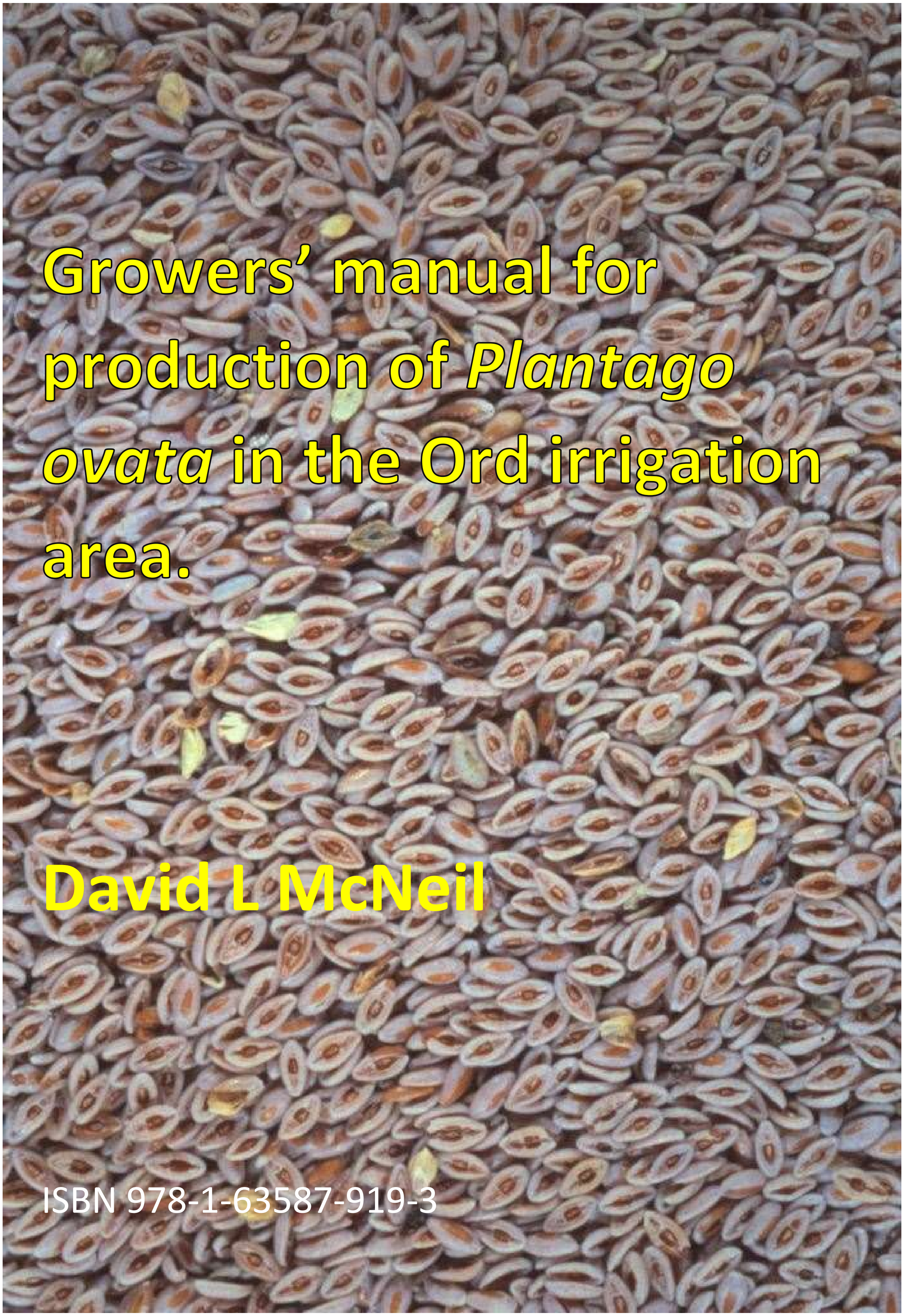

Growers' manual for production of *Plantago ovata* in the Ord irrigation area.

David L McNeil

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Author

DL McNeil

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Abstract

This book considers the requirements for commercial mechanised production of *Plantago ovata* as an irrigated crop and the suitability of the Ord river irrigation area for production. It reviews the production system under the headings; a) introduction/background and philosophy of Australian production expansion, b) genetics, breeding systems, breeding and varieties, c) seed management and sowing, d) within growing season agronomy and management, e) harvest and processing.

The primary information source used was research conducted by the author and others at the Frank Wise Institute of Tropical Agriculture between 1984 and 1988 plus research by the author and students at Lincoln University in New Zealand from 1986 to 1992.

This first hand research has then been checked against and supplemented by an extensive review of the published literature.

Keywords

Isabgol, psyllium, *Plantago ovata*, breeding, agronomy, male sterility, nitrogen, fertilizer, thrips, germination, sowing rate, planting date, harvester ants, irrigation, weed management, genetics, environment, lodging, harvest index, temperature, soils, thrips, herbicides, pesticides, harvesting, nutrient analysis, processing, commercial crops, mechanisation, quarantine requirements,

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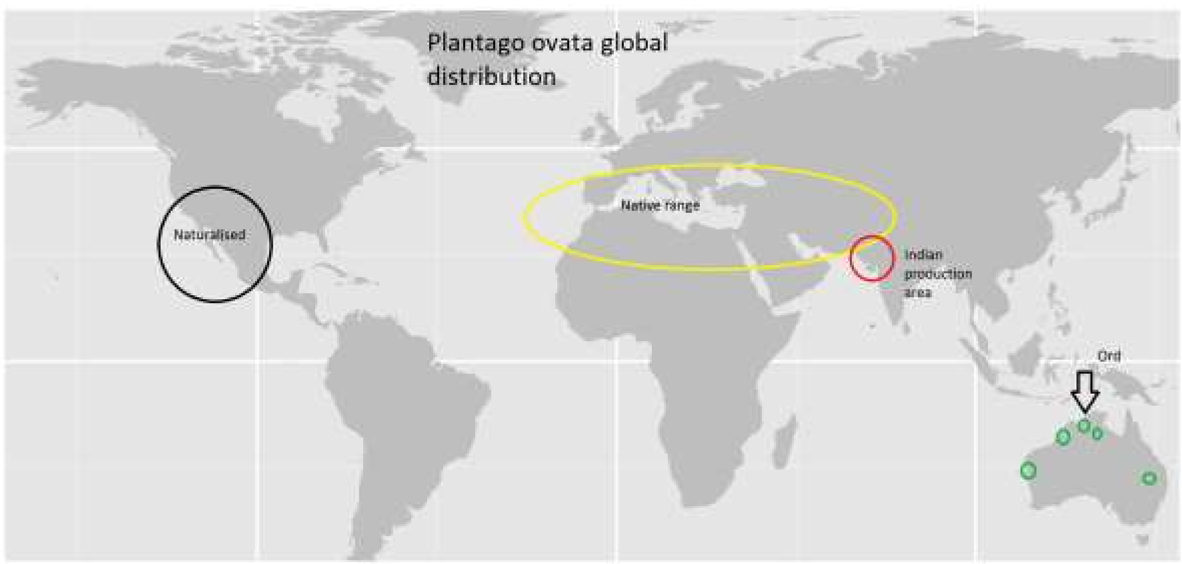
1. Introduction

1.1 General background

Plantago ovata is a native herb which grows across the Mediterranean region from Portugal to Pakistan from approximately 18-34 Degrees North latitude and is naturalised in the SW USA and Mexico (USNPGS, 2003). The dominant production area is Gujarat and Rajasthan states in India (ITC, 2014). Major price spikes have occurred a number of times (eg 2014-2016, ITC 2014; early 1980's, McNeil 1985) largely in response to both political and environmental stresses associated with having a single production area. As a result of these spikes efforts have been made in other regions to expand production in mechanised production areas including Arizona (Rubis and Massman, 1967) and Australia (McNeil, 1985; McNeil, 1989a; McNeil, 1989b; McNeil, 1991a; McNeil, 1991b; McNeil and Duran, 1992; McNeil, 1996; McNeil, et al., 1986; Riley et al., 1987; Riley et al., 1988).

Figure 1.1 Regions of the world relevant to P. ovata *production. Possible irrigation areas in Australia are indicated by green circles.*



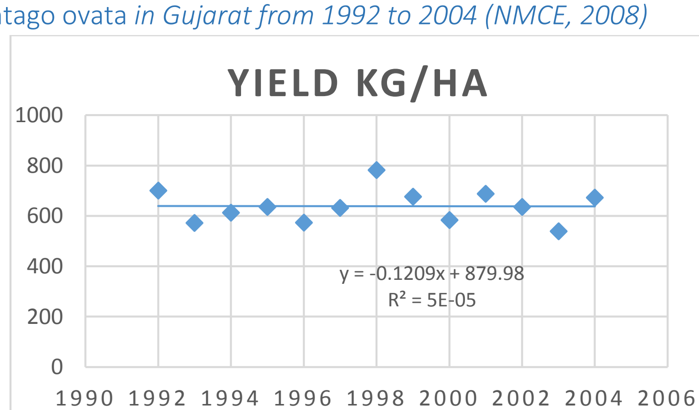
In order to expand the production into different areas an analysis of the suitability needs first to be undertaken and some form of competitive advantage realised. The analysis needs to include: a) competitive advantage of the region; b) potential of alternative expansion areas; c) the logistics, grower/purchaser/researcher inclination and resource availability; d) environmental suitability including soils, water, temperatures, day length, rainfall, sunshine etc.; e) development costs for the production system relative to the potential value of the industry; f) state of knowledge; g) potential profitability.

With respect to these analyses care needs to be taken to be sure that the factors believed to be required are indeed necessary. Thus reliance on published advice for good agricultural practise in existing areas (eg Jat et al., 2015) may not be adequate for other areas. Four examples of these potentially misleading needs are; 1) to sort out the many "known requirements" into those that are real against those that are merely the way it is done presently in the existing areas; 2) the need to develop new specific practices optimised to a new and different production system; 3) there are the "unknown requirements" that are simply done by default in existing areas and not explicitly recognised as critical. These need to be optimised also. Finally, 4) it may be possible to modify the apparent requirements by breeding or system changes. Examples of the four types of issues with respect to *Plantago ovata* are:

1. The first type of issue is illustrated by soil pH needs. In Gujarat Plantago is typically grown on fairly neutral soils and management instructions indicate they are preferable. However, subsequent research leading to expansion into Rajasthan state on more alkaline soils indicated that these could grow good crops as well up to pH 9.6 (Dagar et al., 2006).
2. The very low seed sowing temperature requirements (~20 degrees C) specified by Jat et al., (2015) may be linked to the sandy soils in which they are grown. In heavier soils the germination may occur well at higher temperatures (McNeil, 1989a).
3. An example of the third issue results from the universal Indian habit of growing the crop post wet season. There is very limited information available on day length needs for flowering and the potential to grow the crop out of season. However, experimental plots have been grown in Zanjan, Iran (Omidbaigi and Mohebby, 2002) across the dry summer period producing yields up to 900kg/ha.
4. The need for warm temperatures due to the frost sensitivity of *Plantago ovata* is widely recognised and creates a major restriction on production areas. However, the University of Arizona managed to overcome this specific need by crossing *P. ovata* with the frost resistant native *P. insularis* (Rubis and Massman, 1967).

There seems to be an opportunity for expansion of *P. ovata* from its present growing area. Figure 1.2 shows there has been no significant increase in productivity in Gujarat between 1992 and 2004 with yields remaining at a low average of approximately 630 kg/ha. This expansion growing area could be in Australia. Appendix 2 lists the import conditions in order to bring *P. ovata* seed into Australia and there do not seem to be any significant issues involved. Some seed is held presently held at U. Adel. (https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Identification-of-arabinoxylan-biosynthetic-genes-in-plants).

Figure 1.2 Yield of Plantago ovata *in Gujarat from 1992 to 2004 (NMCE, 2008)*

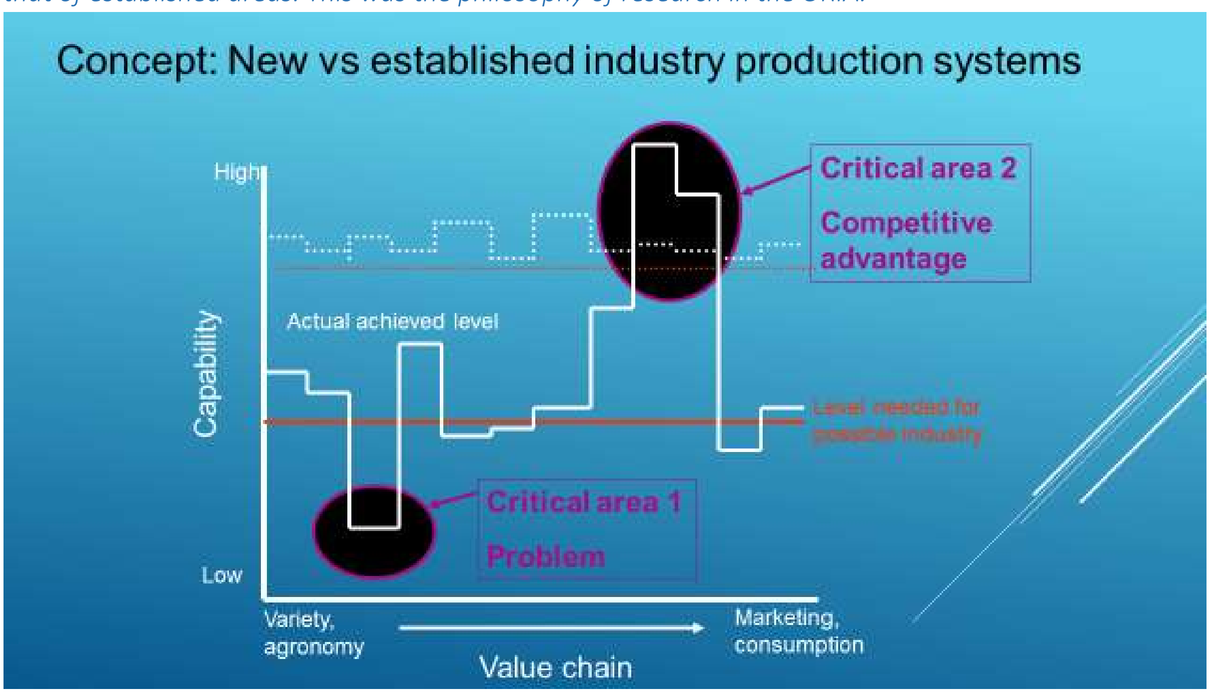


1.2 Ord Irrigation area suitability analysis

1.2.1 General

In order for a crop to be grown in a new area there needs to be specific competitive advantage for that area. Figure 1.3 demonstrates the generalised concept. This lead to the general approach illustrated in the Ord area publications in deciding which research to conduct. Competitive advantage was based on a) the potential ability to grow the crop on large areas using mechanised higher input systems, b) without the same level of environmental and political risk, c) in an out of season location with d) an ability to have greater quality control over the product. The higher risk activities centred around a) the ability to compete with weeds and pests, b) to adequately optimise other areas in the agronomic system, c) as well as maintain a full value chain including processing and marketing. There was also competitive advantages based on the size of the irrigation resource (water and land) in the Ord and therefore a lack of competition for limited resources by existing production systems.

Figure 1.3 A stylised depiction of new and established area production systems for a crop. The dashed lines indicate in an established area all parts of the system have been optimised. In a new area the overall system usually has a lower potential initially but there may be a specific element of the value chain that creates competitive advantage (eg out of season, production security, quality) allowing production to go ahead. There may also be issues that are so poor they prevent production (eg high seasonal temperatures, thrips). Research and Development thus needs to be of three kinds; 1) increasing competitive advantage, 2) eliminating serious issues, 3) optimising the whole system to produce outputs that approach or exceed that of established areas. This was the philosophy of research in the ORIA.



1.2.2 Irrigation area opportunity

The Ord irrigation area (ORIA) is located approximately 16° South latitude in a monsoonal zone with relatively flat land serviced by the Ord dam. The Water Corporation (2016) provides some information on the irrigation area. The Department of Water (2006) provides detailed information on water management, availability, flows and other aspects of water in the ORIA. The Kununurra Historical

Society also provides a wide range of photos of the area during its development (https://www.flickr.com/photos/khs-museum/with/9113867003/). Total dam capacity is 10,763 million cubic meters at full storage with a "top of wall" storage of 40,500 million cubic meters. Most water in the system still flows to flood and out to sea each wet season ensuring that there is always adequate water for present and future irrigation demands as well as environmental flows. The dam has 30 Mega watts of installed hydroelectric capability ensuring adequate power for any industrial needs in the area. There is a local airport, administrative services, hospital and school. Ordco (http://www.ordco.com.au/) has been in operation as a farm supply and processing co-operative since 1963 and more recently as an independent trading entity.

Table 1.1 Soil characteristics comparison between Indian growing regions and the ORIA

Variable	Gujarat *	Poona *	ORIA #		
			Ord sandy loam	**Cununurra clay**	**Cockatoo sand**
Sand %	52	38	78	35	93
Silt %	19	21	14	13	1
Clay %	27	42	8	52	6
pH	7.8	8.0	6.0	7.5	6.5
Description			Northcote (1979)		
^ Bulk density			1.7	1.6	1.6
Possible deficiencies			P, N, Zn, Cu	P, N, Zn, Cu	P, N, S, Zn, Cu, Co, Mo, Fe
Categorisation			Gn 2.1	Ug 5.29	Gn 3.11/21
Description			Grey brown fine sandy loam grading to clay at depth	Deep self mulching cracking clay	Loamy reddish brown sand grading to sandy loam at depth
Potential area			7,000 ha	70,000 ha	15,000
Moisture available			92 mm Top 60 cm	86 mm Top 60 cm	50 mm Top 100 cm
C 0-15cm, 60-80cm %			0.5, 0.25	0.5, 0.45	0.17, 0.10
CEC mEquiv/100g			12	40	2-4
N 0-15cm, 60-80cm %			0.03, 0.02	0.04, 0.02	0.02, 0.01
Soluble P			0.012	0.007	0.004
Soluble K			0.4	0.4	0.04

* Pendse e al., (1976); # Parberry et al., (1968); Gunn (1969); ^ McNeil 1985.

At present stage 1 of the irrigation area is fully developed (16,500 ha) and stage 2 is under development with 13,400 additional ha of irrigation land available for development by Kimberley Agricultural Investment (http://www.kai-australia.com.au/). They have started clearing and planting the first 2,500 ha and are committed to the development of 7,400ha of the Goomig (Weaber Plain) farm area with an option to develop a further 6,000ha of Knox Plain land (WADSD 2016). All of this area is Cununurra clay.

In addition significant further releases of land in both Western Australia and Northern Territory are possible in the area with sufficient water available to fully service these new areas. For example a further 6,000 ha of Cockatoo sands has been investigated in detail for a possible stage 3 release (Smolinski et al., 2015). It is this availability of both uncommitted land and water that puts the Ord in a premier position to consider planting additional crops relative to the other possible northern irrigation areas identified in Figure 1.1. These other areas presently have full utilisation of limiting water in high value crops. Growers in the ORIA also have experience and equipment used with small seeded field crops (Bell, 2015) including vegetable and flower seeds, chia and quinoa and should thus easily adapt to *P. ovata* growing. Table 1.1 indicates that ORIA soils span the characteristics of the Indian growing regions and experiments should be able to distinguish the most suitable locations to grow *P. ovata*. The two main soil types in the area are the Cununurra clay group (a neutral grey, self mulching, cracking clay with high water holding and reasonable drainage) and the Cockatoo sands (Figure 1.6, a very free draining sand) as well as small areas of a silty loam levee soil (Figure 1.4, Smolinski et al., 2011, 2015). The clay soils are generally bed irrigated by gravity feed (Figure 1.5) and have frequently been laser levelled to ensure optimal irrigation. The other soil types are overhead irrigated by a range of means (centre pivot (Figure 1.5), travelling guns and drip or microsprinklers).

Figure 1.4 Levee soils on the Ord showing the Ord river in the background and bananas to the left.

The area is serviced by the town of Kununurra which has government services and links to tourism, a surrounding pastoral area and nearby mining leases (eg Argyle diamond mine), paved road access to southern cities and Darwin as well as links to the nearby port of Wyndham (Water corporation, 2016).

Growers in the region are also serviced by the DAFWA (Dept. Agric. & Food West Aust.) Kimberley Research Station (KRS) which has operated since 1946 (https://www.flickr.com/photos/khs-museum/sets/72157626811329813/) which contains the Frank Wise Institute of Tropical Agriculture where the research reported on later was carried out.

Figure 1.5 Cununurra clay soils showing flat, furrow and bed gravity fed irrigation systems. A centre pivot on Cockatoo sands is in the background.

Figure 1.6 Cockatoo sands.

Taken in total, provided environmental, economic, production system, crop development and value chain (marketing & processing) conditions are suitable there would seem to be potential for *P. ovata* production in the Ord scheme. This does not preclude other areas (eg Gascoyne) having potential and investigation may be warranted. However, the Ord seems the best first choice for investigation.

1.2.3 Environmental comparisons between Ord and Indian production areas

Both Gujarat state and the Ord region are tropical monsoonal climates. They have a wet summer monsoon followed by a cooler dry season (Rabi in India). It is in this dry season that the production of *P. ovata* takes place in both regions using supplemental irrigation. With both areas being at similar latitudes (16° S; Ord: 22° N Gujarat) day length timing variation is similar for the two regions. However, from an environmental perspective this leaves considerable potential variation in the temperature (high and low) and rainfall regimes which could differentially affect production.

1.2.3.1 Temperature and rainfall

In view of the potential for small changes in mean temperatures to adversely affect a *P. ovata* production system (particularly field establishment) it is important to investigate how much effect climate change has had on temperatures in the region. Figure 1.7 shows for the important month of May when sowing may be undertaken there has been no significant drift in either mean monthly maximum or minimum temperatures since the start of records in 1944. Detailed analyses of the dry season climate (Figures 1.9, 1.10) suggest minimal significant drift over the last 50 years which indicates use of the mean data to compare with Indian production areas is a viable option. Importantly there has been no great increase in spring rainfall and, if anything, a small reduction in temperatures during autumn and winter bringing the climate closer to that of Gujarat.

Figure 1.7 Mean monthly maximum and minimum temperatures at the Kimberley Research Station for the month of May. Linear regression formulae and coefficients are attached. BoM Australia.

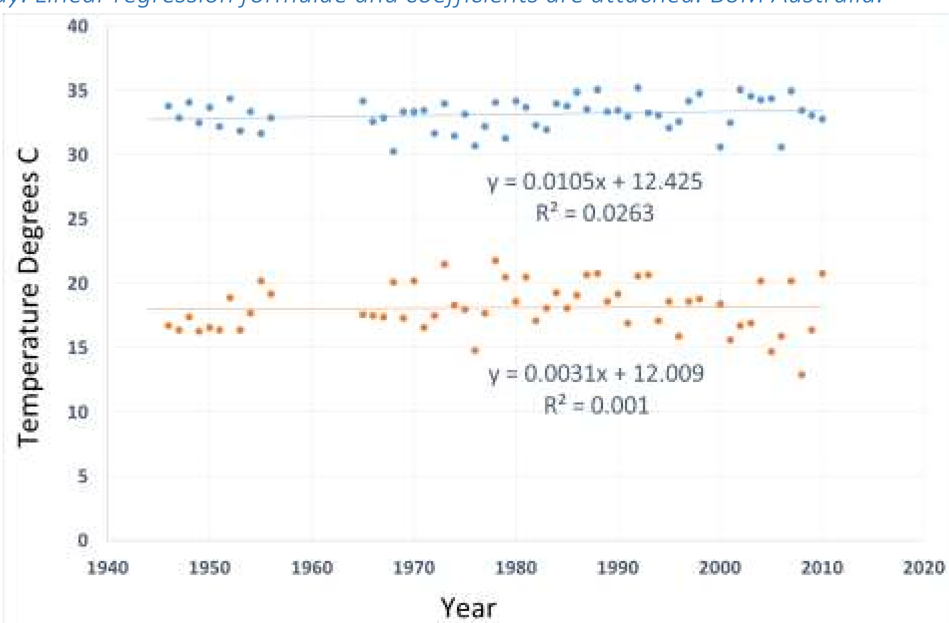


Figure 1.8 Plantago ovata *global exports.*

https://www.thedollarbusiness.com/magazine/isabgol-try-and-digest-this/17417

Seasonal temperatures presented in Figure 1.9 indicate that the seasonal variation is slightly greater in the Indian production area with slightly (~ 2° C) lower mid dry season temperatures and slightly higher mid-summer temperatures. However, for the intervening months (when sowing and harvesting take place) both maximum and minimum temperatures are very similar suggesting the Ord would be suitable for production of *P. ovata*

Figure 1.9 A comparison of temperatures between the Ord Irrigation area and Ahmedabad, Gujarat.

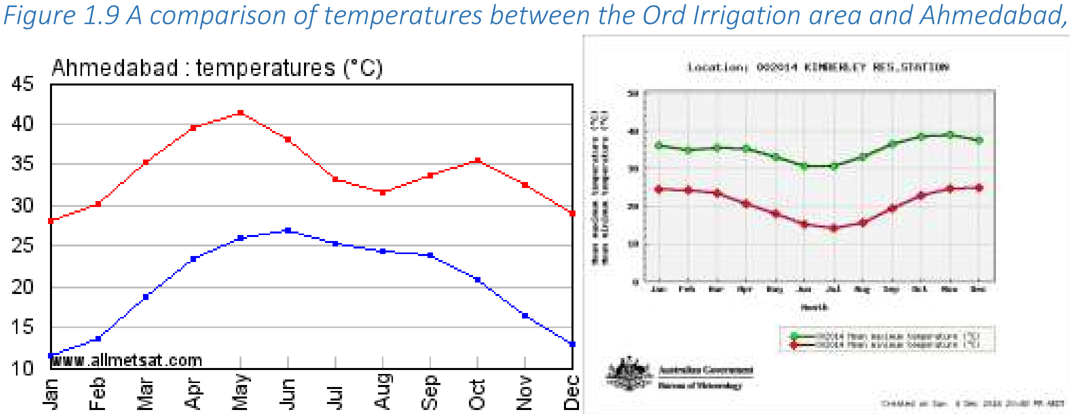


*Figure 1.10 Climate trends for Australia showing mean winter (*P. ovata *growing season) and Autumn (*P. ovata *germination season) seasonal temperatures.*

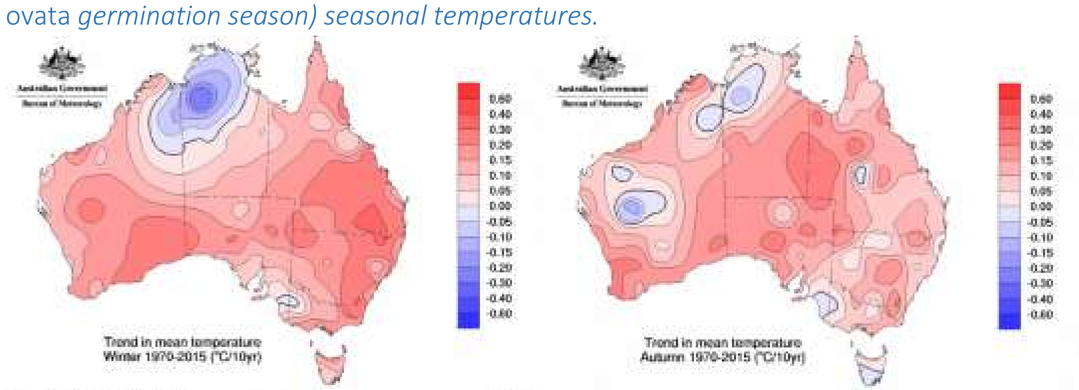
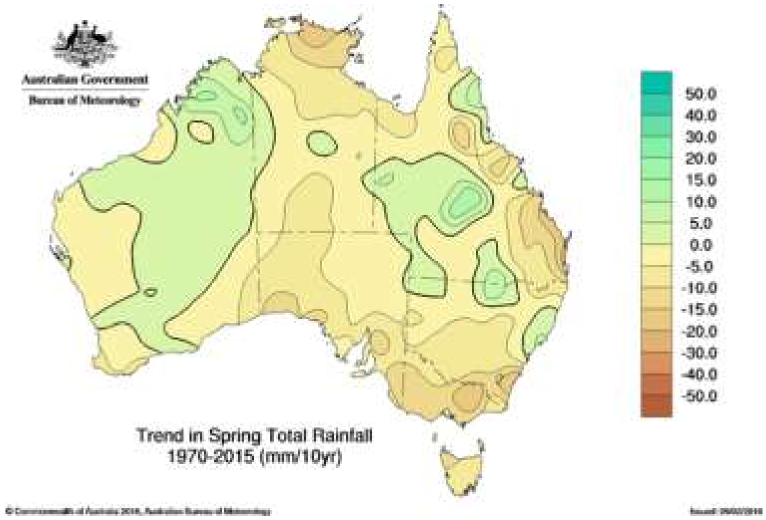
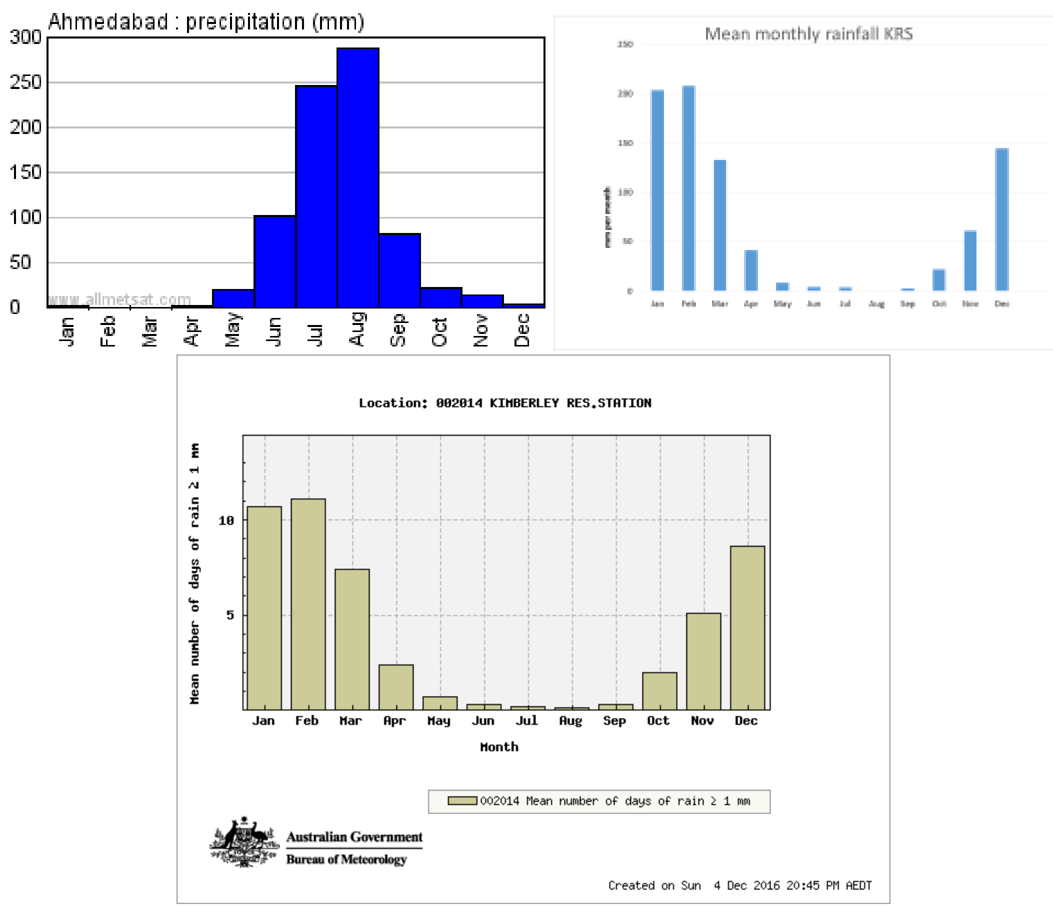


Figure 1.11 Climate trends for Australia showing mean spring rainfall when P. ovata would be harvested.



Rainfall distributions are similar in the two locations with very low rates during the harvest period. Figure 1.12 shows during September in the ORIA there is only a 0.3 chance of getting a day with rainfall of greater than 1mm during the month. The chance of a storm severe enough to shatter heads is less.

Figure 1.12 Rainfall distribution for the Ord Irrigation area (KRS) and Ahmedabad, Gujarat.



1.3 Conclusions

Overall the ORIA and Gujarat seem to have similar climates suggesting that there would not be any environmental constraints to production of *P. ovata* in the Ord system (ORIA). In the Ord:

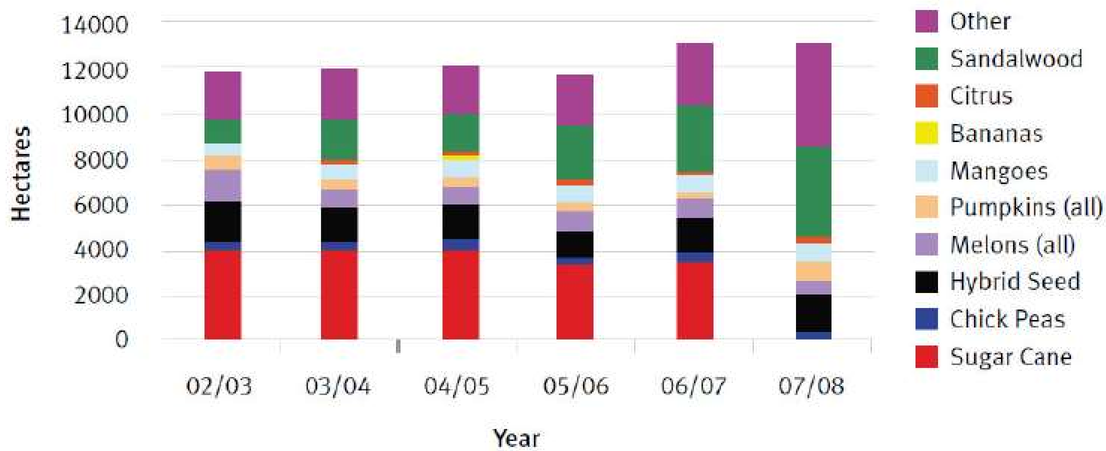
- Soils span the characteristics of those used in India
- Temperatures and rainfall distributions are similar
- The climate seems fairly stable and similar to Gujarat
- Land and water resources are available
- There is adequate infrastructure for production
- There is a substantial research resource available
- There are growers and researchers in the area interested in small seeded crops

The remaining book sections will deal with agronomic research results for the ORIA compared with other published data. One point to remember is much of the research was conducted under sub-optimal conditions (eg old variety and non-optimised agronomy). Thus yield data is often best considered in relative not absolute terms. In addition newer varieties and agricultural chemicals are available that may also improve production. This emphasis on the ORIA should not preclude interest in other Australian irrigation areas but these are at best unknown possibilities and would entail additional risks and need to carry out considerable new development research.

Figure 1.13 Summary rainfall statistics in mm for the Kimberley Research Station 1944-2010

Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean	203.3	207.9	133.1	41.0	8.6	4.1	3.8	0.4	2.6	22.1	60.8	144.8	824.9
Lowest	21.1	31.7	5.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.5	30.4	424.2
5th %ile	65.9	63.1	16.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.5	56.3	478.3
10th %ile	95.0	70.3	26.8	0.0	0.0	0.0	0.0	0.0	0.0	0.1	14.9	66.6	543.0
Median	187.3	187.3	105.9	19.8	0.0	0.0	0.0	0.0	0.0	11.4	46.0	119.7	760.0
90th %ile	341.0	361.3	274.9	88.6	27.5	7.7	2.2	0.0	7.3	53.0	126.7	246.0	1146.1
95th %ile	366.8	406.7	322.3	148.0	41.8	12.3	28.6	1.4	13.3	76.7	150.0	277.9	1345.1
Highest	575.9	533.6	662.9	540.8	130.8	99.4	79.2	13.7	32.5	125.2	229.2	480.3	1564.1

The graph below shows changes in crops grown between 2002/03 and 2007/08.



**Other crops include: culinary beans, hay, maize, small seeds, sunflower, sweet corn, millet, vegetables, papaya, bananas, tropical fruit and nursery plants.*

Figure 1.14 Crops grown in the ORIA from 2003-2008 (for more details see Appendix 5)

2. Genetics, breeding systems, breeding and varieties

All the plantings in the ORIA research and commercial plantings are believed to be Gujarat Isabgol 1 the most common variety grown in India at the time of the research and still a variety in use and recommended (Table 2.1). Since then a range of new varieties have been introduced which are claimed to be substantially better yielding. Table 2.1 below indicates yield improvements of up to 65%.

Table 2.1 Recommended varieties of Plantago ovata *in India.*

Varieties	Seed yield Kg/ha	Source of availability
Gujarat Isabgol 1 (GI 1)	800-900	MAP unit, Anand Agricultural University, Anand, Gujarat.
Gujarat Isabgol 2 (GI 2)	900-1000	MAP unit, Anand Agricultural University, Anand, Gujarat.
Gujarat Isabgol 3 (GI 3)	1300	Spices Research Station, Jagudan, S.D. Agriculture University, Sardarkhrushi Nagar, Gujarat.
Jawahar Isabgol 4 (MIB 4)	1300-1500	MAP unit, College of Horticulture, RVSKVV, Mandsaur, Madhya Pradesh
Haryana Isabgol 5	1000-1200	MAP unit, CCS Haryana University of Agriculture, Hisar, Haryana.
Niharika	1000-1200	CIMAP, Lucknow, Uttar Pradesh

From Jat et al., (2015)

While a number of other varieties are indicated to be available, varietal improvement has not been rapid with the crop. Nekonam and Razmjoo (2007) give productivities for 8 accessions (including Pakistan and Indian) in the summer growing season in Iran. However, yields (240-390 kg/ha), mucilage contents (16-19g) and harvest indexes (0.20-0.23) were low. The DARE/ICAR annual report 2014-15 indicates a new mutant of GI 2, Vallabh Isabgol-1, is high yielding (24.5% higher), semi-erect, and has improved mucilage yield. It is not clear if it is an inbred line or an outbreeding mix. Vahabi et al., (2008) have demonstrated considerable variation of 22 accessions of *P. ovata* from Iran. Examples include 100 seed weight variation from 1.3 to 4.4g and seed yield from 165 to 494g. They have generated a RAPD clustering analysis as well. Taken together these allow selection of most diverse genotypes with potentially desirable characters. However, as with Nekonam and Razmjoo (2007) the existing material would not itself be classed as elite.

Plantago ovata is potentially a strongly outcrossing species with considerable airborne pollen (Ianovici, 2007). It also can represent a severe allergy risk for some people which should be kept in mind in the following discussions of breeding.

At ICAR - DMAPR, Anand, (ICAR, 2015) (which maintains 91 accessions of *P. ovata*) advanced varietal evaluation trials of early maturing and medium maturity *P. ovata* lines were conducted (including "Vallabh Isabgol -1") which was identified for release. Tetraploids may offer some potential as parents owing to their increased seed size (Zadoo and Farooqi, 1977). Advanced breeding methods are also in use with ninety seven tetraploid lines confirmed through cytology and 7 downy mildew resistant mutants and other morphological variants identified. Research has also created RILs, SSR and RAPD markers with a linkage map produced. At NDUAT, Faizabad, thirty accessions were evaluated, with the maximum (low) seed yield for MPI-1 (386 kg/ha) followed by PB-6-1 (344 kg/ha) and JI- 16 (318 kg/ha). At RVSKVV, Mandsaur, eighty accessions were evaluated, the accession MIB-1004 recorded the highest (moderate) seed yield (1022 kg/ha). At AAU, Anand, five mutants (wheat type mutant, ball mutant, PCM, tetraploid and branched spike) were evaluated. At RVSKVV, RVSKVV, Mandsaur, seeds of JI-4 variety were treated with EMS. Screening of 10 promising genotypes against Downy mildew, bacterial blight, leaf spot blight and root rot revealed that five genotypes (P-80, P6, PB-3-1, AMB-2, and MIB-124) showed resistance against the diseases at MPUAT, Udaipur. These data indicate considerable recent interest in breeding of *P. ovata* in India with it being a mandate crop at ICAR-DMAPR. However, no extraordinary success has occurred. This group has now generated a molecular map of *P. ovata* (Ponnuchamy, et al., 2016). Additional accessions are maintained at AAU, Anand (51), CCSHAU, Hisar (93), MPUAT, Udaipur (31), NDUAT, Faizabad (42), RVSKVV, Mandsaur (80).

Manivel and Saravanan (2010) have identified an early *P. ovata* DES treated mutant (DPO-14) of GI-2 that also has high yield, and elevated harvest index is claimed at 22.8%. Patel and Saravanan (2010) consider particular characteristics (eg leaf type, shape, area, density) from among and between different Plantago species as possible sources of enhancement. Vala et al., (2011) provide a list of germplasm with potentially valuable characters (Table 2.2). Sarkar and Lal (2015) examined 106 accessions for mean performance, heritability and genetic advance and accessions GSS-1, GSS-98, GSS-20, GSS-14, GSS-35 and GSS-78 were selected for high seed yield. They suggested accession GSS-1 of psyllium could be directly exploited on a commercial scale. Singh and Lal (2009) using 7 parental genotypes from the same collection looked at a wide range of genetic parameters for *P. ovata* and conclude that hybridizations, isolation of superior genotypes by sib selection and recurrent selection, and exploitation of hybrid vigour in specific parental-cross combinations are good strategies for isabgol crop improvement. However, none of the material presented in any of these papers comes close to the harvest indices presently available in highly bred crops. Most grain crops (eg rice, wheat, maize, barley, peanuts, sunflower) and root crops (eg potato) exceed 50% harvest indices greater than twice that presently possible with *P. ovata* indicating a substantial opportunity for improvement but also a need for a new (eg hybrid; direct HI selection) approach (http://plantsinaction.science.uq.edu.au/content/about).

Table 2.2 List of preliminary screened different germplasm of P. ovata (Vala et al., 2011)

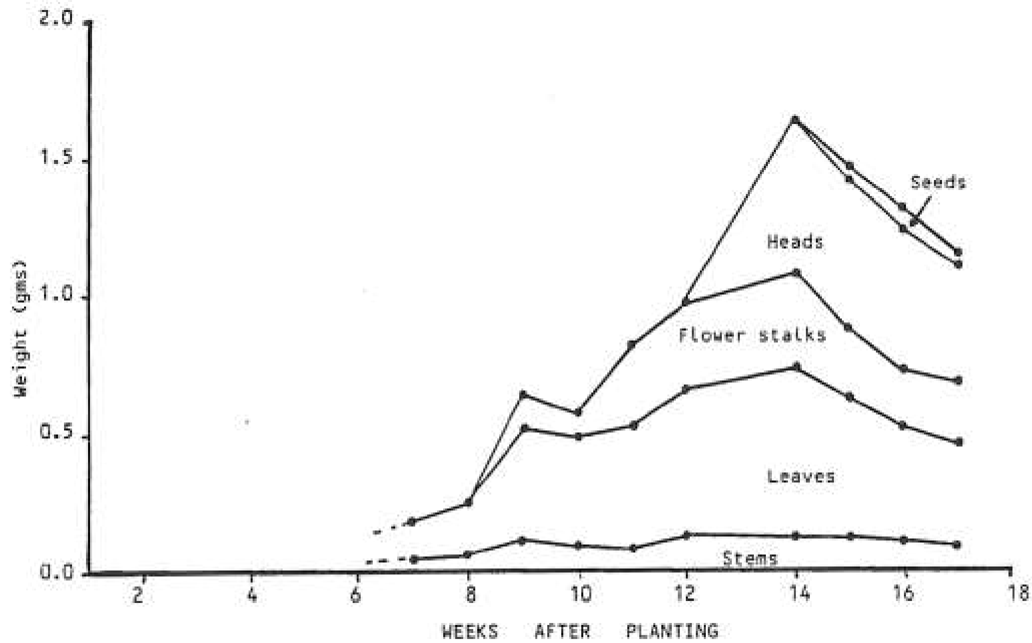
Germplasm line	**Characteristics**
Gujarat Isabgol -2	Medium broad and pale green leaves, medium long spike, more length
Jagudan Isabgol – 189	High yielder
Jagudan Isabgol - 216	Erect type
Jagudan Isabgol – 227	More erect, long spike, synchronize spike
Jagudan Isabgol – 192	Early type
Jagudan Isabgol – 206	Short spike
Jagudan Isabgol – 214	Long spike erect type, tiller more
Jagudan Isabgol – 107	Early type
Jagudan Isabgol – 127	High yielding, more seed, bold seeded
Jagudan Isabgol – 129	More spikes & spike
Jagudan Isabgol – 130	Medium spike length
Jagudan Isabgol – 131	Erect type plants, short spikes
Jagudan Isabgol – 132	More erect, long spikes, synchronous maturity
Jagudan Isabgol - 137	High yielder
Jagudan Isabgol – 150	Tall type

One of the most promising lines of breeding is associated with the existence of male sterility in *P. ovata*. Riley et al., (1988) identified it as present in between 5 and 10% of the lines grown in the ORIA. Other authors have also observed and described to a small degree its presence in *P. ovata* as well as closely related species (Vala et al., 2011, Atal, 1958, Koelewyn and van Damme, 1995). Some limited work has been done on its inheritance and preliminary work by the author suggested at least some temperature dependence for the trait. The male sterility opens a wide range of breeding avenues from hybrid lines, to simplified crossing and synthetics. It is easily recognised in plants where bagging an individual head or isolating a plant leads to an absence of anthers and long stigmas presenting in the flower heads. These bagged heads can then easily be used for crossing.

2.1 Selection work carried out in ORIA

P. ovata has extreme plasticity in its yield components based on the data presented in the plant population trials both in the ORIA and the literature. It was therefore concluded that selections based on yield components or individual plant total yields would not be highly productive. However, the very low harvest indices for *P. ovata* (often below 20%) and the evidence from published reports discussed earlier of good heritabilities for many characters suggested that direct selection for harvest index might be a good strategy. One reason for the poor HI could be that the plants were indeterminate in their nature as evidenced by green heads at harvest and the winnowing and desiccation trials. Thus in 1986 4,500 individual plants were screened for harvest index. From these 1.7% had harvest indices above 30% and these were kept for later evaluation (McNeil et al., 1986). These plants showed no significant relationship between harvest index and plant size from 0.3 to 30 g per individual plant. The data do show however, that much higher individual plant HI's are possible in *P. ovata*. The nutrient analysis data (Figure 4.1) suggests that there may be some redistribution from the plant of N and P. Figure 2.1 shows considerable loss of DW from leaves and stems and flowers stalks to the heads suggesting considerable redistribution of carbohydrate but very little transfer to seeds. In this instance the low seed yield was partly due to thrips but may have had other causes as well. This redistribution, including redistribution of carbohydrate, is essential to obtaining high harvest index and the fact that it occurs for some minerals to seeds and for carbohydrate to flowers is promising for HI selection.

Figure 2.1 partitioning of plant dry weight in a 12% HI, 0.5t/ha p. ovata crop (Riley et al., 1987)



Plantago ovata top weight per plant partitioned into stem, leaf, flower stalk, head and seed components in the 1987 semi-commercial scale planting throughout the growth period

Table 2.3. Field performance of different groups of Harvest Index selections (Riley et al., 1987)

Table 4. Performance of the progeny of four groups of Plantago ovata parents, high, medium and low harvest index groups and unselected bulk material, assessed in the field on Cununurra clay

Harvest index groups	Plant weight (g/plant)	Plant height (cm)	Heads per plant	Head length (mm)	Florets per head	Seeds per plant	Seed weight (g/plant)	Seeds per plant	Seeds per floret	100 seed weight (mg)	Harvest index (%)
High	14.9	39.3	41.6	22.1	24.2	1,250	2.28	26.7 b	1.10	186	12.0
Medium	18.6	41.0	43.8	26.0	27.6	1,638	2.78	35.1 a	1.26	171	12.6
Low	20.4	38.8	53.6	22.5	21.7	1,234	2.17	20.5 b	0.90	169	8.4
Bulk	18.2	39.5	48.6	22.0	22.9	1,367	2.62	24.3 b	1.05	191	10.9
Mean	18.0	39.6	46.9	23.1	24.1	1,372	2.46	26.6 b	1.08	179	11.0
LSD 0.05	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	7.2	N.S.	N.S.	N.S.

It can be seen from table 2.3 that there was no significant effect from the high harvest index selections. However there was a trend as indicated in Figure 2.2 albeit at very low HI values.

Figure 2.2 Data from table 2.3 in order of HI during the selection.

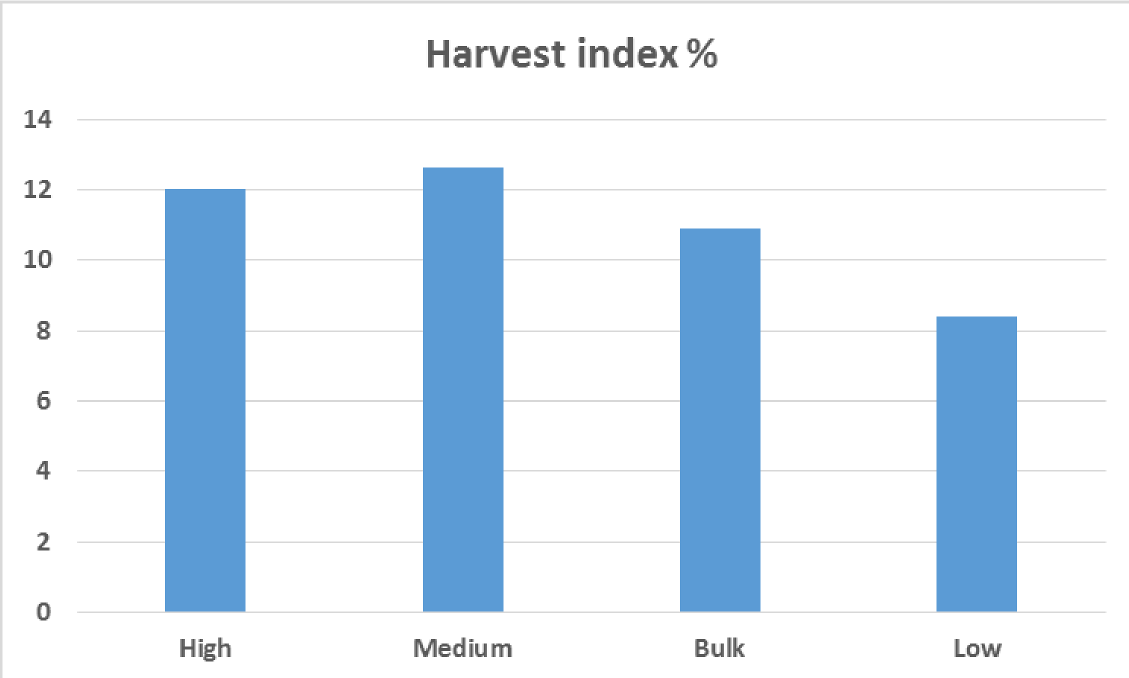
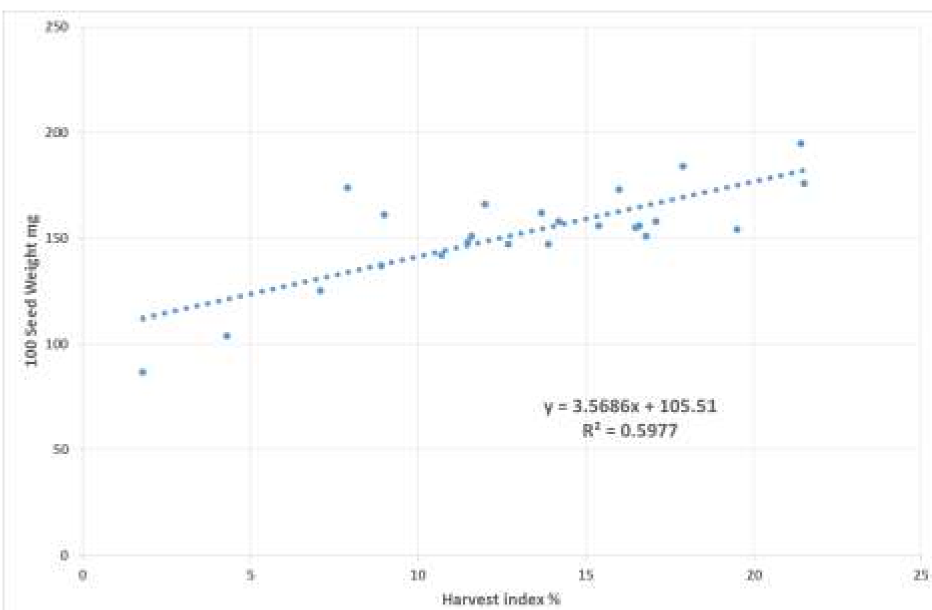


Figure 2.3 relationship between Harvest index of progeny of top 25 HI selections (all greater than 30% mean =36%) and seed weight (Riley et al., 1987) in a glasshouse replicated trial. LSD 0.05 seed weight= 38, HI=5.7.



The evaluation of progeny from high yielding parents indicated that these reverted towards or below the population mean particularly if planted only with their own progeny in pots (Figure 2.2). For genetic improvement in this partially out-crossing species it may be necessary to adopt a programme based on evaluating parents on progeny performance and then using self-pollinated seed from superior parents for further crossing. Variation exists in most characteristics and selection based on those that are density independent yet which strongly contributed to increased seed yield and harvest index may give significant gains. It is important to determine the level of self incompatibility and inbreeding depression that occurs in *P. ovata* before planning a breeding programme. It is possible that the high harvest index plants represented forced outcrossing in male steriles and thus represent real hybrids. This in turn suggests any form of hybrid breeding and development of synthetics could be a good breeding approach.

In 1988 there were further evaluations of the seed selections as indicated in Table 2.4. In addition to these evaluations 95% of lines that had heads bagged to prevent cross pollination produced seed of a size and amount similar to unbagged heads demonstrating good self compatibility.

Table 2.4 1988 field evaluation of lines originating from the 1986 selections (Riley et al., 1988)

Seed Source	Harvest Index %
Bulk seed	**25.8**
Progeny from the 9 highest harvest index plants evaluated in 1987	**21.9**
Sibling seed to the high harvest index plants evaluated in 1987	**22.1**

Over 2 years of selection for high harvest index there were no productivity gains. This leaves two main options. 1) that all the variation in HI was environmental, or 2) that potentially much of the gain was associated with hybrid vigour requiring hybrid stabilisation or/and as yet unclear genetic causes.

2.2 Breeding/evaluation program for the ORIA

As indicated above there are a considerable number advanced varieties and germplasm accessions available globally. Step one in any program will need to be import of these varieties and accessions (potentially the best in significant amounts for direct cropping) for evaluation in the ORIA using best practise. The second step would be to instigate a breeding program to produce locally adapted and potentially substantially superior varieties to give significant competitive advantage to the area. A detailed description of such a project goes beyond the scope of this manual but a brief description of possibilities follows.

2.2.1 Potential evaluation and breeding program for the ORIA.

- Evaluation
    - Import best known varieties in kg seed quantities for testing
    - Import diverse lines for screening and testing in smaller quantities
- Breeding
    - Locate multiple male steriles
        - Evaluate sterility mechanism and reversibility

        - Generate F1 hybrid material and compare to inbreds for important characters. (harvest index, husk, morphology, phenology)
        - Instigate a hybrid breeding program/hybrid enriched multiline program
    - Use male steriles to create a synthetic selection population using above material
        - Create RILs from this population for testing
- Shuttle multiplication
    - Link with southern area to allow bulking and generation progress across ORD summer
        - Seed dormancy may limit magnitude of bulking
        - Autumn (Harvest) rain may limit field growing

3. Seed management and sowing

3.1 Dormancy and Germination requirements

Dormancy is a common problem in a range of Plantago species (Pons and van der Toorn, 1988; Jamian et al., 2014). It has been extensively investigated by McNeil and Duran (1992) for *P. ovata*. They used fresh (approximately 1 month since harvest) and aged (approximately 8 months from harvest) seed. The seed had been stored at room temperature (~20°C) and humidity. Fresh seed had a germination of between 0 and 40% predominately whereas aged seed gave 90-100% germination. NO_3 by itself had minimal effects as did light level. However, addition of KNO_3 and Gibberellin together gave additive effects. GA_3 and GA_4 both successfully increased germination of fresh seed across a wide range of concentrations centred around 1mM. However, it was the interactions with temperature that were of the greatest interest. Figure 3 and 4 from McNeil and Duran (1992) reproduced below (Figure 3.1) indicate that fresh seed could germinate well at low temperatures with germination falling rapidly as germination temperature increased from 15 – 20°C (Figure 3.1 b). However, aged seed showed good percentage germination at least till 25°C. GA_3 overcame the high temperature decline in germination of fresh seed and improved rate of germination at high temperatures for both fresh and aged seed. Seed survival was poor in high temperature germinated (25°C) fresh and old seed. This would suggest that field germination temperatures above 20°C could lead to suboptimal germination. What has not been effectively determined in the laboratory as yet is what effects daily fluctuations in temperature around the optima have as happen in the field. Night time surface temperatures will be as low as 10°C while day time dry soil surface temperatures may exceed 50°C. This suggests a need to keep the surface moist to provide evaporative cooling or possibly a need to slightly bury seed even though seed at depth may germinate less well (Ghaderi-Far, 2012). Trials in the ORIA suggested that 2 mm was the optimum depth with planting at more than 5mm reducing germination. However, high temperatures on the surface may lead to greater loss of germination as indicated later.

In addition to the germination data McNeil and Duran (1992) found that time to flowering and seedling growth rate seemed to be increased by higher temperatures during germination irrespective of seed age and GA treatment. This finding may go part way to explain why Growing Degree Day models for flowering and maturity do not work well in *Plantago ovata* and seasonal variations exist for optimal planting date (McNeil, 1991a,b,). Asghar et al., (2009) and Bannayan et al., (2008) found drought decreased GDDs to flowering and maturity by up to 30%, while ORIA work suggested for the same planting date warmer growing season temperature increased growth period for the crop.

Figure 3.1 Germination results from McNeil and Duran (1992)

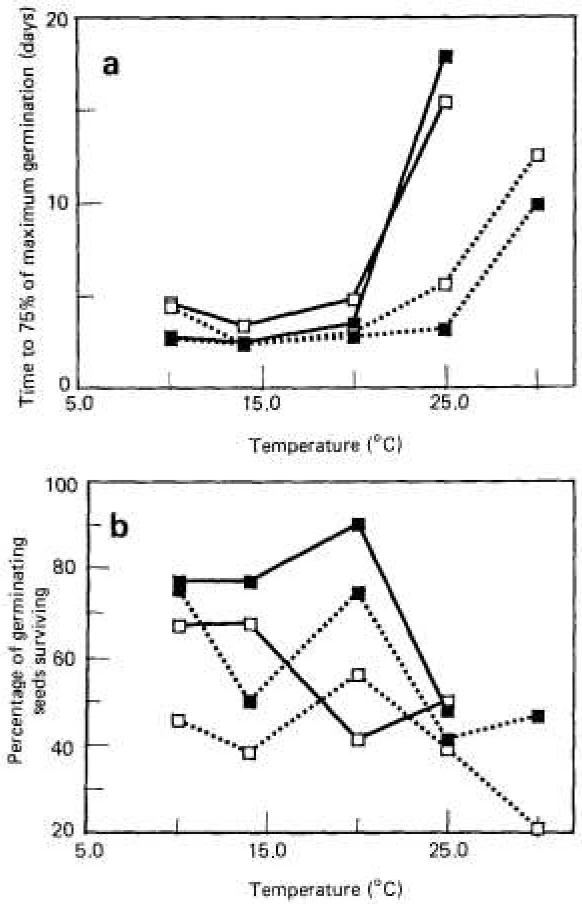


Figure 3 Effect of changing seed treatments for temperature, seed age and 10^{-4} M GA_3 or GA_4 on (**a**) rate of germination of *Plantago ovata* seeds and (**b**) subsequent survival of seedlings. Seed used was fresh, 1-month-old seed (open symbols) or aged 8-month-old seed (closed symbols), either untreated (solid lines) or treated with gibberellin solution (dashed lines)

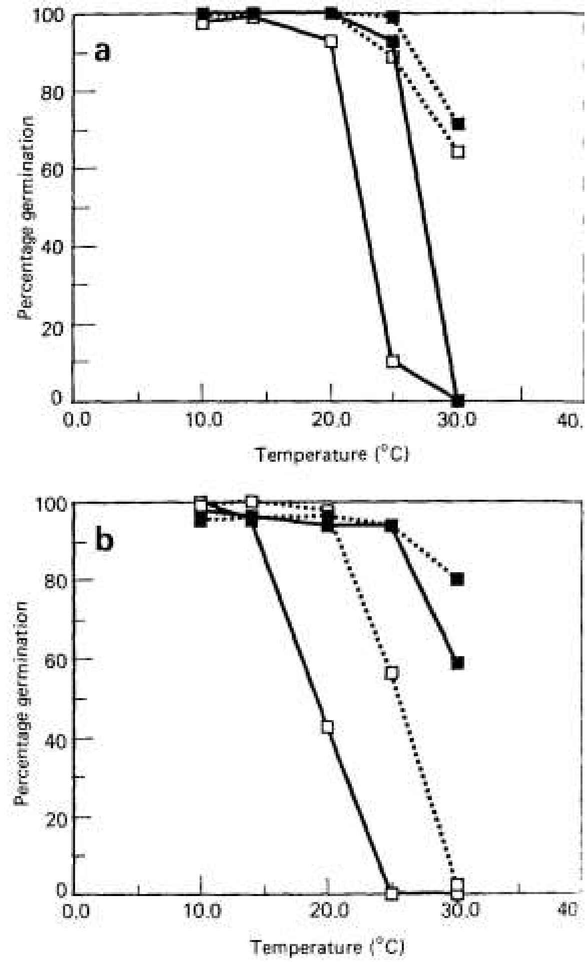


Figure 4 Effect of temperature, seed age and 10^{-4} M GA_3 or GA_4 on germination of *Plantago ovata*. Figures (**a**) and (**b**) relate to experiments 3 and 4, respectively. Seed used was fresh, 1-month-old seed (open symbols) or aged 8-month-old seed (closed symbols), either untreated (solid lines) or treated with gibberellin solution (dashed lines)

More recently a number of authors have reinvestigated dormancy and extended and confirmed these early data. Gupta et al., (2008), Aghillan et al., (2014) and Anshu et al., (2008) all found pre chilling (2-3 days) and GA3 improved seed germination and early growth and vigour but NO_3 had little effect and heat treatments reduced germination. These results were similar in seeds that had very high rates of dormancy as well as seeds showing moderate control rates of germination. Ali et al., (2010) found even brief high temperature treatments with boiling water killed the seeds but 10 days of pre-chilling at 4^0C substantially improved germination and germination rate. External factors were also found to affect germination (Ghaderi-Far, 2012). A 50% reduction in germination occurred at about 320mM NaCl alternatively an osmotic potential of -1.1 M Pa had the same effect. They found pH in buffered solutions from 7-9 reduced germination by about 1/3rd and that there was approximately a 30% decline in germination for each cm of depth of the seed starting from a maximum point at the surface.

Temperature affected germination with it being at a maxima from 10-25^{0}C falling by 50% at 30^{0}C. Germination rate was greatest at 20^{o}C falling by 1/3rd for each additional 5^{o}C. Sousa et al., (2008) gave similar values for temperature effects and found up to 25^{o}C there was no light effect on *P. ovata* germination but at 30^{o}C light enhanced germination. There is not a lot of consistency among germination treatments for different Plantago species. For example *P. major* requires light to germinate (Pons and van der Toorn, 1988) and *P. psyllium* seems to have a higher maximum temperature (30^{o}C) for maximum germination and germination rate (Jamian et al., 2014). Mahdavi (2013) suggested that chitosan may improve germination and reduce adverse effects of salinity.

Overall these data indicate that rapid cycling of *P. ovata* seed is possible by using a combination of temperature, GA_3 and possibly NO_3 treatments. Overall aged seed will germinate quite well at 25^{o}C however, survival and rate of germination is only moderate to poor. Thus seed germination in the field would be optimal at around 20^{o}C based on laboratory and greenhouse trials (though the next section indicates under real field conditions higher temperatures up to 29^{o}C do not always adversely affect germination). There are also indications that high temperature storage may reduce germination and pre planting chilling may enhance germination even of aged seeds.

3.2 Establishment conditions

3.2.1 Cool temperatures

Research has indicated that cool temperatures at establishment can cause severe issues with young seedlings. In spring plantings in Zanjan, Iran (37^0 N) Omidbaigi and Mohebby, (2002) indicated that a 5th of April planting germinated but died in the cool temperatures (frosts?) that followed. Later plantings (20 April – 20 May) survived and grew to produce yields of up to 900kg/ha under the best conditions. Mean climate monthly minima and maxima for the area are 3.7-17.0^{o}C in April and 7.6-22.8^{o}C in May. Arizona plantings also showed severe damage from frosts (USNPGS, 2003) indicating major issues with cool temperatures on young plants. Fortunately such issues will not adversely affect planting in the ORIA. However, it could be an issue if not taken into account when out of season breeding and bulking up of seed is undertaken elsewhere within southern Australia.

3.2.2 Soil types

In 1985 *P. ovata* was grown on all 3 soil types of the ORIA. Data from these trials are shown in Table 3.1. Since Cununurra clay gave the highest yields and is the most available resource and is simple to irrigate using furrow and bed irrigation all later trials were conducted on this soil. This is in spite of all the published information at the time (as well as most recent reports e.g. NMCE, 2008) suggesting lighter soils were the most appropriate. It is only recently that there have been acknowledgements out of India that heavier soils may also be suitable (Jat et al., 2015). Indeed the range of suitable soils has been expanding with Dagar et al., (2004) getting good yields from more alkaline soils of northern India. There are also indications that some salinity can be tolerated by *P. ovata* (Karimi and Pak, 2012). Dagar et al., (2006) found >87% germination of seeds up to 5000ppm NaCl and no yield reduction in alkaline soils up to pH 9.2.

Table 3.1 Row planted yields from 3 soil types in the ORIA in 1985 using best available information.

Soil type	Hand harvested yield kg/ha	Establishment %	Harvest Index %	Row planted yield kg/ha	Broadcast yield kg/ha
Ord Sandy Loam	1114[b]	29.5[a]	19.5	1003[b]	1019[b]
Cockatoo Sand	640[a]	22.5[a]	-	745[c]	535[c]
Cununurra Clay	1464[c]	47.0[b]	26.0	1331[a]	1268[a]

Letters indicate significant differences at the 5% level.

Figure 3.2 Row planting P.ovata *on Cununurra clay.*

3.2.3 Planting system

I have already indicated that Cununurra clays are the preferred soil however, in the ORIA a number of planting systems are possible on the Cununurra clays. These are predominantly planting on the flat or beds and broadcast or row planting. It is also possible to sow on the surface or at depth. Soil harrowing may also be used to roughen the surface to put seeds in hollows (protected from sun) or to bury seed after sowing. In Gujarat typically *P. ovata* is grown on the flat and broadcast (Jat et al., 2015). However, this is likely as much to be a response to the available irrigation system and equipment as to any intrinsic advantage. In the ORIA the opposite is the norm for other crops with bed planting in rows and soil sown below the surface (up to 10 cm for peanuts). Generally, however, these are larger seed crops that grow taller and get better coverage of the soil and have adequate vigour to emerge from depth.

Figure 3.3 May 6 1985 planting on levee soil. Six rows per bed at 52 days after planting. Coverage of the furrows is poor.

Cununurra clay seems to be the most suitable resource for production of *P. ovata* in the ORIA (Table 3.1).

Trials of some of the possible variations (Table 3.2) in both these systems were thus undertaken. Preliminary trials in 1985 indicated that either 8 rows per bed or broadcasting with harrowing seemed to give the best yields over just broadcasting (small difference) or 4 rows (large yield reduction; Figure 3.4) per bed (McNeil, 1985). In May 1988 approximately 1.5 ha was planted to look at irrigation interactions on bed and flat planting in a factorial trial. The areas were fertilized and sown at 12kg/ha and sampled and machine harvested. Yields were generally unaffected by the treatments however, with hand harvested yields of 1.17 t/ha. Surprisingly for this large area the machine harvested yields averaged 1.2 t/ha approximately 102% of the hand harvested value. Populations were adversely affected by the rapid irrigation on the flat which washed seeds off into clumps etc. However, due to the higher seeding rate and good establishment this did not affect yields (Table 3.3). However, it was observed in other small area plantings that waterlogging could take place in areas of flat which lead to substantial plant death and yield losses. Final populations were not significantly different and averaged 317 plants/m^2 across all treatments.

Raised bed farming is extensively used in Australia and represents best practise for water management minimising salinity encroachment and maximising WUE particularly if drain reuse (as in the ORIA) is part of the system. A detailed manual is available (Hamilton et al., 2005). Thus some form of raised bed cropping (broadcast or 8 row planting <0.5mm sowing depth) with a good flat soil tilth above any waterlogging level would seem the optimum option. It may be possible that harrowing before sowing and/or shallow seeding (<0.5cm) especially during high temperature periods may work well.

Table 3.2 Comparison of planting systems on Cununurra clay in ORIA

Planting system	Description	Advantage	Disadvantage	Pictures
Seed distribution				
Broadcast	Scattered over surface, possibly with pre-plant harrowing.	Total planted area even coverage and no loss from deep burial. Can cover furrow edges. No impedance of germination.	Ant predation greater, surface extremes, can wash off on flat,	
Row	Sown on top of soil without furrows 4-8 rows per bed, surface or depth	Space between rows for cultivation, can give more even planting ,	Gaps where droppers hit soil and planting at depth, less coverage of furrow edge	Fig 3.3, Fig 3.2
Ground preparation				
Beds	Mounded with irrigation furrows 1.5 (1.1m top, 0.4m furrow) to 1.8 m (1.4m, 0.4m) wide with ~ 25% furrow	Prevents waterlogging, assists tramlining, provides more even irrigation. Requires matched wheelbase equipment.	Furrow areas may not get cover with small plants. More preparation needed more costly to irrigate. Easier for in field practices. May take time for water to get to centre of bed so longer irrigation needed. Harvest harder if plants fall into furrows. Less waterlogging	Fig 3.3, Fig 3.2
Flat	Levelled flat area with flood irrigation	Less preparation and cheaper to irrigate, Can get full surface cover even with rows. Can be easier harvesting if harvester base differs from bed width.	Potential for waterlogging and washing off of seed and soil. More potential for bogging in field. Lodging may spread more easily.	

These data indicated how well a crop can be grown on the Ord even with the low harvest index of ~16% the machine harvested yield of 1.2t/ha over 1.5 ha was excellent. They indicate little advantage to the use of beds with a slow irrigation system. However, the attempt to bulk this up to larger areas where runs were longer and flows on the flat were necessarily faster did not work well (Table 5.1). The longer watering times on the flat led to waterlogging issues and failures of the crops.

Table 3.3 1988 ORIA irrigation trial results (Riley et al., 1988)

	Establishment population		100 seed weight	Heads per plant	Harvest index
	Total (N/m^2)	Bed tops (N/m^2)	(mg)		%
Beds	419	629	141	5.9	16.65
Flat fast irrigation	326	-	143	10.7	15.67
Flat slow irrigation	452	-	150	8.1	17.79
LSD 5%	74		6	4.2	2.07

The use of row planting does have some advantages with uniform seed sowing. In the ORIA the seed was laid on the surface in rows due to evidence that even small amounts of burial (> 2mm) can reduce establishment. However, in severe hot weather and as a means of avoiding harvester ants there may be some benefit in sowing the seed into the ground. Plots sown in the Ord in 1985 and 1986 at 0.5cm deep seemed to suffer less harvester ant damage but uneven depth control often meant lengths of row did not emerge. Experience in India would suggest whilst not the norm (Jat et al., 2015) it can give good yields. Shivran (2016) obtained yields of 1.26 t/ha with seed sown at 1-2 cm deep. His final survival based on figures supplied in the paper was about 65 seeds/m^2 or roughly 20% of the sowing rate which seems low suggesting the deep placement may have reduced germination but it seems an acceptable figure considering the final yield. Dagar et al., (2006) found that sowing seeds accurately 1cm deep into moist soil was better than broadcasting (23 -54% better) or sowing into dry soils (3-12% better). An issue we found in the ORIA was that sowing into beds aimed at 0.5cm depth would often give areas of deeper planting where germination was poor for a section of a row (left hand side Figure 3.4).

Table 3.4 indicates that harrowing the soil to produce an even rough tilth before sowing produced better seed establishment. While in this instance yields did not increase due to adequate populations for all treatments the method was routinely used in the ORIA to reduce the risk of high temperature failure of the planting.

Table 3.4 Effect of soil management on plant establishment. (McNeil, et al., 1986)

Treatment	**Population x 10^6/ha**			**Vegetative yield (t/ha)**		**Seed yield (t/ha)**	**Weed Pop. $X10^3$/ha**
	Day 26	Day 70	Day151	Flowering	Harvest		Day 26
Control	2.35	2.34	2.03	2.37	5.46	0.80	25
Harrowed after Plant.	1.94	2.01	1.74	2.14	5.27	0.83	41
Harrowed before Plant.	2.62	2.54	2.27	2.50	5.36	0.76	42
LSD 0.05	0.32	0.29	0.24	0.24	NS	NS	NS

Seeds were sown at 8kg/ha on 1.5m beds and irrigated immediately and at various times thereafter.

Figure 3.4 P. ovata *crop on Cununurra clay in 1985 at 40 days after planting. The left side shows 8 rows per bed at 4 kg/ha the right side is broadcast at 8kg/ha (McNeil 1985).*

Thus at present it would seem that the bed system of irrigation is preferable potentially in rows sown <1cm deep, on the surface or broadcast as they have all been shown to work.

3.2.4 High temperature effects

Dormancy and germination discussion has indicated optimal germination around 20°C in laboratory experiments. These temperatures could cause issues in the ORIA so McNeil (1989a) reviewed the germination percentage of field sown crops against air temperature following sowing. These data are presented in Figure 3.5. When crops were irrigated on days 1 and 3 keeping the soil cool then good germination percentages were achieved up to over 27°C with viable germination to 29°C. When the second irrigation was not applied till 7 days after planting good germination occurred only up till 25°C. However, at cooler temperatures there was no apparent establishment benefit from a second watering immediately after sowing. Thus care is needed in planting and managing irrigation particularly early in the season when temperatures are higher. Later trials looking at irrigation regimes often showed no effect of multiple quick irrigations. However, this is to be expected as the benefit only occurs between the 25- 29°C germination range. As excess irrigation is expensive and bad practice for salinity management it would be advisable to link the timing of the second irrigation to sowing temperatures to facilitate earlier sowing when needed.

Figure 3.5 Effect of sowing air temperature on establishment percentage from McNeil (1989a).

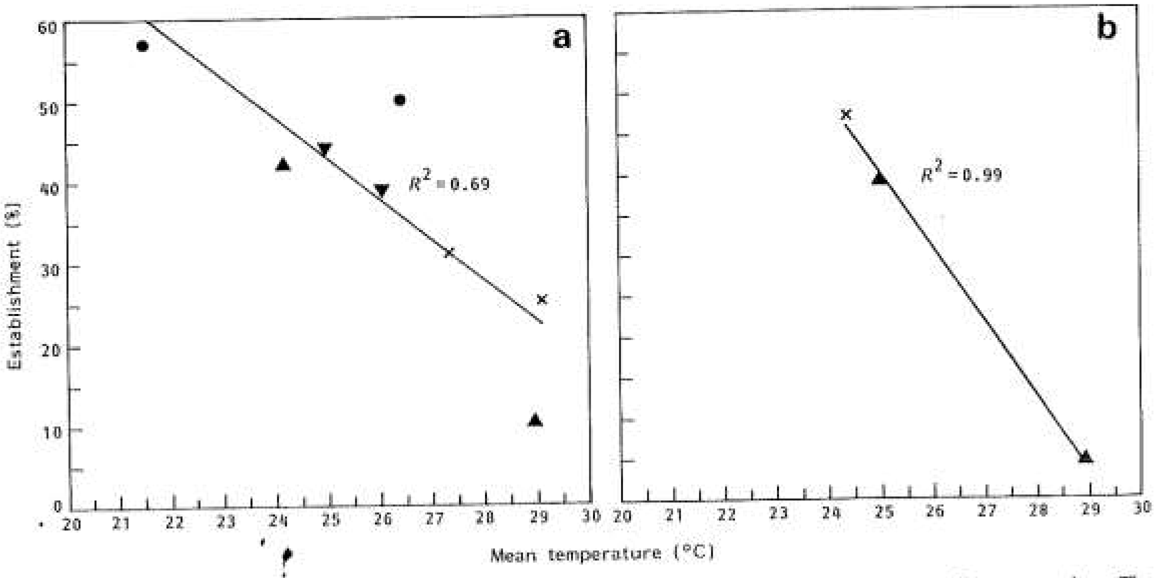


Figure 1 Effect of environmental conditions at planting on field establishment of *Plantago ovata* on Cununurra clays. The temperature is the mean for planting date and the next four days long term means are: April, 27.7°C; May, 25.3°C; June, 22.8°C. (a) Broadcast and watered on days 1, 3, 7 and 14. (b) Broadcast and watered on days 1, 7 and 14. ▲, April planting; ★, May planting; ▼, June planting; ●, July planting. Solid symbols 1986 plantings, open symbol 1985 plantings

3.3 Planting date

If spring planting is undertaken in southern areas for bulking of seed or breeding purposes it will be essential to wait for planting till after any frost risk has passed (Omidbaigi and Mohebby, 2002; USNPGS, 2003). Spring sowing is carried out in Iran where summers are dry and winters wet in a typical Mediterranean climate. Thus the different day length conditions of summer do not impede flowering or harvest maturity for the crop. However, production in Australia and India is based around an Autumn/Winter dry season sowing and thus this will be considered now.

Figure 3.6 compares yields from the ORIA across soil types and seasons with planting date relative to yields from Indian trials. The ORIA yields are superior to, or equal to, yields in the established areas. In some years there was a decline in yields from early plantings attributed to high temperatures and poor establishment which ultimately reduced harvest index. In the 1986 crops the percentage seed establishment increased the later the planting date (cooler) to reach between 50 and 60%. However, by harvest the very high populations of the last plantings had declined to below the mid-season plantings consistent with their poorer performance. Vegetative dry matter followed yield in the trials. Thus harvest index remained constant at approximately 20% in 1985 and 13% in 1986. These were low values when compared to other trials and locations but importantly did not have any thrips control which could be expected to increase yields and HI by about 25% (Tables 4.1, 4.2).

This same trend continues across all Rabi season crops. For example Shivran (2016) at Jobner in Rajasthan (27°N) produced yields of 1.06, 1.26, and 1.20 t/ha from irrigated plantings on days 123, 133 and 143. They similarly attributed the lower yield for the earliest planting date to have arisen as a result of high temperatures during planting. Considering the Jobner yields were achieved 30 years later than those in the ORIA using the latest Indian varieties it seems little has changed. Their varieties were, however, capable of higher harvest indices (26-34%) and had high husk recoveries of 34%. Arunjyothi (2007) planted on days 97, 112, 128 and 143 in Hyderabad (17°N) and produced relatively low yields with a consistent declining trend of 0.55, 0.46, 0.33 and 0.26 t/ha. He used Gujarat- Isabgol –II which was also used by Shivran (2016) because of its higher husk yield.

Figure 3.6 Relationship between seed yield and planting date in 1985 (Ord Sandy Loam; circle) and Cununurra clay(triangle) and 1986 (Cununurra clay; square) and comparisons with published Indian data (b) Mehta et al., (1976) 31°N, (c) Gupta (1982) and Mehta et al., (1976) 23°N, (d) Iyengar et al (1968) 19°N (1982). From McNeil et al., (1986)

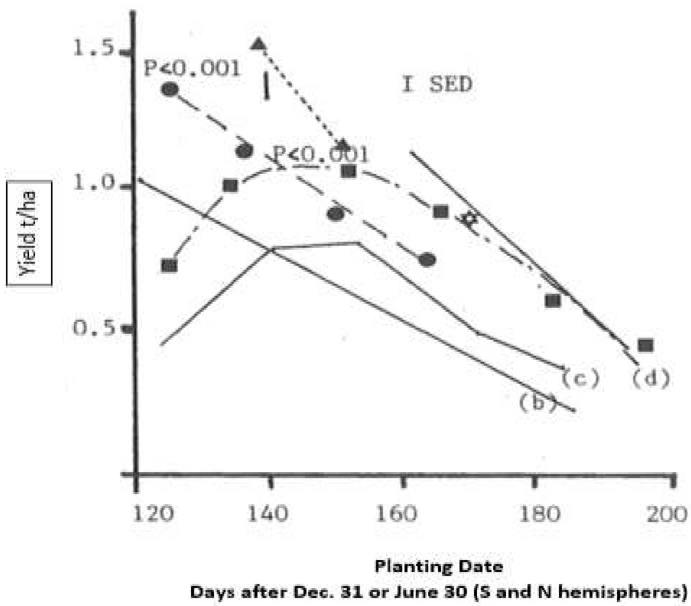


Figure 3.7 Relationship between date of planting time to maturity and harvest and effectiveness of the time in producing yield. McNeil 1986.

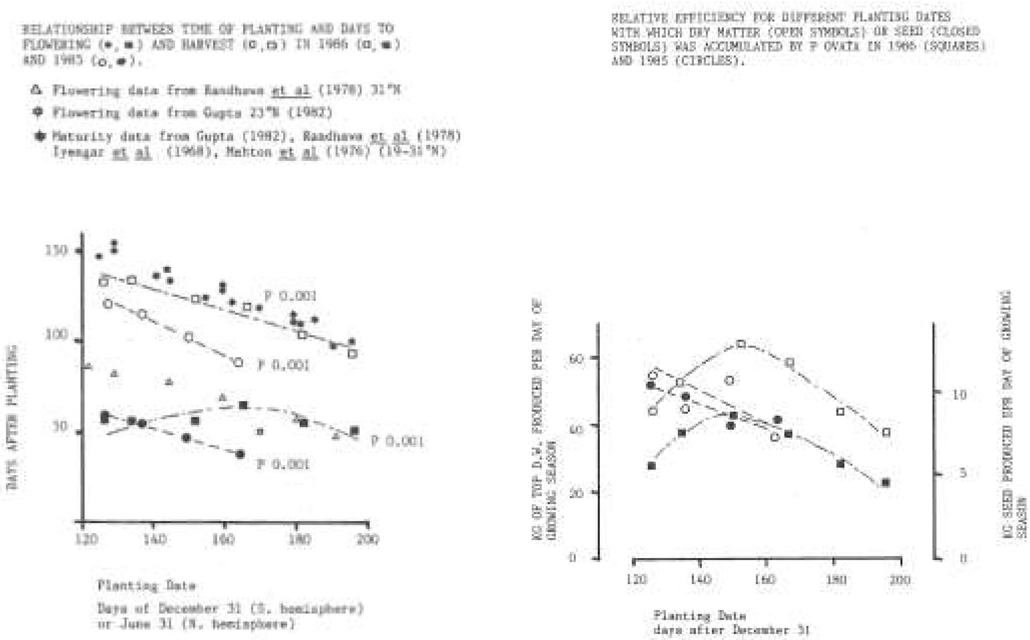


Figure 3.7 shows that the season length and time to flowering are similar in the ORIA and India. However, in some seasons in the ORIA *P. ovata* crops matured early and as a result did not produce as much yield as a longer season might have allowed.

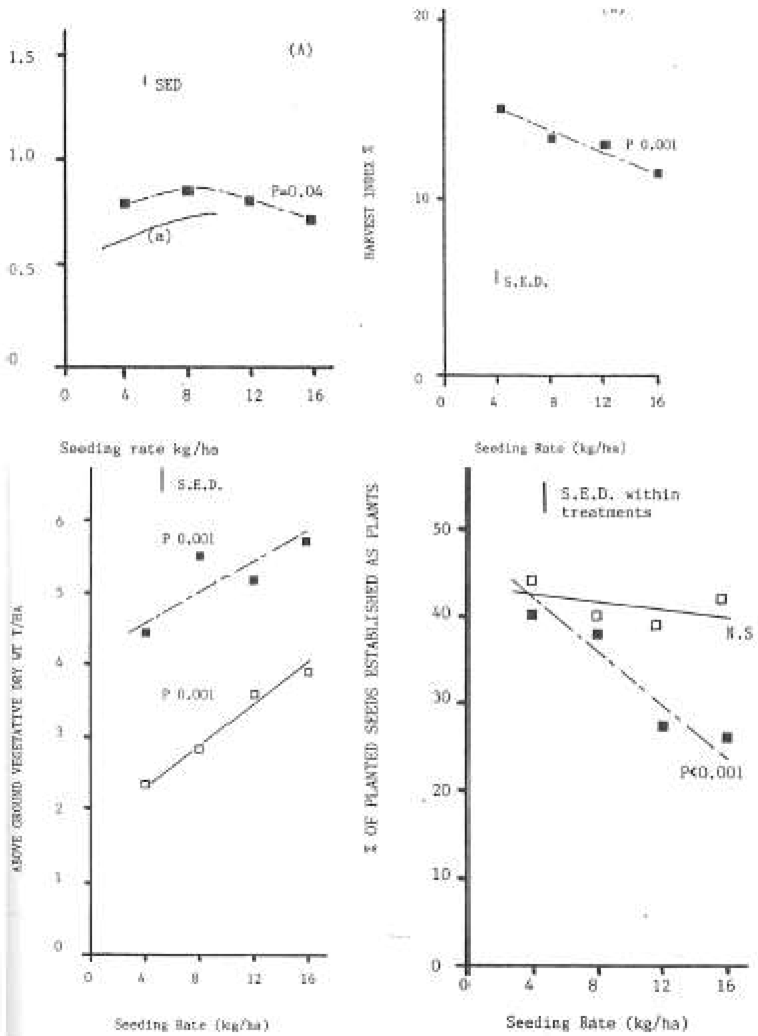
The data on planting date seem to have been consistent globally for over 50 years of intermittent trials. The earlier plantings provide better yields provided they are not carried out during periods of extreme weather. If they are planted early under high temperatures establishment declines and season length may also decline and with it poor HI, yields and season use ensue. Thus as a general ideal early – mid May is the preferred time for planting in the ORIA but high temperature years may cause a delay and/or require irrigation cooling of the soil. This latter is possible as the irrigation and germination data suggest extra post sowing irrigation may be at least partly overcome poor establishment by cooling the soil after planting. Paradoxically shallow sowing (0.5cm depth) may also be beneficial then by keeping the seed below the hottest part of the soil surface.

3.4 Sowing rate

Plantago ovata is a small seed and each kg/ha represents approximately 60 seeds per square meter sown or 80 seeds per square meter if only sown on the 1.5m bed tops in the ORIA. Three factors therefore influence the optimal seed sowing rate, 1) the expected germination and establishment (the previous section indicated 25-50% is usual under good conditions), 2) the desired population taking into account factors specific to the crop (eg weed level, date of planting, layout) and 3) the value/yield/seed cost of a precautionary buffer in sowing rates. Preliminary trials in 1985 in the ORIA (McNeil, 1985) indicated 8kg/ha gave a greater yield than 4 kg/ha and the more uniform spacing of 8 rows per bed was better than 4 at the same seeding rate. In 1986 trials a 12 kg/ha seeding rate increased establishment population by 100%, vegetative yield by 18% and seed yield by 19.5%, relative to 6kg/ha without changing plant height or days to flowering. At the same time weeds yield at harvest was reduced by 35% and weed numbers by 42%. Figure 3.8 indicates that there is little adverse effect from sowing rates up to 12 kg/ha which gives a significant buffer in establishment before yields are reduced. The plants make up to some degree for lower populations and lower dry matter yields by having slightly higher harvest indices. One possible cause of this is that the early flowers were mostly short and sterile (Figure 3.9) and with lower populations these would have been a smaller proportion of the total flowers. Similarly late immature heads may be a smaller proportion of total heads in wider spaced larger plants.

ORIA trials did not give significant interactions between seeding rates and sowing date or irrigation levels. Nekonam and Razmjoo (2007) in a low yielding experiment in Iran found plant populations between 80 and 160 plants /m^2 had no effect on seed weight or mucilage levels. However, there was a 71% increase in yield from lowest to highest population. However, the highest yield was only 360 kg/ha. As in the ORIA trials they found harvest index was higher (but still low; 0.208-0.229) at lower populations. These sowing populations in Iran correspond with expectations from 2-4 kg/ha sowing rates suggesting any reduction below 4 kg/ha has substantial negative effects on yield. Moosavi et al., (2012) in another low yielding very low population trial (17-33 plants/m^2; seeding rates ~0.5-1.0kg/ha) produced an 83% increase in yield by doubling the population indicating little yield compensation at these low populations. However they did have minor statistically significant interactions between planting date and population and yield.

Figure 3.8 Seed rate effects in ORIA Cununurra clay in 1986.



Effect of seeding rate on yield (t/ha), harvest index, Vegetative dry weight and establishment at flowering (open square), and harvest (filled square). Line a) summarises data of Randhawa et al., (1978) and Mehta et al., (1976). Data from McNeil et al., (1986).

Overall Jat et al., (2015) recommend in India 4kg/ha as an optimal sowing rate primarily to reduce the effects of downy mildew which are more severe there at higher populations. Most of the N hemisphere trials discussed elsewhere in this book have used rates of ~6 kg/ha. In view of the data presented here the ORIA optima would be 8-12kg/ha in a situation without downy mildew but with a risk of poor establishment due to high temperatures and relatively low cost of the additional seed. If downy mildew became established in the ORIA reducing sowing rate may be one of the methods for mitigating damage.

Figure 3.9 First flowering heads at 52 days after planting McNeil (1985).

3.5 Conclusions

These data indicate 8-12 kg/ha is a good planting rate. Broadcasting on the surface works well. The main issues to beware of are the need to use non-dormant seed and manage planting date and system to minimise soil temperatures to ensure high germination.

4. Within growing season agronomy and management

4.1 Pest management

In India the major pest is aphids, *Aphis gossypii*, which generally appear 50-60 days after sowing. They recommend neem based formulations but can use 2 sprays of 0.025% Oxydemeton methyl (Metasystox 25 EC) on a date equivalent to S hemisphere August. Sprays are given 15 days apart (Jat et al., 2015). Patil and Patel (2013) have evaluated a number of chemical and botanical insecticide control methods for aphids. Aphid infestations have not yet been observed in the ORIA and this species is not present in Australia (http://www.planthealthaustralia.com.au/wp-content/uploads/2013/01/Cotton-aphid-FS.pdfn). They also suggest white grub and termites can cause some damage. At present no chemicals are registered for use in *P. ovata* in Australia. Information on presently registered insecticides and the requirements for minor use registration can be obtained at http://apvma.gov.au/ . The next sections therefore look at the specific pests found in the ORIA.

4.1.1 Harvester ants

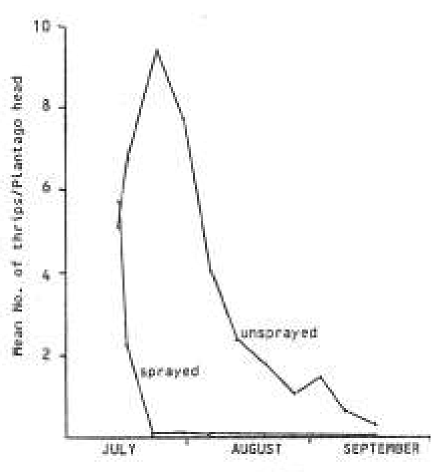
Field crickets and cockroaches will consume some seed at sowing but the main effect is from harvester ants. These will gather seed and move them to ant colonies underground where they either fail to emerge or emerge as scattered dense clumps. Seed harvesting ants can be controlled by dusting the seed with Lorsban 25W at I kg/ 10 kg of seed prior to planting (McNeil, et al., 1986). About 4 kg/ha of treated seed is broadcast about five days before the main sowing of 8 kg/ha of untreated seed. This allows the ants to collect the treated seed and to be controlled before the bulk of the seed is available, otherwise they may still remove a significant proportion of the seed before the chemical takes effect. Any seed not collected by the ants from the first sowing will contribute to the establishment of the crop. Irrigation immediately after the second time of sowing is also beneficial as the ants do not move on wet soil. Harvester ant foraging of other Plantago species has also been observed in the USA (Montalvo et al., 2010) and Spain (Hensen, 2002). While no *P. ovata* registered pesticides exist in Australia information on presently registered insecticides and the requirements for registration can be obtained at http://apvma.gov.au/ .

4.1.2 Thrips

Large numbers of thrips have been observed in unsprayed crops. These were identified as juveniles in the *Phlaeothripidae*, and adults of *Frankliniella schultzei* (Trybom) both pale and dark forms, *Haplothrips froggatti* Hood, *Haplothrips robustus* Bagnall and *Microcephalothrips abdominalis* (Crawford). *Phlaeothripidae* species have been identified as pests of wild Plantago species in California (Hoddle et al., 2012). Thrips have also been identified as being present on *Plantago ovata* in Pakistan (Abro et al., 2016). However, I cannot find any reports of them being considered a pest or warranting control anywhere else globally in *P. ovata* crops. This may simply mean they have been overlooked or are presently managed by the aphid control measures.

The effect of the thrips on the number of seed set per head is shown in Table 4.1. In a trial that was sprayed weekly from the onset of flowering thrips activity reduced seed set by 20% and seed dry weight by 18% giving a yield reduction of 39%. They also reduced seed viability and milling quality significantly.

Table 4.1 Results of 1987 thrips trial in the ORIA (Riley et al., 1987).



	Control	Treated
Seed yield (t/ ha FW)	1.03	1.70
Seed yield (t/ ha DW)	0.94	1.53
Moisture content	8.8	9.8
Seeds per head	50.8	63.4
100 seed weight (mg)	162	198
Germination (96)	63	93

In 1988 a trial looking at lower intensity spraying (1-4 times) and various different chemicals (Thiodan (2 L/ha), Lannate (1 L/ha) or Folimat SC (700 ml/ha)) was performed. Table 4.2 shows the results for single and double sprays at weeks one and 2 after flowering on individual plant samples. Spays beyond 2 did not give any extra improvement. While different chemicals had different effects on rate and level of thrips decline they did not significantly differ from each other in final outcomes. It can be seen that 2 sprays were better than 1 spray and increased a variety of yield components including harvest index by

1.36 fold, seed yield by 70% and seed weight by 11%. It thus appears in the ORIA that thrips control is an essential part of *P. ovata* agronomy.

Table 4.2 Thrips trial in the ORIA in 1988 (Riley et al, 1988).

	Control	Single	Double	LSD 5%
Plant weight (g, less seeds)	2.28	2.42	2.95	ns
Seed weight (mg DW)	402	538	684	(0.119)*
Seeds per plant	294	349	444	(0.117)*
Average head length (mm)	21.2	21.7	23.4	1.87
Heads per plant	8.91	9.40	10.16	ns
Florets per head	24.4	24.2	26.6	2.30
Seeds per head	35.1	39.0	44.8	4.82
Seeds per floret	1.42	1.60	1.71	0.12
100 seed weight (mg)	138	149	153	7.1
Harvest index (%)	18.2	22.3	24.8	3.83

ns, not significant
*Analyses were performed on log_{10} transformed data, data presented is back transformed but the LSD 5% is given in the transformed units

A wide variety of crops, particularly greenhouse crops, in Australia are attacked by thrips and Ausveg provides a detailed description of control and management options (http://ausveg.com.au/intranet/technical-insights/cropprotection/thrips.htm). The previous discussion reviewed the damage done in the ORIA and illustrated means and effects of control. However, registration of any chemical needs to be undertaken before it can be used and there are softer and newer pesticides available in Australia. It is also important to manage control measures to ensure resistance does not develop. Consultation with an Entomologist should be sought before applying any chemicals as thrips levels may need to be assessed to determine if control is warranted. Thrips, in heavily infested crops, have been observed to reduce both seed set and size giving a yield loss of up to 65%. Based on research in the ORIA application of Thiodan (2 L/ha), Lannate (1 L/ha) or Folimat SC (700 ml/ha) a week after first flowering and again after a further two weeks adequately limited the thrips population. Information on presently registered insecticides and the requirements for registration can be obtained at http://apvma.gov.au/ .

4.1.3 Other

Heliothis and other caterpillars have been observed in one particular weedy crop in the ORIA. It is likely that broadleaf weeds attract the moths and then some spread to the *P. ovata*. Control seems to be achieved by minimising weed populations in the crop. Magpie geese have caused lodging problems by landing on the crops on occasions in one year but this is unlikely to be an issue if larger areas are planted.

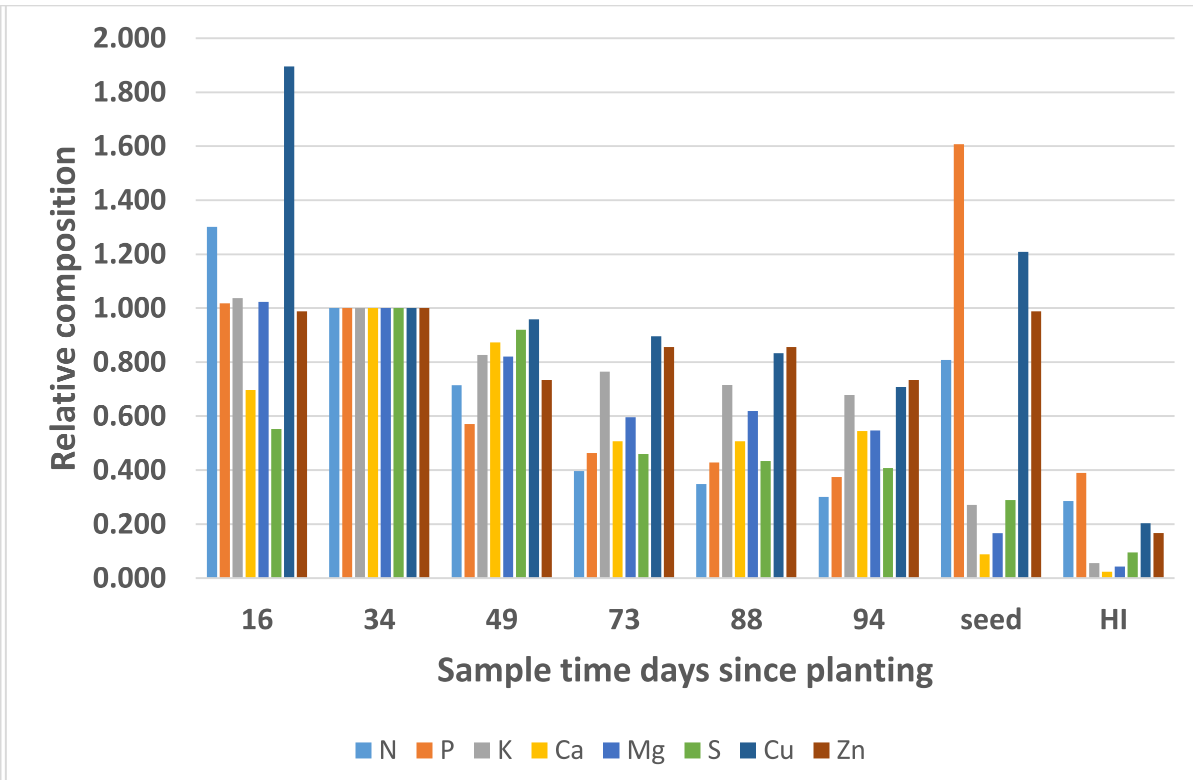
4.2 Nutrition management

Three major areas need to be discussed in nutrition management. 1) the available nutrients in the soil and possible limitations (listed in Table 1.1 as P, N, Cu and Zn for the Cununurra clay), 2) the analysed composition and distribution of minerals as the plant grows, 3) The responses to fertilizer addition. In the ORIA most fertilizers used contain Zn and Cu as default additions. Thereafter various mixes of predominantly N and P are used with Ca and S often as part of the mineral composition of the fertilizer.

4.2.1 General plant mineral composition

Table 4.3 gives the tops (leaves and stems excluding heads) and seed analyses of the 1987 bulk area trial (13% HI, 0.5 t/ha yield, ~100 day season; Table 5.1). It also gives an estimate of the HI proportion for each of the minerals. The crop did not show any obvious mineral deficiencies. N and P HI levels are much greater than the 13% HI for carbon suggesting these may be redistributed to the seeds. Consistent with this is the large decline in top values for these two elements. Other minerals are about the 13% mark (S, Cu, Zn) suggesting little redistribution but possibly adequate levels. K, Ca and Mg are much lower indicating little redistribution from the plant. The fairly stable top values from day 73 on is consistent with little redistribution from the plant to the seed. In the case of Ca it is known not to transfer easily in phloem to seeds but K and Mg should do so (Rengel, 1999). It is possible these may be limiting to the seed development and leaf fertilization later in the season could increase yields.

Figure 4.1 Mineral composition of leaves + stem for the 1987 bulk area P. ovata *planting. The dates are days from planting and followed by seed composition and approximate HI for the element. All values are relative to the 34 day level.*



While it is difficult to understand what the mineral composition values mean without a lot of comparable analyses the values in Table 4.3 suggest N and P are relatively low for what might be expected in a crop. Other analyses from other crops have shown greater concentration values. Thus additional fertilizing with these may be of benefit though in such an undeveloped crop there is a risk of lodging with high N.

Table 4.3 Actual values from Figure 4.1

Days	N % DW	P % DW	K % DW	Ca % DW	Mg % DW	S % DW	Cu microg/g	Zn microg/g
16	4.241	0.236	2.864	1.875	0.733	0.358	12.133	36.409
34	3.259	0.232	2.761	2.693	0.716	0.648	6.400	36.818
49	2.328	0.132	2.284	2.352	0.588	0.597	6.133	27.000
73	1.293	0.108	2.114	1.364	0.426	0.298	5.733	31.500
88	1.138	0.099	1.977	1.364	0.443	0.281	5.333	31.500
94	0.983	0.087	1.875	1.466	0.392	0.264	4.533	27.000
seed	2.638	0.372	0.750	0.239	0.119	0.188	7.733	36.409
HI %	28.627	39.039	5.640	2.375	4.350	9.588	20.313	16.771

Table 4.4 Nutrient analyses from Riley et al., (1988).

Table 10. Nutrient concentrations (dry matter basis) in *P. ovata* foliage one month from planting for commercial crops grown in the Ord River Irrigation Area in 1988.

Site	N	P	K	Na	Ca	Mg	S	Cu	Mn	Zn
	%							ug/g		
1	3.64	0.30	3.44	0.36	2.52	0.62	0.73	6.4	26	31
2	4.15	0.24	4.32	0.28	2.67	0.65	0.62	8.8	35	37
3	4.09	0.35	3.75	0.25	2.84	0.69	0.81	8.3	32	19
4	4.65	0.34	3.60	0.22	2.80	0.61	0.83	11.0	34	52
5	3.88	0.31	3.35	0.34	2.80	0.60	0.67	8.9	30	33
6 beds	3.41	0.41	3.41	0.34	2.58	0.76	0.63	11.0	37	13
6 flat	4.71	0.35	4.40	0.35	2.68	0.77	0.87	10.0	38	48
9 beds	4.19	0.25	3.66	0.23	2.90	0.60	0.81	9.3	22	31
9 flat	4.72	0.29	3.55	0.27	3.13	0.68	0.82	9.7	26	34
Mean	4.16	0.32	3.72	0.29	2.77	0.66	0.75	9.3	31	33

Table 4.4 gives analyses for the commercial crops in 1988. These received additional fertilizer to the 1987 crop and have improved levels of N and P. Several were quite low in Zn at levels (13, 19 micro g /g) that could be expected to be deficient in other crops.

4.2.2 Nitrogen and Phosphorus

Globally N seems to be a major limiting nutrient for *P. ovata* so considerable international data exists and several trials were carried out in the ORIA. Jat et al., (2015) suggest use of organic manure is preferred over inorganic sources. Others (Pouryousef et al., 2007) have found better growth with organic manures as a source of both N and P. The use of organic manures with urea has also been found to increase yield (Yadav et al., 2002). The common factor of all these trials is that *P. ovata* does respond to applied N. However, Jat et al., (2015) suggest isabgol requires very low levels of nitrogen believing inorganic nitrogen should only be applied when the soil is very low in available nitrogen (<120 kg per hectare). They suggest application of 20-30 kg per hectare of nitrogen and 15-25 kg per hectare of phosphorous is optimum to achieve higher yield of isabgol. However, this may be related to the limited yield potential of many of the crops in India as others have found benefit from higher levels of N. For example Karimzadeh and Omidbaigi (2004) found yield, seed swelling and seed weight increases up to 100kg/ha N and only found reductions for 150kg/ha N. Arunjyothi (2007) found that plant height, dry weight and yield all increased up to the maximum rate used of 100kg/ha. This was in spite of the crop only producing HI's of 4-5% and yields of from 395-410 kg/ha from N=0 to N=100kg/ha. Their data did show at the highest rate of N the harvest index fell as plant weight increased faster than seed yield and thus suggested 75kg/ha as optimal. Split applications of N seems to be the preferred method (Jat et al., 2015) globally as well as in the ORIA.

A 1987 nitrogen timing trial (30kg/ha P as double super also applied uniformly) in the ORIA (Table 4.5) indicated up to the maximum application used of 60kg/ha N there were increases in yield, plant height, plant weight and harvest index provided it was provided as a split dose pre-plant and at flowering. Very late N did not seem to be of benefit even though there was evidence of the plant being very short of N late in the growth stages (Table 4.3-4.4). Thus a 30/30/0 split application seems best from the present data. There may, however, be benefits from higher doses in line with other published data described above. However, higher rates were not tested here.

Table 4.5 Nitrogen timing preplant/flowering/seedfill (Riley et al., 1987) effects on P. ovata *growth. Values followed by same letter are not sig. different at P=0.05*

N Treatment Kg/ha	Population Plant /m²	leaf area flowering	Plant height (cm)	Whole Plant weight g/m²	Seed yield g/m2	HI
0/0/0	181a	291bc	25.5bc	265c	40.3c	0.152
15/0/0	148abc	266c	25.0c	261c	43.6c	0.167
30/0/0	133c	302bc	25.6bc	271c	41.6c	0.154
15/15/0	170ab	276c	27.0ab	343ab	53.5bc	0.156
15/0/15	144bc	378ab	26.8ab	300bc	48.7c	0.162
60/0/0	89d	422a	27.6a	331ab	55.3a	0.167
30/30/0	153abc	330abc	27.8a	382a	61.5ab	0.161
30/0/30	159abc	348abc	27.1ab	318ab	55.5bc	0.175

Based on the data from Table 4.5 a further N trial was carried out in 1988. Rates were lifted to 80kg/ha with the same P rate. N was applied either as a single pre-plant dose or split 40kg/ha pre-plant and 40kg/ha broadcast at flowering. The N was either banded or incorporated and applied at 2 depths 20 and 70mm. The results are in Table 4.6.

The data suggest that shallow application of N reduced population as did the high initial application rate arising from using a single application. Thus excess N in the vicinity of the seeds at establishment has adverse effects on establishment. Thus if N is not limiting to establishment deeper placing of a split dose would be best. In terms of yield, plant size, harvest index and seed quality none of the placements had any significant effect. The use of N in this trial by the plant was not particularly efficient in terms of amount taken up by the plants. Thus care is needed to not use more N than is environmentally beneficial.

Table 4.6 nitrogen application method (Riley et al., 1988) effects on P. ovata *in the ORIA*

Nitrogen application method	Population at 3 weeks (N^o/m^2)	Population at maturity (N^o/m^2)
Single, 80 kg N/ha		
Shallow		
Incorporated	260	160
Banded	276	177
Deep		
Incorporated	417	239
Banded	425	258
Split, 40 kg N/ha each		
Shallow		
Incorporated	380	193
Banded	364	235
Deep		
Incorporated	410	284
Banded	450	236
LSD 5%		
Application	0.30	ns
Depth	0.30	0.33
Appln*Depth	0.42	ns

ns, not significant

4.2.3 Other micronutrients

In 1987 a micronutrient trial was carried out in the ORIA in response to earlier suggestions of possible deficiencies based on plant analyses (Table 4.3-4.4). The treatments consisted of (1) no Bo, Cu, Fe and Mn applied, (2) Bo 1 kg/ha, Cu 3kg/ha, Fe 10 kg/ha and Mn 5 kg/ha applied pre-plant and (3) CuS04 1 kg/ha, FeS04 1 kg/ha and MnS04 1 kg/ha in two foliar sprays applied in early and mid July in addition to Bo, Cu, Fe and Mn applied pre-plant. There were no significant responses to the applications indicating in this trial they were not limiting growth. However, the trial was to some degree N deficient due to overly deep initial N application and relatively low yielding on both total growth and seed yield. There may thus be responses to other elements in higher yielding trials or in different bays (Table 5.1).

4.3 Disease

Generally disease did not prove to be a problem in the ORIA plantings. In 1988 bulk areas root rots were observed in areas where the beds were too low and the plants were inundated. No potential causal organism was found by the Department of Agriculture pathologists except for one isolate of Rhizoctonia. This would seem to indicate that waterlogging is an issue for *Plantago ovata* (which is not unusual for the tropics) consistent with published information (e.g. Jat et al., 2015). As a result use of well-formed beds was considered the best option for avoiding the problem. While none are registered for *P. ovata* in Australia information on presently registered fungicides and the requirements for registration can be obtained at http://apvma.gov.au/ .

4.3.1 Downy mildew (Peronospora alta)

In India downy mildew is the dominant disease (which can cause up to 40% loss of seed) with minor occurrences of damping off and leaf blight (Jat et al., 2015). It appears to be worse in the cooler northern growing area of Rajasthan (Rathore and Rathore, 1996) so may be less of an issue in the ORIA even if present. As indicated above only waterlogging based root rots have been observed in the ORIA. It is thus important to keep downy mildew out of the region. Development of downy mildew requires available inoculant, 40-100 (peak susceptibility 60-90) day old plants, low temperature (between 15 and 20°C for 48 hours), leaf wetness and high relative humidity (Rathore, 2008). These characteristics are not likely to be present in bed irrigated ORIA crops. Carryover of inoculant is a major cause of the disease and this needs to be avoided (Rathore, 2009). Cool humid seed storage improves conidia viability, sunlight reduces survival but oospores could survive for years in powdered debris. Leaf debris, seeds and oil all contained spores suggesting rotations would be of benefit in controlling the disease. Jat et al., (2015) indicated practices that lead to high leaf area and thus higher local humidity can increase disease instance (e.g. high nitrogen application, frequent irrigation, early sowing, high seed rates). They indicated control was possible with seed treatment (5g Metalaxyl (Apron SD) per kg seed) and spraying with Metalaxyl & Mancozeb (Ridomil MZ 0.2%) on a 10 day cycle. However, at this stage the disease has not been observed in the ORIA.

Desai and Desai (1969) described control measures in India in 1969 indicating the disease has been around for a considerable period. Patel (1984) published a thesis on downy mildew of isabgol (*Plantago ovata* Forsk) in Gujarat the same year that seed was imported into the ORIA from this region. In view of the survival of the disease in seeds and trash for up to 5 years (Rathore, 2009) and the fact that the initial plantings were not sprayed for downy mildew it is likely that the disease was introduced at the time and did not establish itself either by chance or due to low suitability of the ORIA. Following import the seeds were bulked and sown over a 4 year period of production totalling in excess of 160 ha almost entirely without fungicidal sprays. No evidence of the disease was found during this period by chance or due to poorly suited conditions in the ORIA. Detailed inspections each year of the crop by DAFWA plant pathologists did not observe any disease. It thus appears that the climate in the ORIA may not be conducive to the disease.

However, to minimise the risk it would be advisable to source the imported seed from low risk areas, to clear all trash, to apply seed dressings and to field spray and inspect the crop in the early years (Jat et al., 2015). This is also needed to prevent aphid import.

4.4 Weed management

Appendix 3 gives details on the process of minor use pesticide registration. Appendix 4 provides detail on RIRDC assistance for new industries and minor uses. As Plantago is an experimental crop the herbicides mentioned here are not registered for use in Plantago and are only to be used at the risk of the grower. As the crop would be grown under contract the use of any pesticides should only be done with the permission and at the risk of the contracting party in accordance with APVMA regulations.

P. ovata is a small seeded crop growing in a tropical production area and remains relatively short throughout the growing season. As such it can have major issues with weed management. Typically Indian production of *P. ovata* uses 2 hand weedings during the growing season to control weeds. "*The first weeding is very critical for crop-weed-competition point of view and must be done at 20-25 days after sowing. Pre-emergence application of Isoproturon at the rate of 500-700 g active ingredient per hectare is recommended to control the weeds effectively and increase the profits.*" (Jat et al., 2015). However, Isoproturon (a urea group herbicide similar to Diuron) is not registered for use in Australia. Isoproturon is also banned in Europe as an endocrine disrupter and thus very unlikely to ever be available in Australia (https://www.theguardian.com/environment/2016/apr/19/europe-bans-two-endocrine-disrupting-weedkillers).

Pre-planting preparation should be used for weed control through rotations (eg a grass crop during the wet season such as maize should allow good broadleaf control but may impede land preparation), block selection and possibly a mechanical kill during land preparation. Three effective (though unregistered) strategies for weed control were identified in the ORIA and these are (l) high seeding rates of 12 kg/ha. (2) Diuron (1.5 kg ai/ha) applied before planting and (3) paraquat (100-200 ml ai/ha with wetting agent) applied post emergent at 28 days after planting. However, use of Diuron is problematic as it has been reviewed by the APVMA (http://apvma.gov.au/node/12511) which has now severely restricted in its use. McNeil (1989b) also found at application rates above 1.0 kg ai/ha it had substantial and significant negative effects on a following soybean crop. Paraquat will need a minor use permit and its use is presently being reviewed by the APVMA because of concerns over its acute human contact toxicity (http://apvma.gov.au/node/12666). With beds it is also advisable to cultivate the furrows as needed. Early (<~25DAP) applications of paraquat will damage the Plantago and applications later than about 35 days after planting will not effectively control the weeds. The rate of paraquat used is important as higher rates will most likely cause damage to the crop. High seeding rate plus one of the herbicide treatments gave acceptable results, use of both herbicides may only be of advantage in situations with high weed populations. Efforts to minimize the weed population are essential in this short crop to reduce both competition and contamination of harvested product.

Wick wiping above the crop with glyphosate later in the season may eliminate tall weeds that would interfere with harvesting if many are present.

The use of Diuron is incompatible with a wet season legume crop such as soybean. One advantage of this residual property is that Diuron could be used for weed control in a wet season fallow preceding a dry season Plantago crop.

4.4.1 Preliminary testing and ineffective control strategies

The 1985 tests suggested that pre-plant Diuron, and post plant grass herbicides and post plant paraquat might be options for weed control in *P. ovata Table 4.7*. These were therefore tested further in the next section. At rates sufficient to be effective (2 and 3 in table 4.8) it can be seen that all of the preplant options tested in Table 4.8 did too much damage to be used.

In comparisons of timing of application, rates and use of diquat it was found that 0.1 kg ai/ha of paraquat used at 27 days after planting was as effective or more effective than later applications (37 days) or higher rates (0.2 kg ai/ha). Both of these resulted in some crop damage and no better weed control. It was also found that Diquat over these ranges showed some benefits similar but less than Paraquat. Thus all of these treatments were abandoned and further discussion will only look at the more effective paraquat treatments. Grass herbicides (Fluazifop and Sethoxydim) may also be relatively safe and benefit production (Table 4.7).

Table 4.7 Herbicide testing 1985. (McNeil 1985) Promising chemicals are shown in the second table with establishment counts, flowering dry weight and final harvest weight averaged across the 3 treatments.

Herbicide application rates:

Herbicide	Applic.Time	Act. Ingred. g/L		Product Rates kg or L/ha		
Treflan	pre plant	Trifluralin	400	1	2	3
Lasso	"	Alachor	500	2	4	6
Diuron 50	"	Diuron	500	1	2	3
Simazine 500W	"	Simazine	500	1	2	3
Gesparim 500	"	Atrazine	500	1	2	3
Devrinol	"	Napropamide	500	3	6	9
Lexone	"	Metribuzin	750	0.5	1.0	1.5
Surflan	"	Oryzalin	400	1	2	3
Dual	pre emergent	Metolachor	720	2	4	6
Fusilade	post emergent	Fluazifop	212	0.5	1	1.5
Sertin 186 EC	"	Sethoxydim		0.5	1	1.5
Basagran	"	Bentazone	480	1	2	3
Blazer	"	Acifluorfen	224	1	2	3
Betanal	"	Phenmedipham	157	2.5	5	7.5
Farmco D500	"	2,4D	500	0.5	1	1.5
Afalon	"	Linuron	500	1	2	3
Gramoxone W	"	Paraquat	200	0.5	1	1.5
Reglone	"	Diquat	200	1	2	3
Diuron 50	"	Diuron	500	1	2	3
Gesaprim 500	"	Atrazine	500	1	2	3

Herbicide	Time of Application Days after planting Days	Plant Population 2 wks after planting Plants/ha x 10^{-6}	Dry Weight at flowering t/ha	Yield t/ha
CONTROL	-	1.49	1.43	1.85
Trifluralin	0	0.11	-	
Alachor	0	1.07	-	1.30
Diuron	0	1.57	1.96	2.08
Simazine	0	0.61	-	
Oryzalin	0	0.00	-	
Atrazine	0	0.09	-	
Napropamide	0	0.06	-	
Metrabuzin	0	0.03	-	
Metolachor	1	0.77	-	
Fluazifop	30	-	1.27	1.42
Sethoxydim	30	-	1.27	1.50
Bentazone	30	-	1.52	-
Acifluorfen	30	-	1.19	-
Phenmedipham	30	-	0.99	-
2,4,D	30	-	0.61	-
Diuron	30	-	1.04	1.39
Linuron	30	-	0.60	0.88
Paraquat	30	-	1.56	1.73
Diquat	30	-	1.29	1.69
Atrazine	30	-	0.74	-

Table 4.8 Pre-plant herbicide testing (McNeil et al., 1986

Herbicide	Proportion of plants alive after 2 weeks (%) 1	2	3	4	5
Metribuzin	50	1	0	0	0
Trifluralin	53	4	10	1	0
Prometryn	39	1	0	0	5
Linuron	25	2	7	1	5
Pendimethalin	21	15	18	7	0
Terbutryne	2	10	1	0	0
Trifluralin + Linuron	12	11	17	0	-
Control	28	-	-	-	-

Herbicide active ingredients	Formulation	Formulation	Rates of application (L/ha or kg/ha) 1	2	3	4	5
Metribuzin	700 g a.i./L	Sencor	0.25	0.5	1.0	2.0	3.25
Trifluralin	400 g a.i./L	Treflan	0.75	1.75	3.0	4.5	6.25
Prometryn	500 g a.i./L	Gesagard	1.0	2.25	3.75	5.5	7.5
Linuron	500 g a.i./kg	Afalon	0.5	1.0	2.25	3.75	5.5
Pendimethalin	330 g a.i./L	Stamp	1.0	2.25	3.75	5.5	7.5
Terbutryne	475 g a.i./L	Igran	0.5	1.0	2.25	3.75	5.5
Trifluralin + Linuron	400 g a.i./L + 500 g a.i./kg	Treflan + Afalon	0.5 0.5	1.0 1.0	2.0 2.0	3.5 3.5	

4.4.2 Effective control strategies

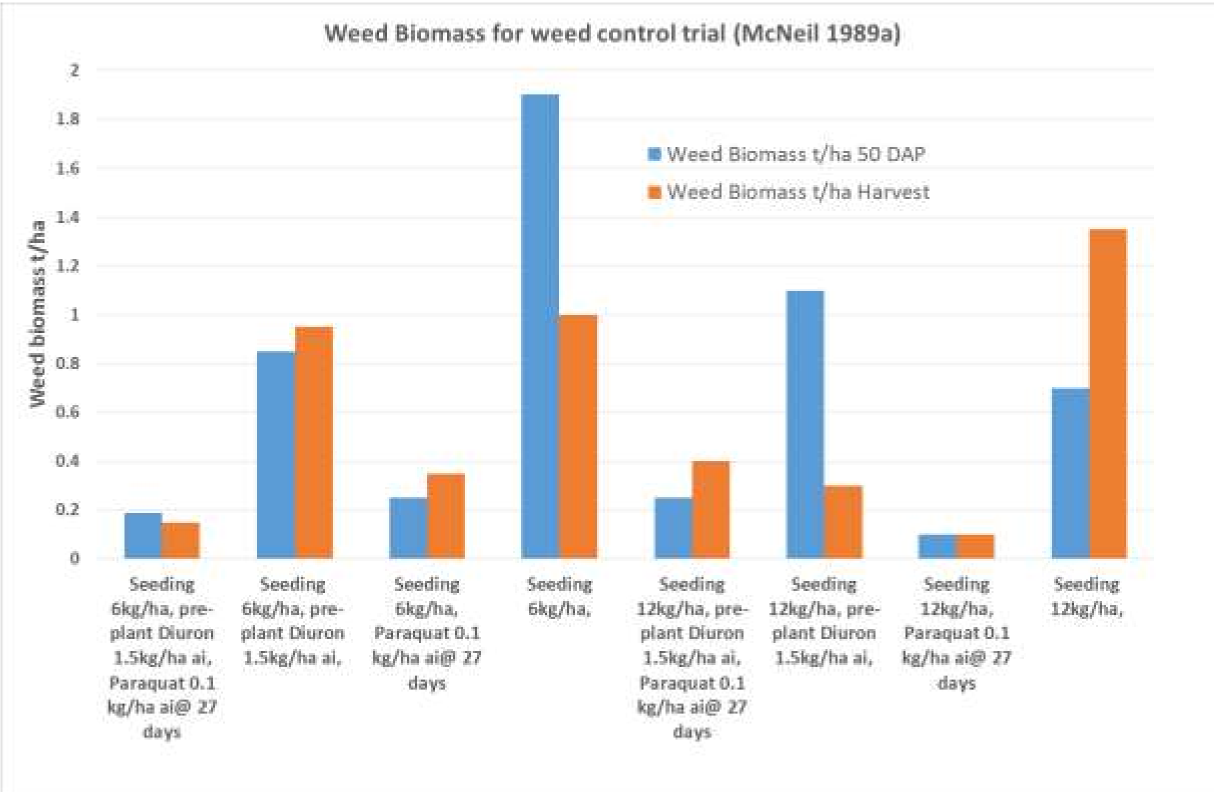
Figure 4.2 and 4.3 show the results of a 1986 trial using the 3 established control strategies of high seeding rate (12 kg/ha), pre-plant Diuron (1.5 kg ai/ha) and early (27 DAP) low rate (0.1 kg ai/ha) paraquat. Even without additional treatments there was a substantial increase of *Plantago ovata* biomass (particularly early) and reduction in the early weed biomass when the 12 kg sowing rate was used. There did not seem to be an additive benefit from use of herbicides and sowing rate on weed biomass but *Plantago ovata* biomass increased with combined herbicide and sowing rate treatments. The two herbicide treatments had similar benefits but the optimum seemed to be the combination of paraquat and high seeding rate.

The benefits of paraquat on plant growth at the low rates is confirmed by Rahim (2005) Table 4.9.

The main weeds identified in the trial were Pigweeds ((Trianthema portulacastrum L., Portulaca oleracea L.), Grasses (Echinochloa colonum (L.) Link., Sorghum album Parodi) and others (Vigna radiata (L.) Wilczek , Physalis minima L., Amaranthus sp., Sesbania cannabina Roxb.). At harvest averaged over the whole trial they constituted approximately 17%, 36% and 47% of the weed biomass respectively.

Harvest indices were low in the trial, probably in part due to lack of thrips control, at between 8.4 and 9%. However there was no evidence of any differences among treatments. Thus yield benefits were similar to dry matter benefits. Averaged over the two seeding rates the control yield was 0.31 t/ha, paraquat alone increased this to 0.56, Diuron alone to 0.51 and the combined treatment 0.57. The higher seeding rate increased yields from 0.41 to 0.49 t/ha across all treatments.

Figure 4.2 Herbicide treatments on weed biomass ORIA 1986.



In addition to these chemicals Fusilade (212g/l Fluazifop –P) was tested in 1985. Table 4.10 indicates it seemed to be safely and successfully used on the crop. The Fusilade treatments averaged 1256 kg/ha with a recovery of 84% for machine harvested yield. In a second year of testing and use on bulk areas Fusilade gave yield reductions of 10-23% compared with Diuron ar paraquat treated plots. Therefore, due to its limited weed control range (grasses) and variable yield effects it was not further used. As already presented 2/3rds of the weeds at harvest in the earlier trial were not grasses. It can also be seen that the 0.25kg ai/ha paraquat treatment gave good yields in this trial.

Figure 4.3 Herbicide treatments on P. ovata *biomass ORIA 1986.*

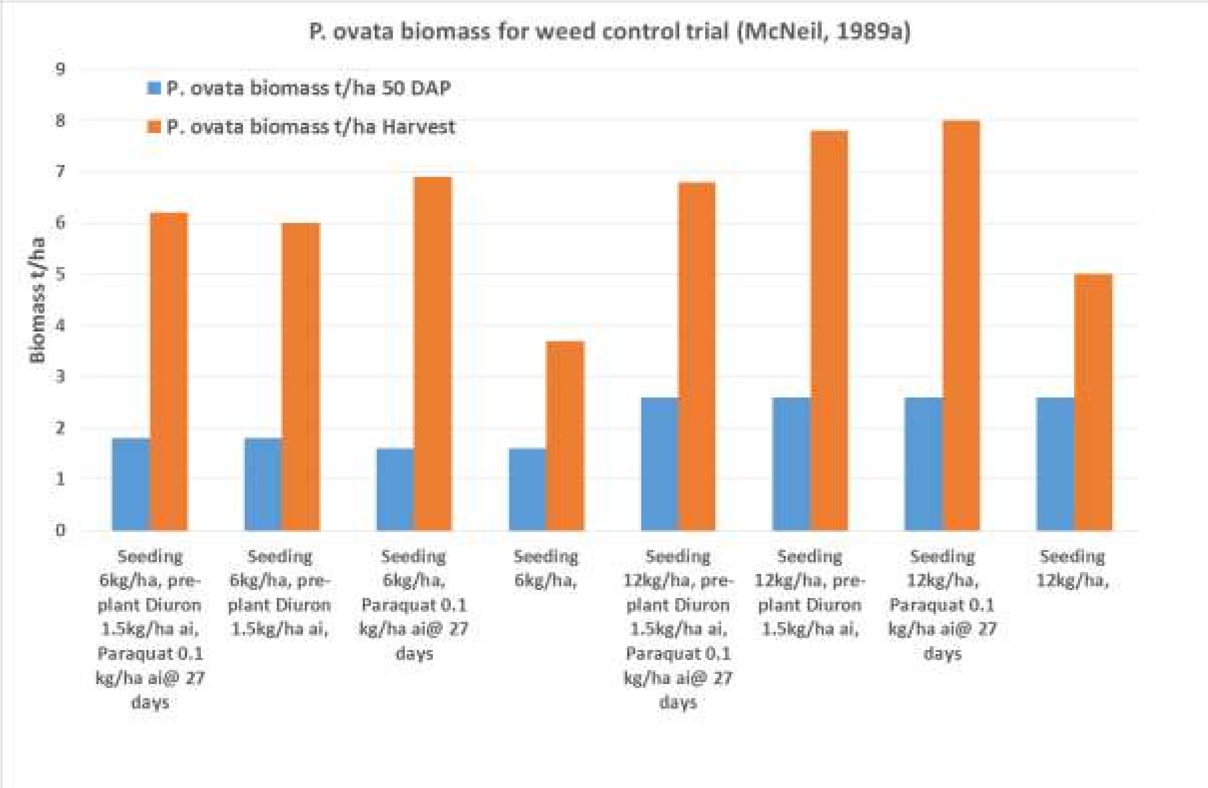


Table 4.9 Response of Plantago ovata *seedlings "AZ 316" to paraquat (Rahim 2005)*

TREATMENT	Responses		
PARAQUAT (%V/V)	Survival % of control	Height cm	Root rating 10=normal, 0=none
TRIAL 1			
0.00	100	11a	8a
0.125	100	11a	7a
0.25	88	7b	4a
0.5	44	3c	3a
O.75	38	3c	4a
TRIAL 2			
0.00	100	15a	7a
0.125	100	14a	7a
0.25	100	15a	7a
0.5	100	11b	5a
O.75	75	8c	5a

Values followed by the same letter are not significantly different at P=o.o5

Table 4.10 Unreplicated 1985 trial of herbicides under varied conditions.

Seed Rate kg/ha	Herbicide	Layout	Hand yield kg/ha	Machine yield kg/ha	Machine/Hand
8	Fusilade 1.5l	8 rows	1117	990	0.886
8	Grammoxone 0.25g ai/ha	8 rows	1730		
8	Fusilade 1.5l	Broadcast	1676	1285	0.767
8	Fusilade 1.5l	Broadcast + Harrows	1497	1173	0.784
4	Fusilade 1.5l	8 rows			
4	Grammoxone 0.25g ai/ha	8 rows	1242	913	0.735
4	Fusilade 1.5l	Broadcast	1171	1060	0.905
4	Fusilade 1.5l	Broadcast + Harrows	820	718	0.876
Mean			1322	1023	0.825
Mean Fusilade			1256	1045	0.843

Figure 4.4 Left side 8kg/ha, broadcast later planted, Diuron treated plot: Right is 4kg/ha, 4 rows per bed, early planted. Desiccated with paraquat prior to harvest. Note the weedy nature & low yield of the thin stand without in season herbicide. (McNeil 1985)

Figure 4.5 Effects of a preplant application of 2 L/ha Diuron 50 forty days after planting. The furrow in the bottom half of the photo received herbicide while the furrow in the top half was untreated. (McNeil 1985)

4.5 Irrigation management

Irrigation management for *P. ovata* consists of three stages: 1) establishment and early growth when roots only explore a part of the soil, 2) main growth phase irrigation, 3) cut off times to allow drying off for harvest and maximum yield production. In a general sense the second phase would be consistent with most other crops grown on the ORIA. Generally because of the nature of bed irrigation watering is done on every 60 mls of pan evaporation. However, it may be made more precise by measuring soil water and using irrigation scheduling (Campbell and Campbell, 2013).

As with all irrigation areas there is a need to manage irrigation both for the present crop and ongoing future. Riasat et al., (2010) provide detailed models for irrigating to manage water needs and salinity in the ORIA. Ord Land and Water (http://www.olw.com.au/land.html#irrigation) and Dept. of Water (2006) provide detailed management plans for the ORIA including irrigation management.

This section will look at some general information with respect to irrigation effects on *P. ovata* and the next sections will look more specifically at establishment and drying off. Much of the international literature looks at quality and yield effects of limited irrigation rather than means to provide optimal water. Usually this is due to limited access to irrigation water. Jat et al., (2015) advise that growers should use good quality water from a clean source for irrigation. Jat et al., (2015) indicate incorrect irrigation will adversely affect yield and quality advising to irrigate on need (ie crop water demand) as indicated here. With respect to the three times mentioned earlier they advocate a single irrigation at sowing and a last irrigation at milk stage. They also suggest that slightly saline water (up to 4 ds/m electrical conductivity) can be used for irrigation purposes without loss of yield or quality.

Mohebbi and Maleki, (2010) showed that both water excess and shortage resulted in reduced seed size and swelling factors. Thankur et al., (2012) found moisture stress imposed at any stage adversely affected LAI and yield. Harvest index was less affected particularly with late stress. Stresses around flowering and early bud fill gave the most pronounced negative effects. Stress reduced seed protein but did not adversely affect swelling factor and increased husk yield. Generally as expected water stress during growth at any stage had adverse effects on yield of *P. ovata*.

4.5.1 Establishment irrigation management

A trial in 1985 with extreme temperatures (Mean 29°C) at sowing looked at the ability of irrigation timing to improve establishment McNeil et al., 1986).

Table 4.11 Establishment watering times on population.(McNeil et al., 1986)

Watering times days after planting	% establishment	Weed population/ha 10^3
1, 2, 14	**10.2**	**87**
1, 5, 14	**6.6**	**80**
1, 7, 14	**4.3**	**133**
1, 14	**4.3**	**147**
cv.	**3.1**	**44**

Table 4.11 indicates that under high temperatures establishment was difficult. However, more frequent early irrigations had a beneficial effect on germination of *P. ovata* as well as reducing weed populations. In a later trial when mean temperatures were 25°C after planting there was no difference in establishment, yield or weed populations with irrigations on days 1,2,3; 1,2,5; 1,2,7; 1,3,7; 1,4,7; 1,7. This interaction of water at planting, establishment percentage and sowing temperature is shown in Table 4.11.

4.5.2 Drying off irrigation management

There is little in the literature relevant to the drying off of *P. ovata* in the ORIA so a series of trials looked at the optimal methods. In 1985 (McNeil 1985) water was withheld from the last two irrigations on the levee block and it resulted in a non-significant 5% yield increase suggesting late watering is not needed. Where an overhead watering was given to plants at harvest maturity there was a 25% loss from shattering. This is consistent with Jat et al., (2015) suggesting that the last watering should be given at milk dough stage as the crop tended to mature non uniformly over a month period. Since the crop did not appear to shatter if left dry late harvesting was not a great issue.

5. Harvesting and processing

5.1 Harvesting

Jat et al., (2015) describe harvesting in India by scything off the plants at ground level, leaving them to dry and then threshing. Thus early work in the ORIA looked at windrowing and then harvesting. There did not appear to be any loss if the crop was left on the ground dry (either before or after cutting) for an extra week provided there were no storms to induce shattering. As the crop did not mature uniformly trials were also undertaken of chemical desiccation (Figure 5.3) using Sprayseed (paraquat + diquat) and paraquat alone. The desiccation improved the ability to deal with weeds but had no yield or harvesting advantages in well managed crops that had dried off. Windrowing was not found to be as good as direct heading (Figure 5.1) and did not warrant the extra effort.

Figure 5.1 The CLAAs harvester in action on a good crop.

The header sample contained some sticks and dirt that was removed by a standard precleaner and all machine yields are quoted after the cleaning had taken place. Pre- and post cleaning samples are shown in Figure 5.2.

Harvesting of broadcast crops seemed to give a better recovery than row crops relative to hand harvesting. The probable cause was the collapse of some rows into the furrows where the machine harvesting could not reach them. Crop lifters in the furrow may overcome this problem. Yields of machine to hand harvesting improved when there was more material flowing through the harvester and there was not much green material. Thus there was a tendency to leave the crop standing till it had dried off well. All crops still had some green heads at maturity but very long drying off times did not seem to fill heads in these and thus did not improve yields. A floating cutter bar was used to get all of the short crop which picked up some dirt. However this was easily removed later (Figure 5.2). Machine to hand harvested yields were variable ranging from approximately 0.5 to over 1.0. For example the average for the commercial plots in 1988 (Table 5.1) was 0.78 and the average for the weed trial in 1986 was 0.83 (Table 4.10). Harvesting was easier in early planted taller crops. It is probable that with experience the machine harvesting would improve above the 0.8 average value.

Figure 5.2 Header sample prior to and after cleaning

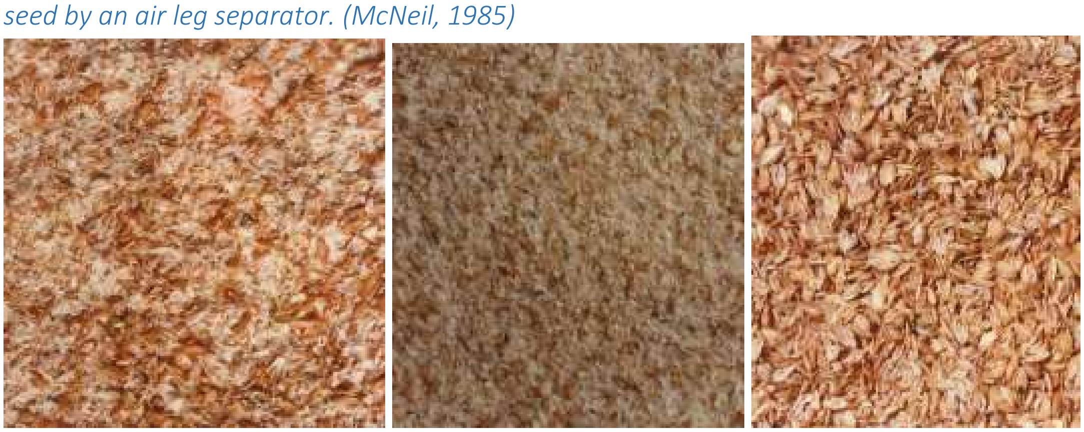
Figure 5.3 The left side of the photo shows P. ovata *at harvest maturity. A late planted/broadcast area at 8kg/ha with 2 L/ha of Diuron. The right side is early planted at 4 rows, 4 kg/ha desiccated with Paraquat + Diquat. Note the much greater weed problems in the thin stand area without preplant Diuron. (McNeil 1985).*

Being a short crop with a tendency to lodge particular care needs to be taken in harvesting Plantago. A header with a floating cutter bar and set with a narrow concave, slow drum speed (about 500 rpm) and low fan speed has been used to harvest Departmental plantings. Any lodging of the crop will be with the direction of the prevailing winds and depending on the orientation of the beds, harvesting may need to be done in one direction only. Timing of harvest can be judged by the seed coat colour, which turns from brown to grey on maturity. The crop should be harvested about 10 days after the majority of seeds begin to turn grey. If weeds have not been successfully controlled an application of a desiccant herbicide about five days before harvest may be needed to stop green material interfering with harvesting.

5.2 Processing

Harvested samples of the material were put through a rice dehusker which produced a mix of husk and squashed seed. This was then separated using an air, gravity table and sieve cleaner to produce the samples shown in Figure 5.4. The partially purified husk as shown could then be further purified as needed as described in Jat et al., (2015). The residual waste is described as Lali (seed waste) and Gola (husk waste) in India. And is used as a nutritive animal feed at up to 25% (lali as pictured in Figure 5.4) and 50% (Gola) of the diet supplement. It is particularly used as a cattle feed and has value for its high fibre properties as well as protein and energy values (Anonymous, 2012,). Isabgol Lali contains: 30-40% Crude Protein and 31.3% Ether Extract, 1% Crude Fibre, 28.1% Nitrogen Free Extract, 1.4% Phosphorus and 0.9% Calcium on dry matter basis. Thus, it is good source of protein and energy. Isabgol gola contains about 18-20% CP. Samples of Lali from the ORIA were also tested for chicken and pig feeds and found to have good digestibility in these animals. Similarly Indian material has good feed values (Shukla et al., 1981, Anonymous, 2012).

Figure 5.4 P. ovata seed after it had passed through the rice huller. Then separated into husk and crushed seed by an air leg separator. (McNeil, 1985)



5.3 Commercial crops

Table 5.1 indicates that significant yields can be achieved in large areas when crops are well managed. However, the data also indicate a significant problem in first time growers achieving high yields and issues with fixing on an optimum system as well as the rare but significant problem of rain at harvest. The highest yields in 1988 were experienced by the 1986/7 grower. There are also issues with getting the machine harvesting to work well first and only time when shifting from the small harvester to the large commercial grower machines. What is of interest here is that if a mean is taken of machine harvest yields across 3 years and all successful large scale plantings it comes to 624 kg/ha. This is almost exactly equal to the average (hand harvested) yield in Gujarat from 1992-2004 (Figure 1.2). If hand harvested ORIA yields are used they average 119% of machine yields at 770 kg/ha, well above Gujarat yields. **This indicates the potential for the crop in the ORIA where the first year of commercial scale production ever (1988) significantly exceeded the mean yields 10-20 years later of the world's dominant growing region.**

Jat et al., (2015) describe the seed as having about 25% husk in India. Generally trials in the ORIA produced values between 26 and 30% (Riley et al., 1987, 1988). Modi et al., (2010) gave a commercial yield of husk of approximately 27% directly comparable with the ORIA values. Seed weight for the ORIA fitted within the usual range of 150 to 190g/1000 seeds.

Table 5.1 Summary data from bulk plantings in the ORIA. McNeil et al., (1986), Riley et al., (1987, 1988),

Year	Bay	Area	Yield	Yield	Machine /hand yields	Planting date	Establishment population	Comments
		ha	**t/ha**	**t/ha**				
		ha	Hand	Machine			x 10^6/ha	
1986	**1**	1.0		1.01	0.80	May		
1987	**1**	12		0.5		May		
1988	**1**	18	1.29	0.86	0.67	May	2.6	
	2	18	0.42	0.37	0.88	June	4.9	
	3	18	0.47	0.27	0.57	June	2.1	
	4	18	0.65	0.3	0.46	May	1.1	
	5	18	0.57	0.56	0.98	June	3.2	
	6a	12	0.12	0.03	0.25	May	2.6	Shattered in local storm pre-harvest
	7	18	0.62	0.58	0.94	May	1.4	
	8	12	0.48	0.59	1.23	May	1.5	
	6b	5	0	0		May	0	Flat no beds failed waterlogged
	9 (3.2.3)	1.5	1.17	1.2	1.02	May	3.2	Mixed beds flat irrigation types

Riley et al., (1988) looked at various ways of extracting the testa from the seed to get estimates of amounts. They found extracting with a blender in water gave a maximum value for the bulk testa of 30% when extracted for 40 seconds with little effect of the water temperature. They found that there was a relationship between seed size and proportion of soluble testa indicating the importance of generating well filled seeds (Figure 5.4). The method is thus a good way to monitor seed quality in agronomic and breeding research and is capable of producing reproducible results for seed quality testing.

Romero-Baranzini et al., (2006) provide a full and detailed analysis of Indian *P. ovata* seed. *"Plantago seeds had 17.4% protein, 6.7% fat, 24.6% total dietary fiber, 19.6% insoluble fiber, 5.0% soluble fiber,* *and a combustion heat of 4.75 kcal/g. Osborne fractionation (based on solubility) yielded albumin 35.8%, globulin 23.9%, and prolamin 11.7%. The oil from Plantago seeds had a high percentage of linoleic acid (40.6%) and oleic acid (39.1%) and a minor proportion of linolenic acid (6.9%). In vitro protein digestibility of the Plantago seed was 77.5%, suggesting a highly digestible protein. Lysine content was 6.82 g/100 g of protein, higher than wheat and oats (2.46 and 4.20 g/100 g of protein, respectively). Rat bioassays showed values of 89.6% digestibility of dry matter, 86.0% apparent digestibility, 88.1% true digestibility, and 4.40 net protein ratio corrected (NPRc). The importance of these findings is that plantago whole grain shows favourable nutritional quality when compared with cereals and legumes."*

Figure 5.5 Estimate of Plantago ovata *mucilaginous testa as a proportion of seed weight using a blender to remove the soluble testa for a range of seed size fractions collected from a gravity table. (Riley et al., 1988)*

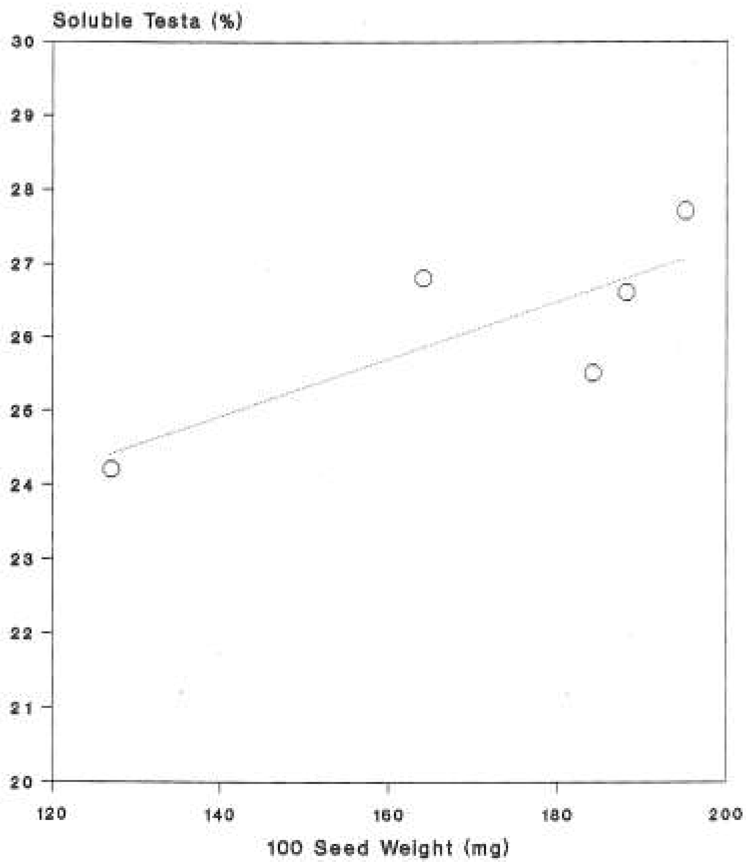


Figure 5.6 1986 ORIA bulk area P. ovata *row planting in beds on Cununurra clay. (McNeil 1985)*

At this stage there is no commercial scale processing available in the ORIA. Transport of the crop elsewhere to process would be an option as the crop does not easily spoil. However, the region has at various times processed a range of crops and if the economics warranted it such an operation could be developed. Harvesting and cleaning of seeds would not be an issue and the processes involved in extracting husk are simpler than other mechanical systems for some crops. There would be a local market for the Lali as a stock feed as the region presently produces and exports some seed as well as being engaged locally in fattening. In the meantime export as grain from the region would be possible along with a range of other crops. It has already been demonstrated that machinery developed for rice husking worked well on the *P. ovata*. Further details of processing and marketing in India including the detailed processing chain are available in NMCE (2008).

6. Conclusions and recommendations

1. Based on the information compiled here the ORIA shows an excellent potential for development of a commercial mechanised *Plantago ovata* production industry.
2. Detailed information on research and commercial growing of *P. ovata* has been provided. This exceeds the information available for any other mechanised world growing region.
3. A preliminary description of possible grower practices based on the detailed growing information is provided in Appendix 1.
4. Development of a *P. ovata* industry will require a partnership among researchers, growers and marketers of the Plantago. It will require financial, time, training, effort and intellectual investment to succeed. Possible partners for initial contact include; (Dr Shär; R&C; Searle; Kellog etc; marketer), D McNeil consulting (researcher), KAI (grower), ORDCO (growers, processors and suppliers) and DAFWA (regulatory, research, funding). Others may be included later including university, government and funding bodies (eg RIRDC, GRDC).
5. The next step would be for an interested partner (Dr Shär; R&C; Searle; Kellog etc) to take the lead to formally establish a partnership development program and investment proposal for the partnership.
6. Presently hundreds of millions of dollars are being spent in the ORIA expanding cropping and this may offer opportunities for development of *P. ovata* in the area.

7. Commercial growing in the ORIA will require that;
    a. A variety import and selection/breeding program is established.
    b. A bulk up of seed is carried out.
    c. Recruiting and training of growers/researchers is undertaken.
    d. Prioritised trial/demonstration plantings are made.
    e. Preparation for minor use registration of Agrichemicals be undertaken.
    f. Preparations for milling and evaluation of produced products commence.

7. References

Abro, G.H. et al., (2016) Arthropods associated with some medicinal plants under field conditions in Sindh province of Pakistan, Journal of Entomology and Zoology Studies 4(1): 516-520

Aghilian, S.; Khajeh-Hosseini, M. and Anvarkhah, S. (2014) Evaluation of seed dormancy in forty medicinal plant species, International Journal of Agriculture and Crop Sciences. 7(10): 760-768.

Ali, T.; Hossein, P.; Asghar, F.; Salman, Z. and Ali, Z.C.M. (2010) The effect of different treatments on improving seed germination characteristics in medicinal species of Descurainia sophia and Plantago ovata, African Journal of Biotechnology Vol. 9(39): 6588-6593

Anonymus (2012) FEEDS AND FODDERS IN INDIA NUTRITIVE VALUE OF COMMONLY AVAILABLE FEEDS AND FODDERS, National Dairy Development Board, Anand-388 001 IN INDIA 112pp

Anshu, D.; Surendra, P. and Navneet, K. (2008) Seed Dormancy Breaking Approach in Isabgol (Plantago ovata), Progressive Agriculture 8(1): 71-3.

Arunjyothi, A. (2007) Effect of date of sowing and nitrogen on growth and yield of Isabgol (Plantago ovata Forsk.) Masters thesis, Acharya N.G. Ranga Agricultural University, Hyderabad, http://krishikosh.egranth.ac.in/bitstream/1/71068/1/D8101.pdf accessed 8/12/2016.

Asghar, R.; Jahansouz, M.R.; Mashhadi, H.R.R.; Majid, P. and Rousta, H.R. (2009) Effect of drought and plant density on yield an phenological stages of isabgol and French psyllium using Growth Degree Days. Electronic Journal of Crop Production, 2(1) 57-74.

Atal, C. K. (1958). Cytoplamic male sterility in *Plantago ovata* Forsk. Current Science. 27: 268.

Bannayan, M.; Nadjafi, F.; Azizi, M.; Tabrizi, L. and Rastgoo, M. (2008) Yield and seed quality of Plantago ovata and Nigella sativa under different irrigation treatments, Industrial crops and Products, 27: 11-16.

Bell, L. (2015) Chinese company Kimberley Agricultural Investment sows first crops in Ord Stage 2, http://www.abc.net.au/news/2015-05-18/kai-sowing-crops-ord-stage-two/6478082 accessed 4/12/2016.

Campbell G.S. and Campbell, M.D. (2013) Irrigation scheduling using soil moisture measurements: theory and practice. 25-41, in Hillel D. ed, Advances in irrigation V1, publisher Elsevier ISBN 1483215253, 9781483215259

Dagar, J.C. ; Kumar, Y. and Tomar, S. (2006) Cultivation of Medicinal Isabgol (*Plantago ovata*) in alkali soils in semi-arid regions of Northern India. Land Degradation and Development, 17: 275-283.

Department of Water. (2006) Ord River Water Management Plan. Department of Water, Government of Western Australia, Water Resource Allocation Planning Series Report No WRAP 15. 208pp

Desai, M.V. and Desai, D.B. (1969) Control of downy mildew of isabgul by aureofungin. Hindustan Antibiotic Bulletin. 11(4):254-7.

Ghaderi-Far, F.; Alimagham, S.M.; Kameli, A.M. and Jamali, M. (2012) Isabgol (*Plantago ovata* Forsk) seed germination and emergence as affected by environmental factors and planting depth, International Journal of Plant Production, 6(2): 1735-6814

Gunn, R.H. (1969) Soils of the Kimberley Research Station, Kununurra Western Australia. CSIRO Division of Land Research, Technical Memorandum 69/21.

Gupta, R. (1982). Recent advances in cultivation of Isabgol (Plantago ovata Forsk.) in India in C.K. Atal and B.M. Kapar, Cultivation and Utilization of Medicinal Plants, p. 406-417.

Gupta, A.; Parihar, S. S.; Choudhary, V. K.; Naseem, M. and Maiti, R. K. (2008) Germination, dormancy and its removal in isabgol (Plantago ovata Forsk). International Journal of Agriculture Environment & Biotechnology 1(3):117-124

Hamilton, G,; Bakker, D.; Houlbrooke, D. and Spann, C. (2005) A manual for raised bed farming in WA. 54pp, Published by DAFWA, South Perth, WA.

Hensen, I. (2002) Seed predation by ants in south-eastern Spain (Desierto de Tabernas, Almería) Anales de Biología 24: 89-96, https://www.um.es/analesdebiologia/numeros/24/PDF/08-SEED.pdf accessed 6/12/2016.

Hoddle, M.S.; Mound, L.A. and Paris, D.L. (2012) Thrips of California. CBIT Publishing, Queensland http://keys.lucidcentral.org/keys/v3/thrips_of_california/identify-thrips/key/california-thysanoptera-2012/Media/Html/browse_species/Haplothrips_leucanthemi.htm accessed 8/12/2016

Ianovici, N. (2007) Plantago atmospheric pollen in the TIMIŞOARA area in 2006-2007, Annals of West University of Timişoara, ser. Biology, vol X, pp 1-10.

ICAR-Directorate of Medicinal and Aromatic Plants Research (2015) Annual report 2014-15.

ITC (International Trade Centre) (2014) http://www.intracen.org/itc/blogs/market-insider/Short-supply-and-price-increases-foreseen-for-2014-ispaghula-crop/ accessed 4/12/2016.

Iyengar, M.A.; Kanitkar, U.K. and Pense, G.S. (1968) Some factors affecting yields of Plantago ovata (Isapghul) in Maharashtra, Indian J. Agron. 13:123-124

Jamian, S.S.; Asilan, K.S.; Mehrani, S.; Tabrizi, A.T. and Goharian, A. (2014) Effects of elevated temperatures on seed germination and seedling growth in three medicinal plants. International Journal of Agriculture and Crop Sciences. 7(4): 173-177.

Jat, R.S.; Nagaraja Reddy, R.; Ruchi Bansal and Manivel, P. (2015) Good Agricultural Practices for Isabgol, Extension bulletin, ICAR – Directorate of Medicinal and Aromatic Plants Research, Boriavi, Anand, - 387 310 Gujarat. 18pp

Karimi, N and Pak, Z.H. (2012) Effect of NaCl salinity on germination, physiology and biochemical parameters of *Plantago ovata* Forsk. Indian Journal of Science and Technology, 5(6) 2816-

Koelewijn, H. P. and Van Damme, J. M. M. (1995). Genetics of male-sterility in gynodioecious *Plantago coronopus* cytoplasmic variation. Genetics. 139: 1749-1758.

Mahdavi, B. (2013) Seed germination and growth responses of Isabgol (*Plantago ovata* Forsk) to chitosan and salinity, International Journal of Agriculture and Crop Sciences. 5(10): 1084-88.

Manivel, P. and Saravanan, R. (2010) DPO 14 – An early maturing mutant of isabgol (*Plantago ovata* Forsk.) Electronic Journal of Plant Breeding, 1(5): 1371-3.

McNeil, D L. (1985), A preliminary report on work conducted in 1985 to evaluate *Plantago ovata* as a potential crop in the Ord River irrigation area. Department of Agriculture and Food, Western Australia. Report, 60p.

McNeil, D.L.; Blyth, M. and Riley, I (1986) *Plantago ovata* - Evaluation and Development. 1986 Dry season report Ord River irrigation area, Department of Agriculture and Food, Western Australia, pp 117-145.

McNeil, D. L. (1989a). Factors affecting the field establishment of *Plantago ovata* Forsk. in northern Australia. Tropical Agriculture 66(1): 61-64.

McNeil, D. L. (1989b). Weed control in *Plantago ovata* Forsk. Tropical Agriculture 66(2): 98-104.

McNeil, D. L. (1991a). Changes in yield components of *Plantago ovata* Forsk. in northern western Australia in response to sowing date and sowing rate. Tropical Agriculture 68(2): 191-195.

McNeil, D. L. (1991b). Growth of *Plantago ovata* Forsk. in northern Western Australia in response to sowing date, sowing rate and method of sowing. Tropical Agriculture 68(3): 289-295.

McNeil, D. L. and R. S. Duran (1992). Effects of pre-germination treatments on seedling establishment and development of *Plantago ovata* Forsk. Tropical Agriculture 69(3): 229-234.

McNeil, D. L. (1996). The effects of sowing rate and sowing date on yield and yield components of Plantago ovata (forsk.) in northern Australia. Proceedings of the 5th Australian Agronomy Conference, Perth WA, Feb 1996

Mehta, K.G.; Modi, J.M. and Gupta, R. (1976) Effect of seed rate, time and method of sowing on the yield of isabgol in Pilwwai tract of north Gujarat, Indian J. Agron. 21: 509-510.

Modi, V.M.; Deai, N.N. and Patel, D.B (2010) Effect of feed rate and different set of clearance on recovery of husk in isabgul processing plant, International Journal of Agricultural Engineering, 3(2): 292-294.

Mohebbi, M. and Maleki, A. (2010) Effect of Water Stress on Some Seed Characteristics of Isabgol (Plantago Ovata Forsk) in Zanjan (IRAN) Advances in Environmental Biology, 4(1): 10-13

Montalvo, A.M.; Cooke, L.K. and Beyers, J.L. (2010) Plant profile for *Plantago erecta*. Native plant recommendations for southern California ecoregions.

http://www.fs.fed.us/psw/publications/beyers/psw_2010_beyers017(montalvo)plantagoerecta.pdf accessed 8/12/2016

Moosavi, S.G.; Hemayati, S.S.; Seghatoleslami, M.J. and Ansarinia, E. (2012) Effect of planting date and plant density on morphological traits, yield and water use efficiency of *Plantago ovata*. Journal of Medicinal Plants Research 6(10): 1873-1878.

Nekonam, M.S. and Razmjoo, K.H. (2007) Effect of plant density on yield, yield components and effective medicine ingredients of blond psyllium (*Plantago ovata* Forsk.). International Journal of Agriculture and Biology 9(4): 606-9

NMCE (2008) Report on Isabgul seed. Ahmedabad, Gujarat, India. www.nmce.com

Northcote, K.H. (1979) A Factual Key for the Recognition of Australian Soils. Rellim Technical publications, Glenside, South Australia.

Omidbaigi, R. and Mohebby, M. (2002) The Influence of Sowing Dates and Nitrogen Fertilizer on the Productivity of *Plantago ovata*. Pakistan Journal of Biological Sciences 5(5): 656-658,

Parberry, D.B.; Rose, C.W. and Stem, W.R. (1968) Characteristics of the three main agricultural soils in the lower Ord river valley, Western Australia, CSIRO Australian Division of Land Resources, Technical Memorandum, 68/7

Patel JG (1984) Downy mildew of isabgol (*Plantago ovata* Forsk). PhD Thesis, Gujarat Agricultural University, India.

Patel, A. and Saravanan, R. (2010) Screening of Plantago species for physiological parameters in relation to seed yield. Electronic Journal of Plant Breeding, 1(6):1454-1460

Patil, S.J. and Patel, B.R. (2013) Evaluation of different synthetic and botanical insecticides against aphid, *Aphis gossypii* Glover infesting an isabgol crop. The Bioscan 8(2): 705-7 (medicinal plant supplement).

Pendse, G.S.; Kanitkar, U.K. and Surange, S.R. (1976) Experimental Cultivation of Isphagula in Maharashtra, Journal of the University of Poona Science and Technology, 48:293-304.

Ponnuchamy, M.; Reddy, N. and Reddy, R. (2016) ASL 1: Towards developing a genetic linkage map of isabgol (*Plantago ovata* Forsk.), a medicinal plant with potent laxative properties. 6th International Symposium Breeding Research on Medicinal and Aromatic Plants, BREEDMAP 6, Quedlinburg, Germany, June 19-23, 2016, Julius-Kühn-Archiv, 453, 11-14.

Pons. T.L. and van der Toorn, J. (1988) Establishmnet of Plantago lanceolate L. and Plantago major L. among grass. 1) significance of light for germination. Oecologia 75: 394-399.

Pouryousef, M.; Chaichi, M.R.; Mazaheri, D.; Fakhretabatabaii, M. and Jafari, A.A. (2007) Effect of Different Soil Fertilizing Systems on Seed and Mucilage Yield and Seed P Content of Isabgol (Plantago ovata Forsk), Asian Journal of Plant Sciences 6(7): 1088-1092

Rahim, F.A. (2005) Thesis writing a manual for researchers, New age international publishers, New Delhi, ISBN 81-224-0542-8

Randhawa, G.S.; Sahota, T.S.; Bains, D.S. and Mahajan, V.P. (1978). The effect of sowing date, seed rate and nitrogen fertilizer on the growth and yield of Isbagol (Plantago ovata F.). J, Agric. Sci. Camb. 90: 341-343.

Rathore, B.S. and Rathore, R.S. (1996) Downy mildew of isabgol in Rajasthan. P.K.V. Research Journal 20: 107.

Rathore, B.S. (2008) Epidemiology factors for development/progression of downy mildew (*Peronospora alta*) on blond psyllium (*Plantago ovata*). Indian Phytopathology, 61(4): 478-485.

Rathore, B.S. (2009) Mode of perpetuation of *Peronospora alta* causing downy mildew of blond psyllium (*Plantago ovata*). Indian Phytopathology, 62(1): 1-8.

Rengel, Z. (1999) Mineral nutrition of crops: fundamental mechanisms and implications, Hawthorn Press, Binghamton, NY, USA ISBN 1-56022-880-6.

Riasat Ali, R.; Byrne, J. and Slaven, T. (2010) Modelling Irrigation and Salinity Management Strategies in the Ord Irrigation Area, Natural Resources 1:34-56.

Riley, I ; Blyth, M. and Hatter, I. (1987) *Plantago ovata* - Evaluation and Development. 1987 Dry season report Ord River irrigation area, Department of Agriculture and Food, Western Australia, pp85-105.

Riley, I ; Blyth, M.; Annice, A.; and Hatter, I. (1988) *Plantago ovata* - Evaluation and Development. 1988 Dry season report Ord River irrigation area, Department of Agriculture and Food, Western Australia, pp86-115.

Romero-Baranzini, A.L.; Rodriguez, O.G.; Yanez-Farias, G.A., Barron-Hoyos, J.M. and Rayas-Duarte, P. (2006) Chemical, physicochemical, and nutritional evaluation of plantago (Plantago ovata Forsk), Cereal chemistry. 83(4): 358-362

Rubis, D. D.; Massman, L. D. (1967) Plantago - - New Crop for Arizona, Progressive Agriculture 19(4) 10-11, http://arizona.openrepository.com/arizona/handle/10150/299782 accessed 4//12/2016

Sarkar, S. and Lal, R.K. (2015) Genetic variability of agronomical and economical traits in Psyllium germplasm, Industrial Crops and Products 65: 515–520

Shivran, A.C. (2016) Response of blond psyllium (Plantago ovata Forsk.) varieties to time of sowing and nitrogen fertilization under semi-arid conditions, International journal Seed Spices, 6(2): 50-54

Shukla, P.C.; Desai, M. C.; Desai, H.B. and Petal, B.H. (1981) Use of of isabgul lali (ovata Forsk) in the concentrate mixture for lactating cows, Indian Journal of Animal Science 51, 825-828.

Singh, N. and R.K. Lal, R.K. (2009) Genetics of quantitative and qualitative traits of isabgol (P*lantago ovata*) Genetics and Molecular Research 8(3): 939-950

Smolinski, H.; Laycock, J. and Dixon, J. (2011), Soil assessment of the Weaber Plain (Goomig) farmlands. Department of Agriculture and Food, Western Australia. Report 369, 41p

Smolinski, H.; Pathan, S.; Galloway, P.; Kuswardiyanto, K. and Laycock, J. (2015) Cockatoo Sands in the Victoria Highway and Carlton Hill areas, East Kimberley: land capability assessment for developing irrigated agriculture, Resource management technical report 391, Department of Agriculture and Food, Western Australia, Perth. 114pp.

Sousa, M. P.; Braga, L. F.; Filgueiras, B.; Filgueiras, J. and & Delachiave, M.E.A. (2008). Germinação de sementes de Plantago ovata Forsk. (Plantaginaceae): temperatura e fotoblastismo. Revista Árvore, 32(1), 51-57. https://dx.doi.org/10.1590/S0100-67622008000100007 accessed 6/12/2016

Thakur, A.; Upadhyaya,S.D.; Upadhyay, A. and Nayak, P.S. (2012) Responses of moisture stress on growth, yield and quality of Isabgol (*Plantago ovata* Forsk), Journal of Agricultural Technology 8(2): 563-570

USNPGS, (United States National Plant Germplasm System) (2003) GRIN Database, *Plantago ovata*, https://npgsweb.ars-grin.gov/gringlobal/taxonomydetail.aspx?28790 accessed 3/12/2016.

Vahabi, A.A.; Lotfi, A.; Solouki, M. and S. Bahrami, S. (2008) Molecular and Morphological Markers for the Evaluation of Diversity Beftween *Plantago ovata* in Iran. Biotechnology, 7: 702-709

Vala, A.G.; Fougat, R.S.; Roshni. S. and Kumar, V. (2011) Cytological causes of blond psyllium for male sterility, Electronic Journal of Plant Breeding, 2(1): 100-106

Vala, A.G.; Fougat, R.S. and G.C. Jadeja, G.C. (2011) Genetic diversity of *Plantago ovata* Forsk. through RAPD markers, Electronic Journal of Plant Breeding, 2(4):592-596

WADSD (Western Australia Department of State Development) (2016) Ord River Irrigation Expansion Project. http://www.dsd.wa.gov.au/state-development-projects/agrifood/ord-river-irrigation-expansion-project accessed 4/12/2016.

Water Corporation (2016) Ord Irrigation Scheme, http://www.lakeargyle.com/wp-content/uploads/2013/04/Lake-Argyle-Ord-Irrigation-Scheme.pdf accessed 4/12/2016

Yadav, R.D.; Keshwa, G.L. and Yadva, S.S. (2002) Effect of integrated use of FYM, urea and sulphur on growth and yield of isabgol (*Plantago ovata*). J. Med. Aroma. Plant sci., 25: 668-671.

Zadoo, S. N. and Farooqi, M. I. H. (1977). Performance of autotetraploid blond psyllium. Indian Journal of Horticulture. 34: 294-300

8. Appendices

Appendix 1 Production system

Preliminary information on potential guidelines for Plantago production in the Ord River Irrigation Area

Compiled 1988 by Dr Ian Riley, Research Leader, Kununurra Regional Office

Modified 2016 by Professor David McNeil to include newer information

The information provided below does not constitute any recommendations for use in any way by the author nor anyone else involved in its generation or research. The document is provided for information only and any use made of this information is wholly at the risk of the user. The authors stress it is entirely the responsibility of any party using this information to comply with all local rules and regulations irrespective of accepting the risk if they make use of the information as well as provide their duty of care to all people involved.

1. Introduction

Plantago ovata is a medicinal crop grown commercially in India. The seeds are high in mucilage which is used in pharmaceutical preparations. The plant is adapted to the lowland tropics and is grown under irrigation or using stored soil moisture. The world consumption of Plantago husk is considerable, with India producing 97,500 tonne of seed in 2007. Presently prices are high due to reduced availability since 2014.

Indian production is based on LOW input, unmechanized farming though it is expanding beyond present growing areas and developing with all Indian agriculture. Research conducted by the Western Australian Department of Agriculture in the Ord River Irrigation Area (ORIA) since 1984 has been directed towards evaluating the potential for Plantago production under large-scale, mechanised agriculture. Methods have been established to permit preliminary scale evaluation of the crop and these are presented here. The recommendations are mostly based on local research findings and comparison to international research but as the experience with the crop is limited they are to a degree tentative and will be modified in the light of commercial experience. The price for seed has varied but is normally about $US1,000 per tonne depending on seasonal and market conditions. With increasing demand for natural health products it is reasonable to expect continued rising demand and price for Plantago. Yields have been achieved of 1.2 t/ha in large areas and over 2.0 t/ha in experimental plots which indicate prospects for Plantago to become a commercial crop with sound financial returns in the foreseeable future. However, average large area machine harvested yields over approximately 160ha (of mostly sub-optimally grown crops due to lack of information and experience) to date have been around 630kg/ha. Continuing research should improve cultural methods and planting material, and coupled with some commercial experience, should result in a viable alternative for growers in the ORIA.

2. Seed

Currently seed needs to be imported and best variety selected and bulked up. Previous plantings were simply bulked up seed from land race material (probably Gujarat Isapgol 1) of uncertain origin imported from India. Selections need to be made from this material and should lead to higher yielding, more uniform lines being released in the future.

3. Sowing

The optimum time for planting is between early May in cooler years and early June in hotter than normal years. Land should be prepared with fertilizer applied by late April. Plantago sown between early May and late July took from 40 to 70 days after planting to flower, with a flowering period of about 28 days, and 180 to 120 days after planting to maturity. The later the time of sowing the shorter the periods, especially the vegetative phase. A crop planted in mid May will flower in mid July (about 60 days after planting) and be ready for harvest about mid to late September (about 125 days after planting). There is an interaction of temperatures and day length such that in a warmer than normal dry season the maturity of the crop may be delayed. The ideal method for sowing Plantago has not been fully established but best results have been obtained by broadcasting at 8-12 kg/ha on 1.5 m beds (1.1 bed top) on Cununurra clay. A seeder with Nordsten boxes has been used in Departmental work with the tines above the ground and the tubes hanging free. Harrowing the surface of the bed (25 mm) before planting has given improved establishment. Planting beyond 0.5 cm of depth is not recommended.

4. Fertilizer

Fertilizers to be applied prior to planting are phosphate 20 kg p/ha; zinc 7 kg Zn/ha and nitrogen 30 kg N/ha. In some soils Cu at 10kg/ha may also be required. The phosphate should be banded at about 5 cm deep and the nitrogen incorporated in the surface or shallow banded. Departmental experience with the placement of fertilizer has been varied but if the soil is of relatively low nitrogen status placement of nitrogen too deep has resulted in early nitrogen deficiency. Too high a level of preplant nitrogen has also been shown to adversely affect establishment. Fertilizers should be applied before any application of Diuron, if it is to be applied. At flowering the crop should be top dressed with a further 40 kg N/ha.

5. Irrigation

After planting the area should be irrigated until the bed is fully wetted and left for 24 -48h. If needed it can then be irrigated again. This intensive irrigation is only needed to allow the seed on the surface of the bed to be fully wet by capillary action and cooled by evaporation and is essential to ensure good germination in hot periods (mean temp > 26^{o}C). Alternative methods for establishment need investigation to avoid this seemingly excessive irrigation. The crop should be irrigated after a further week and then 2 weeks and thereafter on 6O mm of potential pan evaporation or as required by intensive soil moisture monitoring. The last irrigation should be at least three to four weeks before the estimated time for harvesting (milky dough stage).

6. Weed control

Use of Diuron is severely restricted now in Australia and while effective its use cannot be recommended and special use permission is needed. No herbicides are presently licensed for Plantago production in Australia and minor use permits are required before their use. However, the following systems have been shown to work.

Preplanting preparation should be used for weed control through rotations, block selection and possibly a mechanical kill during land preparation. Three effective strategies for weed control are (l) high seeding rates of 12 kg/ha. (2) Diuron (1.5 kg ai/ha) applied before planting and (3) paraquat (100-200 ml ai/ha with wetting agent) applied post emergent at 27-28 days after planting. However, as indicated use of Diuron is problematic and Paraquat will need a minor use permit. With beds it is also advisable to cultivate the furrows as needed. Too early applications of paraquat will damage the Plantago and applications later than about 35 days after planting will not effectively control the weeds. The rate of paraquat used is important as higher rates will most likely cause damage to the crop. High seeding rate plus one of the herbicide treatments gave acceptable results, use of both herbicides may only be of advantage in situations with high weed populations. Efforts to minimize the weed population are essential in this short crop to reduce both competition and contamination of harvested product.

Wick wiping above the crop with glyphosate later in the season may eliminate tall weeds that would interfere with harvesting if many are present.

One proviso on the use of Diuron just prior to planting is that it has sufficient residual effect to be incompatible with a wet season legume crop such as soybean. One advantage of this residual property is that Diuron could be used for weed control in a wet season fallow preceding a dry season Plantago crop.

Note: As Plantago is an experimental crop the herbicides mentioned here are not registered for use in Plantago and are only to be used at the risk of the grower. As the crop would be grown under contract the use of any pesticides should only be undertaken with the permission and at the risk of the contracting party.

7. Insect Control

No pesticides are presently licensed for Plantago production in Australia and minor use permits are required before their use. However, the following systems have been shown to work.

Plantago is relatively free of insect pests, however, two problems have been encountered that must be controlled, seed harvesting ants and thrips. Seed harvesting ants can be controlled by dusting seed with Lorsban 25W at I kg/ 10 kg of seed prior to planting. About 4 kg/ha of treated seed is broadcast about five days before the main sowing of 8 kg/ha of untreated seed. This allows the ants to collect the treated seed and to be controlled before the bulk of the seed is available, otherwise they may still remove a significant proportion of the seed before the chemical takes effect. Any seed not collected by the ants from the first sowing will contribute to the establishment of the crop. Irrigation immediately after 8 kg/ha sowing is also beneficial as the ants do not move on wet soil. Thrips, in heavily infested crops, have been observed to reduce both seed set and size giving a yield loss of up to 65%. Application of Thiodan (2 L/ha), Lannate (1 L/ha) or Folimat SC (700 ml/ha) a week after first flowering and again after a further two weeks should adequately limit the thrips population. Consultation with an Entomologist should be sought before applying any of the above chemicals as thrips levels may need to be assessed to determine if control is warranted.

Note: As Plantago is an experimental crop the insecticides mentioned here are not registered for use in Plantago and therefore cannot be recommended in for use in a market crop. As the crop is to be grown under contract the use of the insecticides should only be undertaken with the permission and at the risk of the contracting party.

8. Bird Control

Birds have not generally been a problem in Plantago, however in 1987 some problems were experienced with Magpie Geese Landing in the crop. Some effort may be required to limit the numbers of geese landing in the crop as they may easily trample the short plants. It is difficult to predict the extent of this problem in the future once increased areas are sown however they did not cause problems in the 1988 planting of 144 ha.

9. Harvesting

Being a short crop with a tendency to lodge particular care needs to be taken in harvesting Plantago. A header with a floating cutter bar and set with a narrow concave, slow drum speed (about 500 rpm) and low fan speed has been used to harvest Departmental plantings. Any lodging of the crop will be with the direction of the prevailing winds and depending on the orientation of the beds, harvesting may need to be done in one direction only. Timing of harvest can be judged by the seed coat colour, which turns from brown to grey on maturity. The crop should be harvested about 10 days after the majority of seeds begin to turn grey. If weeds have not been successfully controlled an application of a desiccant herbicide about five days before harvest may be needed to stop green material interfering with harvesting.

Note: As Plantago is an experimental crop the herbicides mentioned here are not registered for use in Plantago and are only to be used at the risk of the grower. As the crop would be grown under contract the use of any pesticides should only be undertaken with the permission and at the risk of the contracting party.

10. Processing

The valuable part of the crop is the testa and it would be advisable to at remove this prior to export from the ORIA. Thus a local processing operation would ultimately need to be established. Meanwhile the crop can be exported and processed elsewhere but will need a contracting partner. The residue left after processing is a high quality animal feed that could be used locally. Poor quality seed for husk production could possibly still have feed value as a moderate to high protein, high fibre feed.

Appendix 2 Quarantine requirements

WA regulations

https://www.agric.wa.gov.au/organisms/100895?search_string=plantago%20ovata&per-page=20&sort-by=taxon&order-by=asc

Plantago ovata Forssk.

Common name(s): blond psyllium, desert Indianwheat, ispaghul plantain, loppfr flohkraut.

Legal status: Permitted - s11

Permitted organisms must satisfy any applicable import requirements when imported. They may be subject to an import permit if they are potential carriers of high-risk organisms.

Presence in WA: Unknown

- **Control / Keeping categories**

The *Plantago ovata* Forssk. is Permitted - s11 for the **whole of state** and is not assigned to any control category for a local government area at this time.

Australian Regulations

Plantago ovata is on the permitted seed for sowing list.
https://bicon.agriculture.gov.au/BiconWeb4.0/ViewElement/Element/CaseScientificNames?caseElementPk=551027

The following describes the specific import conditions for seed of *Plantago ovata* for sowing.
https://bicon.agriculture.gov.au/BiconWeb4.0/ImportConditions/Conditions?EvaluatableElementId=171189&Path=UNDEFINED&UserContext=External&EvaluationStateId=c3183a71-c3d4-4840-aeca-acd6d7a3cd5d&CaseElementPk=551027&EvaluationPhase=ImportDefinition&HasAlerts=True

Import Conditions

Case: Permitted seed for sowing Effective: 06 Dec 2016

Permitted species — Not genetically modified — Non-pelleted seed — Not purity tested offshore — If goods arrive as freight (excluding full container load sea freight), mail or passenger baggage

Import Conditions

The following Import Conditions are applicable to this Import scenario. The department will assess the suitability of your import against the import conditions.

a. The following requirements apply to the specified scientific names which have been assessed as permitted entry into Australia without the need for an import permit.

Warnings and Information Notices

If a plant is permitted at the species level then all subordinate taxa (e.g. varieties, subspecies, forms and subforms.) of that species are also permitted. Similarly, if a plant is permitted at a genus level, then all species are permitted etc.

Where the parents of a hybrid are permitted the hybrid plant may be imported without a separate BICON case. Imported hybrids must be clearly labelled with their full parentage for identification by the department.

If the species you wish to import is not listed but you believe it is a synonym of a permitted species please contact the Import Services Team for an assessment.

It is the importer's responsibility to check state and local government requirements to ensure that the seed is permitted entry into that state/territory.

b. A Department of Agriculture and Water Resources import permit is not required.

c. Each shipment must be packed in clean, new packaging, clearly labelled with the full botanical name (i.e. genus and species).
Note: seed (of a single species) are permitted where they are packaged between strips of clear plastic or transparent paper and where the seed can be readily examined by the biosecurity officer.

d. In order to facilitate clearance, airfreight or mail shipments should have all documentation securely attached to the outside of the package, and clearly marked 'Attention Quarantine'.

e. All consignments imported into Australia for all end uses must meet Department standards for seed contaminations and tolerances.

f. These import conditions are applicable to a single species of seed, and seed blends that contain varieties of the same species only.

For packets of seed containing mixed genera or species, please refer to the Mixed seed for sowing (permitted species) case.

g. All consignments must be inspected on arrival by a biosecurity officer for freedom from live insects, soil, disease symptoms, contaminant seed, other plant material (leaf, stem material, fruit pulp, pod material, etc.), animal material (animal faeces, feathers, etc.) and any other extraneous contamination of biosecurity concern.

h. For consignments of seed imported as sea or air cargo, the importer must contact the Department of Agriculture and Water Resources regional office in the first point of entry to confirm all arrangements for inspections and treatments.

i. Consignments may require ISTA testing.

Seed lots less than or equal to 10 kg in weight OR seed lots containing seed greater than 8 mm in diameter:

The seed lot must be thoroughly inspected by a biosecurity officer for the presence of live insects/snails, disease symptoms and contamination (contaminant seed, soil particles, animal and plant material). Seeds should be inspected both visually with a hand lens and sieved to assess contamination.

If contamination is found, a sample must be drawn in accordance with ISTA procedures and submitted to a Department of Agriculture and Water Resources approved seed testing laboratory for analysis. Consignment must be held under quarantine pending results of the analysis. Alternatively, the importer may choose to export or dispose of the consignment at their expense.

Seed lots greater than 10 kg in weight AND containing seed less than 8 mm in diameter:

The seed lot must be sampled by a biosecurity officer in accordance with ISTA procedures and the sample(s) forwarded to a quarantine approved laboratory for analysis. The consignment and sample should be inspected for disease symptoms and the presence of live insects/snails. Consignment must be held under quarantine pending results of the analysis. Alternatively, the importer may choose to export or dispose of the consignment at their expense.

Warnings and Information Notices

If the ISTA testing results confirm that the contamination exceeds department standards for seed contaminations and tolerances, the importer will be given the option to have the seed cleaned at an approved arrangement site (AA site), exported or disposed of.

Any seed that requires cleaning must be re-sampled by a biosecurity officer (and tested if appropriate) to ensure that the contamination has been removed or reduced to an acceptable level.

j. If live insects or other pests are found they will be referred to a Department of Agriculture and Water Resources entomologist for advice on an appropriate remedial action, which may include treatment (if an appropriate treatment is available), export or disposal.

Warnings and Information Notices

Fumigation can reduce the germination rate of sowing seed. Fumigation should only be undertaken following consultation with a Department of Agriculture and Water Resources entomologist and with the consent of the importer.

k. If disease symptoms are detected an assessment of the biosecurity risk will be made by a biosecurity plant pathologist to determine the options that may be available to the importer. Options may include further identification, treatment, export or disposal.

Further identification may not result in the release of the goods and may incur substantial additional costs and time delays for the importer. Further identification will only be offered if it is deemed feasible and the importer agrees in writing to accept all costs and risks involved.

l. Following inspection and provided all of the above conditions have been met the consignment may be released from biosecurity control by a biosecurity officer.

m. Under the Biosecurity Charges Imposition (General) Regulation 2016 and Chapter 9, Part 2 of the Biosecurity Regulation 2016, fees are payable to the Department of Agriculture and Water Resources for all services. Detail on how the department applies fees and levies may be found in the charging guidelines.

n. Non-commodity information requirements for imported cargo also apply, please refer to the BICON case Non-Commodity Cargo Clearance.

Warnings and Information Notices

Timber packaging, pallets or dunnage associated with the consignment may be subject to inspection and treatment on arrival, unless sufficient evidence of a Department of Agriculture and Water Resources approved treatment is provided.

All documentation presented to the department to assist in determining the level of biosecurity risk posed by transportation pathways and packaging must also meet the requirements of the non-commodity case.

What happens next?

When you are importing into Australia a departmental officer will assess the risk posed by your import and determine the appropriate outcome to apply. You may use the link below to view the likely outcomes for this particular import scenario. Please be aware that the assessment conducted may result in an outcome that is not listed.

View Onshore Outcomes

Previous

Exit to find new Case

Appendix 3 Amount of nutrients in the actual 1986 bulk crop (0.5t/ha, 13% HI) and in a theoretical 1.5 t/ha crop at 25% HI

	DW Kg/ha	N Kg/ha	P Kg/ha	K Kg/ha	Ca Kg/ha	Mg Kg/ha	S Kg/ha	Cu Kg/ha	Zn Kg/ha
Seed*	500	13.19	1.86	3.75	1.19	0.60	0.94	0.039	0.18
Tops	3346	32.89	2.91	62.74	49.05	13.12	8.84	0.152	0.90
Roots	501	2.47	0.22	4.71	3.68	0.98	0.66	0.011	0.07
Total	4348	48.54	4.99	71.20	53.92	14.70	10.44	0.202	1.15
HI+	0.11	0.27	0.37	0.05	0.02	0.04	0.09	0.19	0.16
seed#	1500	39.57	5.59	11.25	3.58	1.79	2.81	0.116	0.55
tops	4500	44.224	3.91	84.37	65.97	17.64	11.89	0.204	1.21
roots	675	3.317	0.29	6.33	4.95	1.32	0.89	0.015	0.09
total	6675	87.110	9.79	101.95	74.49	20.76	15.59	0.335	1.85
HI	0.22	0.45	0.57	0.11	0.05	0.09	0.18	0.35	0.30

- Actual data 1986 bulk crop, # Optimal crop 1.5 t/ha yield at 25% HI, + includes roots

Appendix 4 Minor use permit process

http://apvma.gov.au/node/10931

Note *Plantago ovata* is not listed here as a major crop.

Australian Government

Australian Pesticides and Veterinary Medicines Authority

This content is current only at the time of printing. This document was printed on **9 December 2016**. A current copy is located at http://apvma.gov.au/node/10931

Home ▸ Registrations and permits ▸ Permits ▸ Before you apply ▸ Types of permits ▸ Minor use and emergency permits ▸ Guide for Determining Minor Uses

Guide for Determining Minor Uses

The Agricultural and Veterinary Code Regulations 1995 state that a minor use:

> In relation to a chemical product or an active constituent, means a use of the product or constituent that would not produce sufficient economic return to an applicant for registration of the product to meet the cost of registration of the product, or the cost of registration of the product for that use, as the case requires (including, in particular, the cost of providing the data required for that purpose).

It is recognised that a minor use can include:

- use on a minor crop, animal or non-crop situation, or
- limited use on a major crop, animal or non-crop situation.

The APVMA recognises that whilst the current legislative definition is still relevant, it is nonetheless somewhat difficult to operate within because the issue of "sufficient economic return" is a very subjective concept. One of the recommendations from the APVMA Review of the National Permit System was to develop guidelines to assist in determining whether a particular use can be defined as a 'minor use'.

This notice includes APVMA guidelines to assist in determining whether a use is defined as a minor use for the purpose of making an application for a permit or product registration.

Guidance

Please note: The following are only guidelines. The final decision on which uses are determined to be a minor use rests with the APVMA.

1. Based on the list in Schedule 1, is the crop, animal or situation a minor crop, animal or situation?

- **YES** - then use is a **minor use**
- **NO** – go to 2.

Pre-application assistance

Revised pre-application assistance arrangements

The pre-application assistance arrangements have been re-designed to better meet the needs of our clients.

Industry has worked closely with the APVMA to co-design a new process which better manages all types of requests for assistance from applicants as well as simplifying the fee for service arrangements for pre-application assistance.

What is pre-application assistance?

Pre-application assistance is designed to give applicants the opportunity to get technical advice before submitting an application. It can also be used to obtain an appraisal on a trial protocol or for agreement to project plans for a Global Joint Review.

It provides applicants with the opportunity to reduce uncertainty for a specific prospective application. It is provided on a fee-for-service basis which can take the form of a written response, a face-to-face meeting or a teleconference.

The fees charged directly relate to the complexity and effort required and have been divided into three tiers.

Tier 1

This tier is designed to support the early stages of preparing an application such as guidance and clarification on the types of assessments necessary for the proposed application.

For written assistance only there is a one month timeframe for this tier which extends to two months if a meeting is requested—this allows for setting up a mutually agreeable time and date.

Tier one assistance can provide advice on:

- planning an application
- the types of regulatory assessments likely to be needed for an application
- the relevancy of efficacy criteria
- likely assessment modules, fees and timeframes
- clarification of guidance documents on the website.

Tier 2

This is used for technical advice to support a particular application and to give applicants greater confidence that their proposed submission will contain relevant information to address the safety, efficacy and trade criteria.

There is a two month timeframe for tier 2 and it can include a meeting if needed.

Tier 2 assistance can provide advice on:

- types of supporting data or information appropriate to the application

- relevance or suitability of overseas data and/or assessment reports
- the types of trials needed to generate appropriate data
- a scientific matter relevant to an application
- the development of an agreed project plan for a timeshift application
- specific aspects of the design of a study or trial.

Tier 3

This advice level can include an appraisal of a specific study design and finalisation of project plans for Global Joint Reviews.

There is a three month timeframe for tier 3 and it can include a meeting if needed.

Advice provided can include:

- appraisal of trial protocols before commencement of studies
- assistance on a proposed new methodology or variations to existing data guidelines for generating data
- finalisation of project plans for Global Joint Reviews.

Note: advice provided about the adequacy of trial protocols does not guarantee that the data generated from the study will satisfy the statutory criteria.

Applying for pre-application assistance

The process for pre-application assistance.

Getting the most out of pre-application assistance

The more specific the information you provide, the more tailored the advice the APVMA can give you

Pre-application assistance— timeframes and fees

What will it cost to access pre-application assistance?

How to withdraw a request for pre-application assistance

Details on how to withdraw a request for pre-application assistance.

Content last updated: 4 November 2015
Content last reviewed: 4 November 2015
URL: http://apvma.gov.au/node/106

Appendix 5 Minor use RIRDC consultant project.

Australian Government
Rural Industries Research and Development Corporation

RURAL INDUSTRIES
Research & Development Corporation

News & Updates | Subscribe | Home

About RIRDC   Research Programs   For Researchers   Publications   Rural Women's Award

Research Project Details

Home Research Project Details

Project Details

BACK TO RESEARCH PROGRAM

	Minor Chemical Consultant for small and non-levied industries
Summary	The selective use of pesticides to control diseases, insects and weeds plays an important role in increasing production, enabling growers to manage a complex biological system, improving the quality of agricultural produce and enabling growers to earn improved returns on their investments. The challenge currently faced by many small industries is: • Limited knowledge of how to access permits, • Limited funds, • No forum to voice their needs, • Poor access to agchem manufacturers for support, and • Sometimes a lack of cohesion within their own industries. The aim of the project is to provide appropriate pesticide information and advice to RIRDC industries to address existing and future disease, insect or weed problems. All pesticide selections should reflect Good Agricultural Practice.
Program	New and Emerging Plant Industries
Research organisation	Agaware Consulting Pty Ltd
Objective summary	This project will educate, advise and assist RIRDC identified new, emerging and small industries (RIRDC industries) to source appropriate pesticides to manage a range of plant diseases, insects and weeds. This project will collaborate and coordinate a focused and streamlined process to address pest management issues to achieve excellent environmental and financial outcomes for growers. This project will: • Engage with RIRDC industries and respond to queries regarding the APVMA and the minor use permit system. • Assist RIRDC industries to understand pesticide regulatory guidelines, regulations, product information, use patterns, registration and permit processes and the collection of data. • Assist RIRDC industries to maximise production with effective use of appropriate pesticides and other pest control options. • Assist RIRDC industries to develop a pesticide prioritisation list. • Assist RIRDC industries to engage and collaborate with Horticultural Innovations Australia and the Grains Research and Development Corporation on pesticide projects. • Assist RIRDC industries to prioritise their pesticide requirements to submit to the Ag Vet Forum grant scheme to ensure a collaborative approach to pesticide access . • Assist RIRDC industries to effectively respond to an emergency pest situation. • Assist RIRDC agvet projects to disseminate current project information as required.
Project Stage	Current
Project start date	Friday, October 30, 2015
Project completion date	Sunday, July 30, 2017
Journal articles from project	Not Available
National priority	An environmentally sustainable Australia
Rural priority	Adoption of R&D
RIRDC goal	NEPI-RD&E to generate benefit across several plant industries

Appendix 6 Farming the Ord fact sheet.

Government of Western Australia
Department of Regional Development and Lands

ROYALTIES FOR REGIONS

Ord-East Kimberley Expansion Project

FACT SHEET

15 December 2009

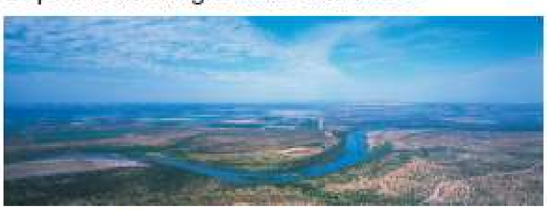
Farming in the Ord

The Ord River Irrigation Area (ORIA) is a well-established and productive agricultural precinct comprising approximately 14,000 hectares of prime irrigated agricultural land in Western Australia's far north.

More than 30,000 hectares of land is currently undeveloped and suitable for irrigated agriculture in the area. With its close proximity to international markets, abundant water resources and excellent growing conditions the area has underutilised development potential.

The Western Australian Government recognises this potential and has started a program of works, through the Royalties for Regions program, to provide the necessary infrastructure to support an irrigation development of about 8,000 hectares on the Weaber Plains. This will be released in 2011.

This fact sheet outlines some of the key agricultural elements of the area. More detailed information on soil, crop research and emerging trends is available from the Department of Agriculture and Food.



Competitive advantages

Agriculture in the area has some distinct seasonal advantages. The region has a sub-tropical climate with an average annual maximum temperature of 35 degrees Celsius and an annual average rainfall of 830 millimetres. Most of this rainfall is between October and April. May to September has an average rainfall of only 4 millimeters.

This presents a distinct market advantage:

- The region is counter-seasonal for many of the tropical crops (citrus and fruits) grown in the northern hemisphere and the temperate summer crops of southern Australia.
- Growing months that are mostly rain-free reduce the risk of rain damage and lower disease pressures.
- The region is relatively free of major pests and diseases encountered in other parts of Australia and the world, in particular Mediterranean and Queensland fruit fly. A regional biosecurity plan is in place to reduce the risk of incursions.

Soil types

The soils of the Weaber Plains area are 30 per cent Cununurra clays and 70 per cent Aquitaine clays. Both soil types are also common in the existing irrigation area (commonly known as the M1 area).

The Cununurra clay soils are mostly neutral to mildly alkaline.

The Aquitaine clays have higher clay content and while they can be very productive, require careful management and irrigation practices. Aquitaines in the northern part of the Weaber Plains are known to have high salt content at depth and irrigation must be carefully planned to prevent water seepage and subsequent water table elevation.

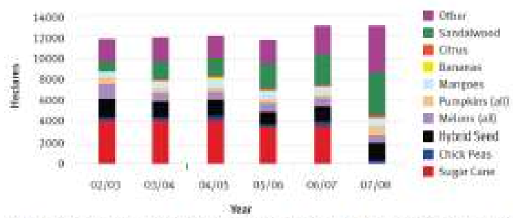
A detailed soil map of the Weaber Plains can be found on the project website www.royaltiesforregions.wa.gov.au/ord

Agricultural practices

The M1 area is about 14,000 hectares of mostly black Cununurra clays under furrow irrigation. There are small areas of lighter soils and also some drip and sprinkler irrigation.

In the past a number of agricultural crops have been grown, including rice, cotton and sugar cane. For a number of reasons, including low prices and insecticide resistance, these crops do not dominate the landscape now.

The graph below shows changes in crops grown between 2002/03 and 2007/08.



**Other crops include: culinary beans, hay, maize, small seeds, sunflower, sweet corn, millet, vegetables, papaya, bananas, tropical fruit and nursery plants.*

Emerging trends

There has been a recent increase in land demand that has been driven mainly by the introduction of forestry, particularly sandalwood. The first commercial harvest of sandalwood is expected to be in 2013 from initial plantings in 2000. The graph below shows the historical and predicted level of land use change from agriculture to forestry since 2002/03.

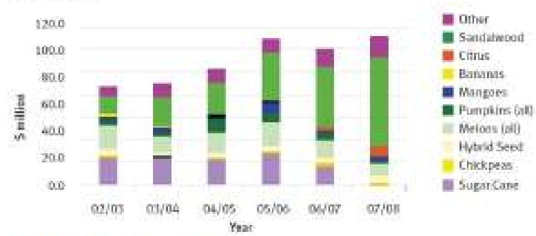
Another new emerging crop is chia (*Salvia hispanica*). About 1,500 hectares of chia was planted in 2009, 50 per cent more than in 2008.

Horticultural opportunities have also bolstered the demand for land over the past five years including a growing national demand for fresh fruit and vegetables. The ORIA is also well placed to supply some of the more densely populated Asian countries, as well as other world markets, with quality produce.

In free-trading global markets, economy of scale is required for agricultural production to remain competitive. The release of the Weaber Plains agricultural lots will provide additional land to meet current demand. The types of crops grown will depend on the market signals at the time.

Value of irrigated farm activity

The value of irrigated farm activity has increased over the past decade. The graph below shows the relative value of different crops in the ORIA between 2002/03 and 2007/08.



More information

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