terms of model validation, McCarl & Spreen (2002) suggest an approach of comparing model results to real world counterparts. The solution was considered realistic by the farm mangers of the Llara farm in Narrabri (Peter Bell & Kieran Shephard, Llara Farm managers, pers. comm).

Sensitivity Analysis

In the analysis below crop solutions on arable land remain as per base solution results so only the results for the native grass activities are presented.

Native grass seed prices

For the native grass activities, GMs are costs that mostly reflect the current high retail price of seed assumed ($150/kg). As the GMs for all pasture cropping management options are constructed using the same price for seed it is not possible to vary the GM of one activity alone. Native seed prices are also part of the marketing/sales activities. As the model represents an average year in a 20-year span, one approach is to consider seed prices for production given and focus on the effect of price changes on the sales activity GMs. These sensitivity analyses are presented below.

Unthreshed seed

The threshold constraints cap the unthreshed seed sales, so the farm plan is not sensitive to price increases. The sensitivity analysis indicates that the unthreshed price could fall to $0.5/kg before the solution to the farm plan would change. However, from the GM budget in the appendix, Indigenous harvesters would withdraw their offer to pay $10/kg if the retail price falls below $64/kg for unthreshed seed (roughly $22.4/kg farmgate) as it becomes uneconomic. At retail prices below $64/kg the Indigenous business could not cover all costs including employment of 2 full time workers. Accordingly, the model was estimated with a GM on unthreshed seed sales of $21 (corresponding to $22.4/kg farmgate price) and with the indigenous harvest block removed. The results are presented in Table 6 below.

Table 6. Sensitivity of farm plan to unthreshed seed price

Unthreshed seed price (farmgate)	NG_{CB} (ha)	NG_{PC} (ha)	NG_{THS} (kg)	NG_{RVGS} (t)	FB_S (t)	TGM ($m)
$22.40/kg *	39	39	60	10	39	0.6735
$1.64/kg*	39	39	60	10	39	0.4640
$1.60/kg *	3	3	65	0	3	0.4639

*sale to Indigenous harvesters excluded in model at these prices

A solution that includes native grass production emerges over a large range of prices. Because of the vertical stacking of outputs (faba beans and threshed seed) and the rotation requirement the price for seeds can fall to very low levels and pasture cropping remains included in the plan. At almost any price, native grass seed production that includes a mix of pasture cropping and cool burning management is in the plan. A sensitivity analysis on the price of sales to Indigenous harvesters (not presented) yields similar results.

Threshed seed prices

Prices would need to become unrealistically high (over $200/kg) before the plan changes to a slight increase in threshed seed sales. The farm plan is not particularly sensitive in the downward direction either. As can be seen in Table 7, a fall from the current retail price of $10/kg to $0.95/kg would stop seed sales to that market. Again, due to the profitability of faba beans from pasture cropping, native grass production remains in the plan.

Table 7. Sensitivity of farm plan to threshed seed price

Threshed seed price	NG_{CB} (ha)	NG_{CBI} (ha)	NG_{PC} (ha)	NG_{PCI} (ha)	NG_{THS} (kg)	NG_{RVGS} (t)	NG_{OTH} (t)	FB_{S} (t)	TGM ($m)
$280/kg	57			57	88	10	5	58	1.0292
$10/kg (base solution)	56			56	61	10	5	56	1.0133
$0.95/kg	29	25	54			10	5	54	1.0128

Faba bean prices

The faba bean sale GM ($429) is calculated using a market price of $450/t. This price can vary between $460 and $263 before a new farm plan would emerge. The results are presented in Table 8. Unsurprisingly, higher prices result in more pasture cropping. As can be seen from the table, at high prices a large amount of land is devoted to pasture cropping with Indigenous harvest. This falls along with the price and for $263/t less land is devoted to native grass harvested by Indigenous labour.

Table 8. Sensitivity of farm plan to faba bean price

Faba bean price	NG_{CB} (ha)	NG_{CBI} (ha)	NG_{PC} (ha)	NG_{PCI} (ha)	NG_{THS} (kg)	NG_{RVGS} (t)	NG_{OTH} (t)	FB_{S} (t)	TGM ($m)
$460/t	54	173		227	61	10	5	227	1.014
$450/t	56			56	61	10	5	56	1.0133
$263/t	29	25	54			10	5	54	1.0032

Native grass seed yields

To explore the sensitivity of results to seed yield, all native grass seed yields were reduced proportionally over a range of values and the results are reported in Table 9 below. As seed yield declines, the nonarable land devoted to native grass expands. If yield is 10% that assumed in the model, native grass production expands, use is made of seasonal feed transfers and the use of Indigenous harvest is no longer in the farm plan.

Table 9. Sensitivity to native seed yield (including lucerne)

Yield (kg/ha) % of base solution value	NG_{PC} (ha)	NG_{PCI} (ha)	NG_{CB} (ha)	NG_{CBI} (ha)	NG_{RVGS} (t)	NG_{OTH} (t)	NG_{THS} (kg)	FB (t)	Non arable land use (ha)	TGM ($m)
100%		56	56		10	5	61	56	112	1.0133
80%		70	70		10	5	60	71	140	1.0131
60%		94	94		10	5	59	94	188	1.0129
40%		140	140		10	5	55	141	280	1.0129
10%	375		350	25	10	5		375	750	0.9644

In Table 10 yield sensitivity analysis for the model without lucerne in the rotation is presented. When native grass is only 10% as productive as the base case, land devoted to unimproved pasture for feed falls to 84 ha, and is replaced by 105 ha of native grass grazing (100 ha Kangaroo Grass on hilly land and 5 ha pasture managed by grazing). There is a substantial increase of feed that is carried over with 300 LSM Spring to Summer, 7140 LSMs carried over from Summer to Autumn, and 4966 carried over from Autumn to Winter. Grass seed is produced from 328 ha devoted to native pasture managed by cool burning.

Table 10. Sensitivity to native seed yield (excluding lucerne)

Yield (kg/ha)	UP (ha)	NG_{G} (ha)	NG_{KG} (ha)	NG_{PC} (ha)	NG_{PCI} (ha)	NG_{CB} (ha)	NG_{CBI} (ha)	NG_{RVGS} (t)	NG_{OTH} (t)	NG_{THS} (kg)	FB (t)	Non arable land use(ha)	TGM ($m)
100%	209				60	60		10	5	134	60	329	1.171
80%	209				75	75		10	5	131	75	359	1.1708
60%	209				99	99		10	5	127	99	407	1.1705
40%	209			134		71	63	10	5		100	477	1.1544
10%	84	5	100	333		328		10			100	750	1.004

For both arable land rotation scenarios the reduced productivity of native grass seed production induces more nonarable land to be devoted to native grasses (more rapidly when lucerne is excluded).

Discussion

The representative farm model was constructed with the aim of exploring native grass potential and linkage to local Indigenous business. Across a range of native grass seed prices, grass seed yields and rotations, the farm decision model indicates that native grass production would be included in the farm plan along with crops and cattle fattening. Indigenous harvest in the results links farm production to Indigenous business. An underlying assumption is that native grass seed markets function well, and technical issues of production have been mastered, which raises caveats for the results.

Firstly, when modelling activities such as native grass production it is assumed that the technical difficulties of production are understood and mostly mastered. There are successful examples of native grass pasture cropping (e.g. Winona Farm, NSW), however there are challenges associated with native grass production in particular, establishment. Establishment problems have been attributed by some to poor seed quality, a problem associated with market failures in native seed markets (Coggan *et al.* 2009; Hancock *et al.* 2020). Secondly, markets for native grass seed are fragmented and poorly functioning (Reseigh *et al.* 2008, Coggan *et al.* 2009; Hancock *et al.* 2020). The demand in native seed markets is inconsistent and supply is erratic. In these markets information flows are poor, and a range of market frictions/failures can be identified at the institutional (associated with the nature of government revegetation programs, inconsistency of seed collection permits across states, poor specification of native seed provenance), industry (fragmented industry, small scale production, high industry turnover, poor quality control) and biophysical (insufficient access to seed resources) levels (Coggan *et al.* 2009; Whitten & Shelton 2005).

However, although there are market challenges some carefully targeted intervention as suggested in Coggan *et al.* (2009) might encourage commercial development. There are many sub-markets for native grass output: mine site rehabilitation, government and NGO revegetation programs, human medicines and food, lawn turf, pasture cropping, stock fodder, soil rehabilitation, and carbon sequestration. The demand from some of these is potentially large: there are currently over 50,000 abandoned mines in Australia (Unger 2017) and the 2011, the NSW Auditor-General's report indicated thousands of hectares of degraded and contaminated lands (NSW Auditor-General 2011). Hence there is scope for targeted policies that will generate on-going demand for native seeds. There is also potential to repurpose government Indigenous welfare expenditure to start-up capital for projects that provide diversified economic development opportunities that allow for connection to country (Sangha *et al.* 2019; Campbell 2016). Beyond economic gains these will include social, environmental and cultural benefits. Compared to introduced grass species, native grasses store more carbon underground and there might be greater soil stabilization and larger root masses with native grasses (Lauren Waller, ecologist, pers. comm.). The environmental benefits of production with an ecosystem approach of a mix of native grasses are likely to be substantial.

Conclusion

Vertical stacking of products such as native seeds and pasture crops make the inclusion of native pastures on a representative Narrabri farm economically viable. Native seed production brings with it the possibility of linking with local Indigenous enterprises. Many challenges and opportunities exist in native seed markets. From a broad perspective there a substantial intersection of Australia's Strategy for Nature 2019 – 2030 and the Closing the Gap policy. Restoring native grasslands and raising the welfare of Indigenous people accord with the goals of these policies.

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Appendix: A small Indigenous enterprise

Many different enterprises could be constructed in the native grass production context. Below is an example of a simple business enterprise.

Description

The enterprise involves employment of 2 full time staff and the hiring of casual labour to harvest grain from local farming properties as described in nonarable land activities in the paper above. Consistent with that description, the Indigenous business pays the farmer $10/kg of grain harvested. The Indigenous harvesters are paid $30/hr for their labour. This harvested unthreshed grain can be retailed directly to the revegetation or rehabilitation markets at a price higher than the farmgate price. An alternative is to thresh the grain and sell the clean seed into other markets (for example as botanicals to distillers or for other further value adding, for example to be milled). A thresher and a cleaner would be required for this (approximate cost $20K). To keep calculations simple, only sales of threshed seed are considered below. The enterprise would require start-up funding of approximately $120K. It would require:

- harvester on a trailer
- utility vehicle
- shed on a concrete slab to house the machinery and equipment and act as office
- IT equipment.

This enterprise is built on land already owned by either the Narrabri or Wee Waa Local Aboriginal Land Council. The enterprise would require 1-2 full time staff and so the net income would need to cover the variable and fixed costs associated with the business operations. To examine the potential, simple gross margins budgets were calculated (presented in Tables 11 and 12 below). Harvesting is an intermediate activity so the GM is a cost of $1630/ha, the GM for the sale of unthreshed seed is $66.53/kg, and threshed seed GM is ($14.7). The negative GM is due to the machinery costs for the threshing. Threshing could alternatively be done by hand, but for simplification it is assumed here that sales are of unthreshed seed alone. Market potential for threshing could be considered based on future market prospects at a later stage.

Table 11. Native seed harvest GM

Activity Name:	Harvesting of native grass seed
Activity Unit:	1 ha harvested (yield 150 kg seed)
Income:	No direct income
Variable Costs:	
Contract labour 1hr/ha @ $30/hr	$30
Machinery (fuel, oil, filters, tyres, batteries & repairs)	$60
Insurance	$10
IT, phone	$20
Sundries	$20
Total variable costs (GM)	$1630

Table 12. Sale of unthreshed native seed GM

Activity Name:	Sale of unthreshed seed
Activity Unit:	1 kg harvested (yield 150 kg seed)
Income: 1 kg @ $100/kg	$100
Variable Costs:	
Bags and tags	$0.5
Insurance (2.97% on-farm value)	$2.97
IT, phone	$20
Sundries	$10
Total variable costs	$33.47
Gross margin	$66.53

If the numbers from the farm LP solution above are applied to production for this business, then 56 ha are harvested by the Indigenous harvesters. Assuming the indigenous enterprise could put a retail price of $100/kg on unthreshed seed this would yield a TGM of $467572 for the business if the business were to sell unthreshed seed only. This amount would then need to cover the fixed costs of the business (presented in Table 13 below) of $10688.93 plus the wages for the two full time employees (assume $80,000p.a./employee). This yields a net income for the business of $296,883. This amount of net income could be used to cross-subsidise some sales into the threshed seed market as an attempt to explore further market potential. There would also be potential for milling. If the retail price received for the unthreshed seed were to fall close to the farmgate price, say $70/kg, net income would be $52367. At $60/kg the enterprise could only employ 1 person at the assumed wages. The business would be sensitive to fluctuations in the price of unthreshed seed but because of the low start-up costs would only require a small grant if ready cash were unavailable.

Table 13. Fixed costs

Insurance costs	
harvester & trailer	$400
shed	$500
IT, phone	$8
utility van	$342.4
Depreciation costs	
harvester & trailer	$2000
shed	$2500
IT	$419.60
utility van	$2149.33
Interest costs	
harvester & trailer	$100
shed	$125
IT	$5.25
utility van	$80.6
Shedding costs	
harvester & trailer	$12.5
utility van	$6.25
Registration cost	
utility van	$737
trailer	$1303
TOTAL	$10688.93

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