Potential of new Australian oldman saltbush varieties to fill ruminant feed-gaps in arid and saline areas of Pakistan

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1 Project background and scope:

Small ruminant production is a major source of income to smallholders in the irrigated, rain fed and semi-arid areas of Pakistan. Like much of southern Australia, one of the major constraints to ruminant production is the pattern and scarcity of rainfall, leading to seasonal nutrient gaps. Salinity and shallow water-tables are additional threats to agriculture in southern Australia and Pakistan (where it is estimated that 25% of irrigated land is impacted by salinity). Drought- and salt-tolerant perennial shrubs from the Chenopodiaceae family, such as saltbushes (*Atriplex* spp.), offer an opportunity to use land and water resources that are too saline or arid for traditional crops and forages. Saltbushes can play a critical role within livestock systems as a dietary complement to poor-quality crop residues. Previous Australian Centre for International Agricultural Research (ACIAR) funded research has demonstrated that several saltbush species can persist in saline soils in Pakistan.

In the past decade there has been a significant research effort in Australia to improve the feeding value, palatability and growth of old man saltbush (*Atriplex nummularia*), an Australian native. This species is tolerant of both salinity and aridity. The first cultivar from a cohort of elite material was released by CSIRO under the name Anameka™ in 2014. To date it has been successful and adopted by over 170 producers across southern Australia. The selected genotypes have significantly higher energy values, growth rates and relative palatability (to sheep) than the average saltbush in the collection from across Australia. Pre-experimental systems-modelling was used to identify improved energy (digestibility of organic matter) as a critical trait, as the shrubs are used to complement poor quality crop and pasture residues in summer and autumn.

The aim of this scoping study was to explore the opportunity to improve the livelihoods of smallholders in arid and saline areas of Pakistan through the introduction of the Anameka™ old man saltbush varieties (The original clones and selected seed lines) from Australia. We have assessed the outcomes of previous saltbush introductions, investigated the various roles of saltbush within farming systems and identified researchers and NGO's within Pakistan who could partner in future saltbush evaluation and extension activities. The opportunity for women to lead saltbush propagation businesses was considered. Our final aim was to seek to link saltbush seed, propagation and machinery businesses in Australia with counterparts in Pakistan.

2 Summary of outcomes of this project:

The primary goal of the project, to get the Australian Anameka™ saltbush cultivar to Pakistan for future research and adoption opportunities, was achieved. The process was not straightforward, and the plants and seed did not get to the University of Agriculture in Faisalabad (UAF) until September 2018. Seventeen Anameka™ plants survived the phytosanitary measures and transport delays.

These plants are being grown at the UAF as a future source of germplasm for in-country experiments. Dr Ed Barrett-Lennard has undertaken three trips to Pakistan to talk about the shrubs with scientists from the National Agricultural Research Centre (NARC), Pakistan Agricultural Research Council (PARC) and other key institutions. From these discussions, it is clear there is a role for high nutritional value saltbush for saline and arid land in Pakistan. Dr Barrett-Lennard has been working with the ACIAR salinity team to better understand the opportunities for these plants in salt-affected farming systems. Work conducted by Dr Rebecca Doyle and Dr Angus Campbell's ACIAR Small Ruminant research teams demonstrates that there is a need for an energy and protein supplement for small ruminants in the Punjab region. There is no doubt this need is more acute in the arid areas of Balochistan. Based on emerging research in Australia, we suggest that the saltbushes may also play a significant role in improving health and productivity of small ruminants, especially those that are young or reproducing. Saltbushes are a rich source of antioxidants and minerals that are critical for the metabolic pathways in mammals that reduce oxidative stress during hot conditions. The opportunity for Anameka™ saltbush is for saline (but not waterlogged) fields, arid areas where sheep and goats persist on poor-quality crop residues and in marginal land adjacent to villages. Other saltbush species (for example *Atriplex amnicola*) are better suited to areas that are regularly waterlogged and inundated.

Due to the restrictions and time taken to import and establish the shrubs, we were not been able to generate plants to set up field experiments. However, the plants should be available for new projects such as Dr Doyle's new ACIAR project 'Enhancing small ruminant production to benefit farming families in Sindh and Punjab, Pakistan' and the salinity project, if funded. We developed the outline for a training program for key Pakistani researchers to Western Australia. The aim would be to expose trainees to the activities and wealth of knowledge held by the Australian research, farming and commercial nursery communities.

3 Project Activities:

3.1 Activity 1. Desktop review of local and Australian literature and the previous ACIAR saltbush projects in Pakistan. Describe what has been done, conduct a meta-analysis of previous research outcomes

The review is presented in Appendix 1. In summary;

Interventions to improve agricultural production in Pakistan will assist to alleviate poverty and interventions that address small ruminant production will directly benefit women. In 2013, it was estimated that more than 20% of the population of Pakistan live on less than US$1.25 a day and have limited access to basic services. Agriculture employs over 44% of the population and accounts for 60% of export earnings. Growth in agriculture in Pakistan has the potential to be four times more effective in alleviating poverty than growth in non-agriculture sectors. In addition, up to 70% of all women in Pakistan are employed in agriculture, many working with small ruminants at a subsistence level. Improvements in agriculture, particularly improvements associated with small ruminant production, will benefit rural women.

Salinity and aridity are major problems in Pakistan. Lack of rainfall is the biggest constraint to agriculture in Pakistan. Almost 87% of Pakistan has a climate that is extremely arid to semi-arid (<200mm annual rainfall). Climate change and associated sea level rise are threats. Salinity and shallow water-tables constrain production in irrigated areas. Depending on the source, it is estimated that 25 to 33% of irrigated land is impacted by salinity and approximately 1.4 million hectares have now been abandoned. Recent work in Australia has focussed on how to characterise the capability of saline land. It is now recognised that salinity and waterlogging both constrain the growth and survival of plants in different ways. The combined effects are devastating to the majority of plants. Land capability and the management of surface water must be considered as part of the package in plant-based interventions for saline land.

Livestock are a major source of income in irrigated, rain-fed, arid and semi-arid areas of Pakistan and feed gaps limit small ruminant production systems. In the irrigated areas, salinity is impacting on farmers' ability to grow forage (and crop residues). Out of the total area of semi-arid Balochistan, 21 million ha (~60%) of land is used for grazing small ruminants. Pakistan has two periods of acute fodder deficiency one in summer and the other in winter, and ruminants typically lose condition and sometimes perish during these periods. Overgrazing of rangelands and semi-arid areas has led to a decline in species diversity and forage quality. In addition, expansion of dryland farming into marginal areas and the use of trees and shrubs for household fuel has led to a decline in the natural resource base. Typically, women are responsible for feeding small ruminants and have a vested interest in feed-base interventions.

Previous and current saltbush research in Pakistan yields critical information to inform future activities. There have been a series of projects that have explored the use of drought and salt tolerant forages, particularly saltbush (*Atriplex*) species. From the two ACIAR projects in the 1990's we learnt that saltbush species persisted in saline land to varying degrees and waterlogging was a major constraint for some species. River saltbush (*A. amnicola*) was the most persistent species. A better understanding of salinity and waterlogging interactions will assist scientists and land managers to plant the correct plants into different environments. A second outcome of the ACIAR research was that small ruminants cannot maintain weight on saltbush alone. We now know from more recent work in Australia, that this inability to maintain weight is partly due to the high salt accumulation in saltbush (up to 25% salt in leaves), which restricts voluntary feed intake. Sheep do not tend to consume more than 150 g per day of salt and work in Australia suggests that saltbush leaves should be no more than 30% of a ruminant diet. Reproducing, growing and lactating animals may need an additional energy supplement. Saltbush should therefore be treated as a supplement that has nutritional traits that complement poor quality cereal diets: it is not a diet in its own right. The soluble salt content of saltbush and other halophytes tends to result in the overestimation of the energy value of the forage in normal laboratory analyses. Unfortunately, this problem persists in some research programs. Emerging research in Australia suggests that the antioxidants and some minerals in saltbush (those associated with antioxidant pathways) could lead to higher reproduction rates and improved survival of young animals. Ruminant nutritionists must work with the shrub agronomists to ensure the material is being used correctly. Key feeding messages will need to be translated into local languages.

What is the scope for Anameka™ saltbush? The literature and our experience leads us to anticipate a significant scope for oldman saltbush in arid areas such as Balochistan. There is ongoing research in this region with several saltbush species (*A. nummularia*, *A. canescens* and *A. halimus*). It would be clearly worth comparing the performance of Anameka™ with locally adapted shrubs in this region. There could also be a role for less waterlogging tolerant saltbushes like Anameka™ in unirrigated, marginal areas that are near villages. A small number of plants may be sufficient to provide a protein and antioxidant supplement to household flocks (typically > 10 individuals). For irrigated land that has become saline, Anameka™ provides an option where the land is not waterlogged for extended periods. Work needs to be undertaken to clarify the ecological boundaries of the species, compare it to river saltbush and explore the use of soil surface water management and/or mounding. Environmental benefits in the form of increased water use (assisting with salinity issue) and improved ecosystem functionality would be expected.

Shrubs must be considered as part of a farming system and where feasible, complementary understorey species should be established. The value of halophytic shrubs must be considered within the context of a farming system. In Australia, many of the benefits of the shrubs are generated in non-saline areas. For example, grazing shrubs on saltland in late autumn allows Australian farmers to defer the grazing of establishing annual pastures on other parts of the farm, thus boosting pasture productivity. The shrubs also allow farmers to reduce supplementary feed inputs and reduces risk associated with droughts. Improving the shrub understorey leads to a further boost in productivity and allows grazing animals to select a diet that meets their needs. There are a number of dryland and irrigated understorey species that have been developed for saline and arid systems in Australia and elsewhere that could be trialled with shrubs in Pakistan. Legumes are useful companion plants to saltbushes, as root nodule rhizobia fix nitrogen. Recent work in Australia shows that saltbush growth rates are very responsive to nitrogen inputs. Tree planting machines and improved nursery propagation and management techniques offer opportunities to improve shrub establishment rates and reduce costs.

Shrubs could offer an opportunity for women to fill the feed gap and generate income. As women are the primary carers for small ruminants, they tend to have an interest in feeding systems and often identify poor nutrition as the primary constraint to production. Saltbushes are very easy to propagate by cuttings and do not require expensive equipment or materials. There are examples in Jordan of women running small nurseries to produce shrubs for sale. In another ACIAR project, we have been working with Afghan women to start small household/village nurseries. We believe that this opportunity also exists in Pakistan.

3.2 Activity 2. Establish contact with the Federal Plant Protection Department to alert them to this work and explore seed (and possibly live seedling) import protocols.

This was a much more time-consuming process than initially anticipated due to in-country communication and changes in AQIS protocols. Dr Norman initiated contact through the Pakistan web-based application early in the project. While an acknowledgement of the application was returned, there was no response. Dr Kazmi then initiated contact from Islamabad and attempted to expedite the process. It was not until May 2018 that the paperwork that stipulated an import procedure and approval was received. This paperwork was required to import the shrubs to Pakistan and allow export of the shrubs from Australia. At this point the first batch of Anameka™ plants that had been prepared for export were too old to survive the root washing procedure. A second batch was initiated and fast-tracked through specialty glasshouses with a plan to send them with Dr Barrett-Lennard in late May 2018. This trip was subsequently cancelled and re-scheduled for September 2018 when Dr Norman and Dr Barrett-Lennard planned to take the shrubs to UAF and participate in other meetings. Dr Norman did not receive invitations in time for a visa to be offered, so Dr Barrett-Lennard travelled alone. Seventy-two Anameka™ saltbush seedlings had their roots washed of soil and were sterilised according to Government of Pakistan and Australian Quarantine regulations. They were successfully imported in September 2018 and handed to Dr Javaid Akhtar's team at the University of Agriculture at Faisalabad (UAF). Seed, representing several populations of CSIRO's elite old man saltbush F1 seed lines was also sent with the seedlings. Saltbush is octopoid and dioecious so plants established from the F1 seed lines represent a population where some plants have high feeding value and some may be less useful. Seed lines however provide diversity that could be useful if Anamaka™ is not suited to all of the target environments in Pakistan. In another ACIAR research project, some of these seed lines have been successfully established and appear very productive in dry areas in Afghanistan.

On 8 November 2018, Dr Zulfiqar Ahmad Dasti from UAF provided an update. Due to the phytosantiary processes, delays in transit and very hot weather on arrival, 17 of the 72 plants survived. This is not a problem as only 1 healthy plant was needed to provide cuttings for future field experiments. The UAF team planned to shift the plants to the field in late November, Dr Barrett-Lennard suggested that not all plants should be transplanted at the same time to reduce risk.

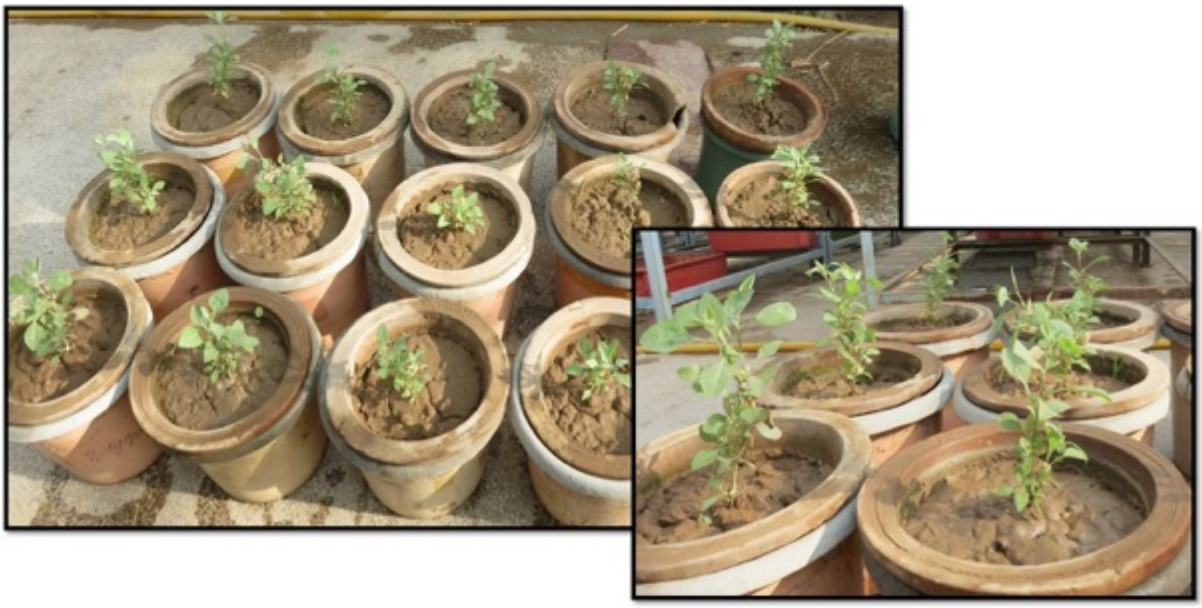

Fig 1. Anameka™ saltbush cuttings imported from CSIRO in Australia and growing at the University of Agriculture in Faisalabad. Photos supplied by Dr Zulfiqar Ahmad Dasti.

3.3 Activity 3. Scoping visit by Australian saltbush/salinity specialists

The trip was originally planned for March 2017 and was to include a visit to key University and research institutes, including; Pakistan Agricultural Research Council (PARC), Balochistan Agricultural Research Institute, UAF, the Islamia University of Bahawalpur, a Provincial Salinity Research Institute, the Desert Research Institute, International Centre for Agricultural Research in the Dry Areas (ICARDA) and provincial governments. The aim was to identify future research partners and present seminars about the Australian saltbush work. Unfortunately due to a combination of visa application issues, cancelled trips (for in-country reasons) and an injury arising from a car accident, Dr Norman was unable to travel to Pakistan during the course of the project. Dr Barrett-Lennard was able to visit on 3 occasions. The scoping study, with a revised travel itinerary, was conducted by Dr Barrett-Lennard and Dr Kazmi (ACIAR) from 11-18 November 2017.

Itinerary and notes from the scoping study in November 2017:

- **11 - 12 Nov 2017.** Dr Barrett-Lennard travelled from Perth to Lahore. He was met by the Australian High Commission driver and stayed at the Avari Hotel.
- **13 Nov 2017.** Travelled from Lahore to Faisalabad and stayed at Serena Hotel.
- **14 Nov 2017.** Participated in an inter-agency workshop at the Serena Hotel. Dr Barrett-Lennard delivered a presentation to workshop "Brief overview of state of salinity research internationally and in Pakistan, and rationale for currently proposed salinity project."

The inter-agency workshop, facilitated by Michael Mitchell and Catherine Allen, culminated in a multi-agency group of researchers identifying and prioritising aims for a future salinity project that would incorporate saltbush research. Other speakers included; Dr Robyn Johnston (ACIAR's Program Leader for Land and Water), Dr Munawar Kazmi (ACIAR's in country manager for Pakistan), Dr Ashfaq Ahmed Sheikh (Pakistan Council of Research in Water Resources (PCRWR) -'Salinity Issues and Management Options in Pakistan'), and Dr Altaf Ali Siyal (Mehran University) - 'Holistic approaches to salinity research and management in Sindh'). After presentations and an open panel session there was consensus that there needed to be a more integrated method to deliver research outcomes and extension advice to farmers to achieve landscape change and poverty alleviation on the scale required. Prof. Riaz Qureshi (former head of the Saline Agriculture Research Centre, former Vice Chancellor of UAF, and former advisor to the Higher Education Commission) provided valuable interventions and insights.

- **15 Nov 2017.** Participated in field site visits in the Faisalabad area. Meeting of project team members. Dinner with Dr Z. Saqib.

The field trip was kindly coordinated by Prof. Javaid Akhtar and Dr Zulfiqar Saqib of UAF. The field trip focused on two locations, in each case supported by local farmers. Surface salt was visible at both sites, despite the fact that there had been recent rain. At the first site, there was an interesting example of barren waste saltland immediately adjacent to a recently harvested rice crop. The rice field had been reclaimed by the use of tile drainage, and the application of gypsum and organic matter. It had been irrigated with local tube-well water. It provided a dramatic example of the difference that technology, management and farmer confidence could make. The second site was a field for wheat cultivation that had been recently reclaimed from saline wasteland. While the tour did not include forage production paddocks, the group did encounter herds of goats.

- **16 Nov 2017.** Travelled from Faisalabad to Islamabad with Dr Kazmi and Dr Robyn Johnston ACIAR). Discussed opportunities for the saltbush to be incorporated into an ACIAR salinity project in Pakistan. Stayed at Australian High Commission Transit House.
- **17 Nov 2017.** Dr Barrett-Lennard met with Her Excellency, Margaret Adamson and received a security briefing from her team.

Dr Barrett-Lennard observed that Ms Adamson was strongly supportive of the need to develop a new project integrating technology and delivery in the salinity area, and pledged ongoing project support. The discussion covered underestimation of the extent or severity of the problem, the need to support development efforts in Balochistan and opportunities to utilise knowledge exchanging mechanisms like the Australian Alumni website.

- **17 Nov 2017.** Dr Barrett-Lennard delivered a seminar that had been prepared in conjunction with Dr Norman on "Australian saltbush species *Atriplex nummularia* for fodder production on saline land" at NARC.

The talk focused on Dr Barrett-Lennard and Dr Norman's previous work on saltbush (in both Pakistan and Australia) and the potential for new old man saltbush lines developed by CSIRO to play a role in saline agriculture. The presentation was chaired by the NARC DG (Dr Azim) and others who participated were the PARC Director for Land and Water (Dr Asad), the Director of Rangeland Management (Dr Imtiaz Qamar) and the Director of Natural Resource Management (Dr Safraz). The seminar was attended by approximately 100 people. Dr Barrett-Lennard met with group of interested people after the seminar, including;

- Dr M. Iqbal Aujum – SSO/PL (AMO) – ASI, NARC
- Dr M. Shazir Zahid – PL (MSM&F) – CSI
- Dr M. Munir Ahmed – Director, CAEWRI, CAEWRI
- Dr Imtiar Ahmad Qamar – Director – RRI, NARC
- Dr Sanfariz Ahmad, Director RM & L – NARC
- Dr Arshad Ali – Director LRRI – NARC
- Abdul Wahid Jasra – CR, ICIMOD - ICMOD/NARC.

Dr Safraz suggested that we include the PARC in the saltbush activity, look at the use of brackish water for saltbush irrigation and develop mechanised planting techniques. He also wanted more information on the pelleting of seeds from complementary understorey species in a bid to improve establishment. There was strong support for the incorporation of saltbushes into rangeland activities in Balochistan. (There has been considerable work in this area already with two alternative saltbush species, *A. halimus* and *A. canescens*). When Dr Kazmi pointed out that our High Commission activity did not have funds to undertake substantial field testing, it was suggested that Safraiz look at options to fund this kind of testing out of Pakistan funds. The development of a large project might take a couple of years to fund.

- **18 Nov 2017**. Dr Barrett-Lennard met with the Chairman of PCRWR (Dr M. Ashraf), Dr Mazoor, Dr Kazmi and Dr Johnston.

The Chairman was most supportive about the need for a new national approach and could be a key player in the development of inter-agency consensus for a national salinity delivery strategy. It was noted that at the national level, it would be important to include the Ministries of Science and Technology (bringing PCRWR), Agriculture and Food (bringing in PARC and the NARC), Education (bringing in the Universities), Power and Water, and a similar group of departments operating at the provincial level. Dr Ashraf suggested that ex-Minister Nisar Memon could be a person of influence in bringing about a new inter-agency collaborative approach. Other issues concerning groundwater management and groundwater use were also discussed.

- **18-19 Nov 2017.** Dr Barrett-Lennard returned to Perth and had a debriefing meeting with Dr Norman.

Outcomes and reflections from the scoping tour. As Dr Barrett-Lennard has a long history of working with saltbush in Pakistan and has an interest in the ACIAR salinity project ('Improving salinity and agricultural water management in the Indus Basin of Pakistan'), his observations are extremely valuable in terms of future directions for the saltbush activities. He felt that the program of meetings and the participants provided opportunities to discuss the formation of a national movement for change in the delivery and implementation of better outcomes for farmers affected by salinity. It was his impression that significant stakeholders in the meetings in Faisalabad and Islamabad agreed with the proposition. Currently the mandate for the development and delivery of saline agriculture technologies was divided amongst a range of national and provincial authorities, so action on the ground was piecemeal and inadequate, and consequently affected farmers continued to be impoverished. To some degree this lack of cohesion in strategy was the case in Australia in the late 1990's when agronomists, hydrologists, animal nutritionists and economists did not collaborate effectively in systems research projects. Significant impacts for farmers were achieved in Australia through a program of multidisciplinary and multi-agency research from 2000-2010. It was Dr Barrett-Lennard's impression that Australians could play key roles in;

- catalysing the formation of a network of researchers and policy development stakeholders,
- assembling and synthesizing currently available information across disciplines,
- developing a range of 'venues' or 'platforms' for interagency cooperation and collaborations
- demonstrating the value of such cooperation in pilot on-ground interactions with farmers, and
- using the examples of these to catalyse permanent interagency cooperation driven at the Ministerial level.

From the perspective of utilising saline land for forage production, the successful importation of Anameka™ to Pakistan was a critical step. However, the value of this shrub and other saltbush species would only be realised when agronomists (saline and arid), animal scientists and farming systems specialists worked together with farmers and other stakeholders. The ACIAR Small Ruminants and Salinity projects, working together, have significant potential to facilitate this process. Bringing a delegation of key, active Pakistani researchers and stakeholders to Western Australia to see multidisciplinary research, commercial business associated with saline and arid agriculture and producer engagement with researchers could be very useful.

3.4 Activity 4. Conduct site visits to meet with communities and NGO's in arid and salt affected areas. Develop linkages with the Balochistan Sheep Program staff (as a visit is unlikely). Seek to understand the use of shrubs and saltbush within feeding systems, plant propagation and establishment and the potential role of women in shrub propagation.

Opportunities to conduct site visits with NGO's were limited by travel restrictions. Given her inability to travel, Dr Norman sought information from Dr Rebecca Doyle in understanding the feeding systems. These learnings are summarised in the review document. Linkages with the Balochistan Sheep Program were harder to obtain.

There is no doubt that there is a role for saltbush in dry and saline areas of Pakistan. As for similar ecogeographical areas of Australia, Afghanistan and Iraq – saltbush can play a role by providing a supplement to the diets of ruminants grazing poor quality crop residues. In an ACIAR/DFAT forages and water projects in Afghanistan, Dr Norman and colleagues from ICARDA found that women in villages were the most likely to propagate, plant and manage saltbush. This was in part due to the fact that women are largely responsible for feeding small ruminants. Dr Norman has worked with six Afghan women to help them develop skills in saltbush propagation (from seeds and cuttings), seed testing, establishment and feeding systems for small ruminants. This training would be ideal for women in Pakistan as the old man saltbush becomes available. It was unclear if this training is available in Pakistan already. Dr Norman will seek opportunities to provide the training through the ACIAR Salinity and Small Ruminants activities and/or through Crawford Fund support. This would be run in conjunction with a leading Australian commercial tree farm and engineering business (Chatfield's Tree Farm in Tammin, WA) and several Australian farmers who are early adopters of Anameka™ saltbush. It is our hope that women will be part of future delegations.

Fig 2. Examples of training and commercial linkage opportunities in Australia. Clockwise from the top. Anameka™ saltbush growing on saline land in WA, Afghan scientists talking to an Australian farmer who uses saltbush as a component of his farming system and to Dr Brad Nutt (legume expert from Murdoch University and Dr Kelly Pearce (meat quality expert), Iraqi scientists visiting Chatfield's Tree Farm to learn more about commercial scale shrub production and a commercial Chatfield's Tree Planter in action.

3.5 Activity 5. Identify potential saltbush research collaborators, including farming systems scientists, ruminant nutritionists and plant physiologists. A second visit in September 2017 (4 Australian researchers) will develop research ideas and (with the assistance of partners identified during the first visit) establish some saltbush germplasm for further in-country testing.

As explained previously, delays in importing the saltbush led to delays in the design of ongoing experimental/demonstration activities. Key likely players in future saltbush development include;

- Prof. Javaid Akhtar and Dr Zulfiqar Saqibb (UAF)
- Researchers involved in the saltbush work in Balochistan (NARC)
- Researchers at the Muhammad Nawaz Sharif University of Agriculture, Multan.
- Researchers working with Dr Doyle's small ruminant project. This includes researchers from the University of Veterinary and Animal Sciences, Lahore and the Sindh Livestock Department.

3.6 Activity 6. Write a report outlining the potential of the new Australian saltbush cultivars within agricultural systems in Pakistan. Describe opportunities for further research and development that align with the Australian Pakistan Aid Investment Plan. Identify research teams who could partner in future research and highlight opportunities for linkages between Australian and Pakistan businesses.

This report has been written to address Activity 6.

3.7 Activity 7. Visit the Australian High Commissioner in Islamabad and present a seminar about saltbush development in Australia (start of the project) and project outcomes/future opportunities and pathway to commercialisation (end of the project).

Dr Barrett-Lennard presented some information to Her Excellency, Ms Adamson the Australian High Commissioner in 2017. As plans to utilise saltbush are developed within the Small Ruminants and Salinity projects, Dr Norman and Dr Barrett-Lennard will seek an opportunity to visit the Australian High Commissioner in Islamabad to present an update. If any of the High Commission staff are travelling through Perth, Dr Norman and Dr Barrett-Lennard would welcome the opportunity to present the research and show them some of the commercial-scale outcomes in saline and arid areas of Western Australia. Equally we would be happy to meet staff in another Australian city.

4 Future Directions

Where possible, we will continue to collaborate with UAF and the ACIAR Small Ruminants and Salinity teams to identify opportunities to trial Anameka™ saltbush and the improved seed lines. If additional funds were available, we would suggest that they be used to maintain the Anameka™ plants at UAF and provide a training opportunity for Pakistani researchers in Australia.

There is a significant opportunity to test Anameka™ and other saltbush cultivars in Pakistan and to incorporate biomass into feeding systems.

One opportunity to increase the uptake of Anameka™ saltbush in Pakistan may be through the development of a future ACIAR Project focusing on salinity. This project is being managed by Dr Michael Mitchell from Charles Sturt University. The aims of this project are still being developed, but the work could be used to further the adaption of saltbush into saline affected communities.

5 Acknowledgements

We are grateful for the financial and administration support from DFAT and ACIAR. Thanks to staff from the Australian High Commission, Dr Munawar Kazmi, Dr Peter Horne, Dr Werner Stur and the excellent drivers (especially Akram and Farook). We would like to thank Dr Rebecca Doyle and Dr Angus Campbell for sharing information and insights concerning ruminant production systems. This was very much appreciated given Hayley's inability to visit villages during the project term. Thank you to Dustin and Lisa McCreery at Chatfield's Tree Nursery in Tammin for growing the shrubs and generously allowing us to bring visitors through their facility, and to Tony and Simon York for maintaining a shrub collection on their farm. CSIRO's Matt Wilmot, Elizabeth Hulm, Paul Young and Josh Hendry prepared shrubs on a number of occasions for phytosanitary requirements and export. We appreciate the support of Prof. Javaid Akhtar and Dr Zulfiqar Saqibb (UAF Saline Agriculture Research Centre) for taking the saltbush plants and growing them on for future research activities.

6 Appendix 1. The potential role of halophytic shrubs in small ruminant systems in Pakistan – a review of the literature and future opportunities.

6.1 Summary of the review

This review focused on the climate, agricultural systems and opportunities for improvements in livestock systems. This review focuses on two of the six major landscape units in Pakistan, the Indus Plain and the Balochistan Plateau within the provinces of Sindh, Punjab and Balochistan. Key points from the review include;

- One in every three Pakistanis still does not have regular and assured access to sufficient food so food security is a critical issue. Livestock provide food, draught power, social benefits, risk mitigation in mixed farming systems and a source of cash in times of need.
- Agriculture employs over 44% of the population of Pakistan and accounts for 60% of export earnings. In rural areas, more than 60% of the population is involved in agriculture. Livestock production is undertaken by an estimated 8.4 million rural families and women are responsible for 60-80% of the labour. Any improvement in livestock productivity will improve livelihoods of a large number of women and children.
- Lack of rainfall is the biggest constraint to agriculture in Pakistan. Almost 87% of Pakistan has a climate that is extremely arid to semi-arid (<200mm annual rainfall). Climate change and associated sea level rise are threats. Salinity and shallow water-tables constrain production in irrigated areas.
- The most productive systems involve the intensive irrigation of crops and forages. These systems are constrained by urbanisation, increasing desire to grow cash crops, lack of quality forage seed and environmental degradation. Rangelands are a critical component of the livestock systems in rainfed areas. Overgrazing has led to a decline in forage quality and quantity.
- Ruminant production systems are constrained by the quantity and quality of forage. Lack of crude protein in diets is a major problem. Feed gaps occur in summer and winter.
- Halophytic shrubs such as saltbush (*Atriplex)* species are tolerant of both salinity AND aridity. The offer an opportunity for forage production on soils that are too saline for traditional crops and forages and in rainfed areas that cannot be cropped, including rangeland, wasteland and irrigation banks.
- Previous work on saltbush in Pakistan focussed on very saline areas with shallow water-tables with varying degrees of success. Shallow water-tables are the biggest limitation to growth of saltbush. Since these projects, a lot of activity in Australia has led to a better understanding of the interaction between salinity and waterlogging on plant growth and survival. In Pakistan, a bigger opportunity could exist in the marginal land in dry areas, on irrigation banks that are not inundated and around dwellings that tend to be on more elevated land.
- After inundation, lack of grazing management is the biggest threat to shrub survival. For this reason saltbush plants are probably better suited to areas adjacent to villages and homes. Introduction to rangelands in Balochistan will require fencing or community-based grazing management.

- Previous and ongoing work demonstrates that saltbush species persist in Pakistan and have significant potential to fill feed and nutrient gaps. Saltbush leaves are high in crude protein, essential antioxidants and minerals. However, digestible energy levels can be poor and the plants synthesise anti-nutritional secondary compounds. High salt in the biomass limits intake by stock and increases the requirement for drinking water. Saltbush as a *supplement* could improve health and reproductive capacity, due to high concentrations of vitamins and minerals associated with antioxidant pathways.
- Over the past 15 years in Australia scientists have been working to identify superior oldman saltbush (*Atriplex nummularia*) genotypes with improved feeding value. Anameka^{TM}, a vegetative cutting, was commercialised by CSIRO in 2014. The team are currently developing a second generation of cultivars based on propagation from seeds. This has potential for large-scale rangeland rehabilitation. Australian scientists are still researching management strategies to optimise livestock performance and shrub growth.
- There is a significant opportunity to introduce and test improved Australian saltbush shrubs as a feed supplement to ruminants in Pakistan. Saltbush is very easy to propagate by vegetative cuttings. It may be possible for rural women to generate their own cuttings and perhaps develop small businesses. This has been demonstrated in Jordan and is underway in Afghanistan. Within-village production could circumvent issues with the formal forage seed production and certification schemes.
- During this SRA, we successfully imported Anameka^{TM} saltbush as live plants to the University of Agriculture in Faisalabad. If these plants are maintained, the material would be available for future research projects. There is also an opportunity for training in Australia covering aspects of saltbush propagation, establishment, grazing management and associated science.

6.2 Agriculture in Pakistan

6.2.1 Importance of agriculture to support livelihoods

Pakistan has recently been ranked the 5th most populous country in the world, with about 207.7 million people. In 2013, it was thought that more than 20% of the population of Pakistan live on less than US$1.25 a day and have limited access to basic services (UN Human Development Index, 2013). In 2016, it was estimated that 45% of the population was living on less than $2 per day (United Nations Development Programme 2016). Agriculture employs over 44% of the population and accounts for 60% of export earnings. In rural areas, 62% of the population is involved in agriculture (Nosheen, 2008). One in every three Pakistanis still does not have regular and assured access to sufficient food. Pakistan's Vision 2025 document suggests that growth in agriculture in Pakistan has the potential to be four times more effective in alleviating poverty than growth in non-agriculture sectors. Although growth is a target, improvements in overall agricultural performance in Pakistan has been poor in recent decades. One of the top five objectives that the Pakistan Government has set for the agriculture sector is protection of the most food-insecure and the creation of a modern, efficient and diversified agriculture sector (Vision 2025). Alleviating poverty and improving food security in Pakistan is also a goal of the Australian Government's Pakistan Aid Investment Plan.

Improving livestock production systems will have a large impact on rural poor, especially women and children. About two third of the farming community in Pakistan consists of small farmers who are characterised by small land holdings of less than 5 hectares (Iqbal and Ahmed 1999). Livestock production supports 8.42 million rural families (Afzal 2010). It has been estimated that women contribute 60-80% of the labour for livestock rearing in Pakistan (Younas et al. 2007). In small holder systems, women raise livestock to meet household needs and provide income for the family.

The Agriculture Value Chain Collaborative Research (AVCCR) program-funded SRA 'Smallholder goat value chains in Pakistan; challenges and research opportunities' explored sheep and goat production systems in Punjab and Sindh. The authors found that women's roles in raising small ruminants chiefly involve feeding and caring for animals. Women and children perform substantially more of the day to day work. They seldom deliver health care, interact with animal health providers or lead decision making.

6.2.2 Agricultural areas of Pakistan that are suited to saltbush

Pakistan covers an area of about 800 000 square km and about 35% of the area is considered agricultural land with 28% arable and 6.5% permanent pasture (World Factbook). Pakistan's major river, the Indus, provides irrigation water as it flows from the Tibetan plateau to the Arabian Sea. The land in Pakistan comprises six major landscape units; (1) the northern mountains on the western ranges of the Himalayas, (2) the Hindu Kush and the western mountains on the boundary between Pakistan and Afghanistan, (3) the highly dissected Potwar Plateau and Salt Range which lie between the Indus and the Jhelum rivers, (4) the dry Balochistan Plateau, (5) the Indus Basin, and (6) the Cholistan and Thai deserts (Qureshi and Barrett-Lennard 1998). **This SRA focuses on two of the six landscape units, the Indus Plain and Balochistan Plateau in the provinces of Sindh, Punjab and Balochistan.**

The Indus Plain (~21 Mha) extends about 1000 kilometres from the Peshawar vale to the Arabian Sea and is the considered the most prosperous agricultural region of Pakistan (Ghassemi et al. 1995). Its northern zone comprises the Province of Punjab and parts of Khyber Pakhtunkhwa (previously known as North West Frontier Province), while the southern zone forms part of the Province of Sindh. The Indus Plain is extremely flat; it has an average gradient towards the sea of only 19 centimetres per kilometre (Ghassemi et al. 1995). Balochistan is situated in the southwest of Pakistan and covers an area of about 347 000 square kilometres. The Balochistan plateau has an average elevation of about 600 metres and consists of ranges of dry hills (generally running from northeast to south-west), dry valleys, saline lakes and vast areas of desert.

Lack of rainfall is arguably the biggest constraint to agriculture in Pakistan. Almost 87% of Pakistan has a climate that is extremely arid to semi-arid (<200mm annual rainfall). Further, Adnan et al (2017) observed a 5% decrease in precipitation over the 30 years from 1981 to 2010. The semi-arid zone is more vulnerable to drought, while intensity and severity are greater in the extremely arid region (Adnan et al 2017). Rainfall is too low and irregular for cropping in much of Pakistan and irrigation is used on about three-quarters of the cultivated land (FAO 1989).

In Sindh and Punjab provinces, 60% of rain falls primarily in the monsoon months of July, August and September. Some areas (especially in the north and west) have a rainfall distribution with two peaks, mid-winter being the second rainy season (Qureshi and Barrett-Lennard 1998). In general, summers are very hot, especially on the plains. In June, daily maximum temperatures may exceed 40°C (> 45°C in Upper Sindh). Temperatures are milder in the coastal belt and mountains. Temperatures begin to decrease in July with the onset of the monsoonal rains. In much of the Indus Plain, minimum temperatures are about 4°C and frost is possible in late December and January. Frost is much less likely along the coast (Qureshi and Barrett-Lennard 1998).

Balochistan is situated in the south western part of Pakistan and has an area of approximately 35 million ha and a population of 5 million (Mirza et al 2009). Balochistan has an arid or semi-arid climate with erratic rainfall distribution. Annual precipitation varies from 50 mm to over 400 mm (from West to East). Temperatures are cool in winter (very cold in the highlands) and very hot in summer, with temperatures exceeding 50°C.

Pakistan has two annual cropping seasons, the kharif season in which summer crops like rice, maize and sorghum are grown (sown in July and harvested in October), and the rabi season in which winter crops like wheat, clover, oats and barley are grown (harvested in April/May). With low evaporative conditions in winter, very good rabi crops can be raised with only a few irrigations (Qureshi and Barrett-Lennard 1998). Where irrigation is unavailable, dryland crops and forages supplement extensive grazing systems. In the irrigated zone, there is a shortage of good quality water for crops, therefore the use of poor quality water and dryland forage species for ruminants is a good opportunity to boost productivity without reducing food security (Ahmad and Ismail 1996).

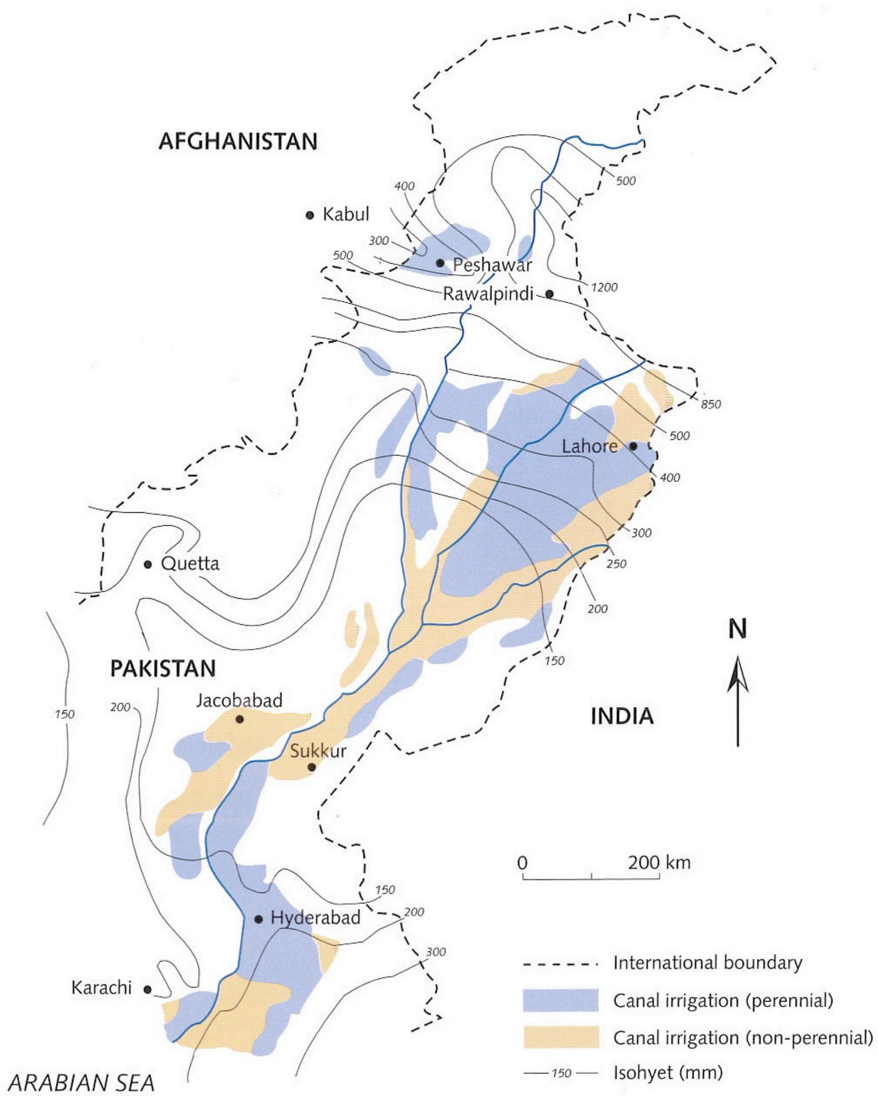

Fig 1, Rainfall distribution and irrigation areas of Pakistan (Taken from Qureshi and Barrett-Lennard, 1998 via Badruddin 1987 and Ghassemi et al 1995)

6.2.3 Salinity, waterlogging and rangeland degradation in Pakistan

After aridity, salinity and shallow water-tables represent a significant agricultural production constraint. Pakistan has 0.6% of the world's land mass but accounts for 3.9% of land that is affected by salinity (ACIAR 2007). Ahmad and Ismail (1996) estimate that salinity and shallow water-tables reduce productivity of up to a third of agricultural land in Pakistan, with nearly two thirds of irrigated land being impacted. The causes include over-irrigation, poor drainage, seepage from irrigation channels, use of poor-quality groundwater and seawater intrusion. Water-tables in Pakistan are deepest at the end of the dry season and shallowest immediately after the wet season. At the time of the year when water-tables are deepest, it has been estimated that only about 13 % of irrigated land has water-tables of less than 1.5 metres (Qureshi and Barrett-Lennard, 1998). Nearly 50% of irrigated land has water-tables deeper than 3 metres – a level where capillary rise of salt is unlikely (Qureshi and Barrett-Lennard, 1998). Approximately 1.4 million hectares of land has now been abandoned (ACIAR 2007) and crop yield has been substantially reduced in other areas. Salinisation is increasing in extent and severity, with an estimated 40 000 ha of additional land becoming impacted annually (Government of Pakistan, 2017).

There have been many efforts to prevent salinity and remediate saline land. This includes the usual suite of engineering (tubewells, lining channels) and chemical solutions (flushing with excess water, and the application of gypsum and organic matter). ACIAR made a substantial investment in the introduction of Australian salt-tolerant halophytic shrubs in the 1980's and 1990's (Projects 8619 and 9302). While there has been some progress, the scale of the problem means that these options will not solve the salinity problem and large areas of land will continue to be too saline for traditional crops. A recent review examined Pakistan's salinity management strategies (Akhtar, 2018) and it emphasised the need for consideration of social, technical, economic and environmental aspects. Like Australia, for large areas, productive uses of saline land may be more practical than remediation for salt-sensitive crops and forages.

In Balochistan, rangeland degradation has occurred due to over-grazing and the harvesting of woody perennials for fuel. Some of the indicators of rangelands degradation include a reduction in vegetation cover, reduced above ground plant productivity, soil erosion, elimination of soil seed banks, and a shift in species composition (Sarfraz et al. 2012). In some areas, above ground dry biomass production varies from 40 to 200 kg/ha in open areas compared to 200 to 865 kg/ha in protected areas. As in other countries in the region, viable solutions are difficult to implement due to land tenure.

6.2.4 Ruminant Production Systems and Feed Gaps

Livestock production is a major source of income in both the irrigated and rain-fed areas of Pakistan and supports an estimated 8.42 million rural families (Afzal 2010). Livestock as a sub-sector of agriculture accounts for about 11% of Pakistan GDP and contributes approximately 56% of the value of agriculture (Rehman et al 2017). As an example of the scale of livestock production, Pakistan is the third largest milk producing country in the world (Afzal 2010). The livestock sector is growing faster than agriculture overall; in 2014 overall growth of the agricultural sector was 2.9% whereas growth in livestock was 4.1% (Rehman et al 2017). Livestock farming is an integral component of rural smallholder production and has been described as having a vast untapped potential for productivity increase and income generation (Iqbal and Ahmed 1999). The recent increases in animal production is thought to have been the result of an increase in animal numbers, not productivity per animal. However, improved animal efficiency will be an imperative necessity for the future increase in food production (Dahlin 1998; Iqbal and Ahmed 1999).

In 2015, Pakistan had approximately 65 million goats, 25 million sheep, 40 million cattle and 32 million buffalo (see Fig 2, Rehman et al 2017). Based on census data from 2000, the majority of cattle and buffalo are in the Punjab and Sindh provinces, with very few in Balochistan (Fig 3, Afzal and Naqvi 2003). Of the goats, 37% were in Punjab, 24% in Sindh and 22% in Balochistan. Sheep predominate in Balochistan with 44% of the nation's flock, while Punjab and Sindh had 24% and 18% respectively. Ruminants are kept in small rural household systems or in extensive herds in the rangelands. Livestock are not only used for food production; they are also valued as a source of draught power and for the fulfilment of social obligations (Horne and Stur, 1997). About 9 million goats, sheep, cattle and camels are slaughtered each year during Eid-al-Adha observances (about 30% of the annual slaughter for these species).

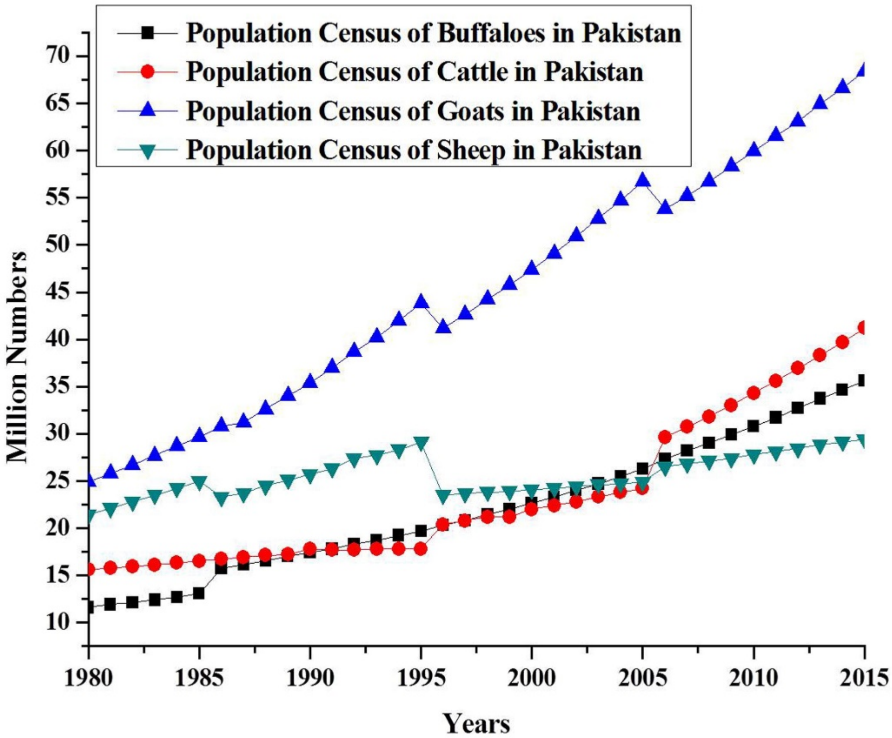

Fig. 2. Numbers of ruminants in Pakistan. Graph taken from Rehman et al 2017.

In the Punjab, the average flock/herd sizes in rural household systems are small. In a survey of 55 households in each of six villages in Punjab, 80% of households had goats with an average herd size of 5-7 animals (Muhammad, 2015). In irrigated areas, it has been estimated that 85-90% of the nutritional requirements of ruminants are met by non-conserved forage (Ul-Allah et al 2015). Forage species include berseem clover (*Trifolium alexandrenium*), persian clover (*Trifolium resupinatum*), oats (*Avena sativa*) and barley (*Hordium vulgare*) in winter, and corn (*Zea mays*) and sorghum (*Sorghum bicolor*) in summer. Forage production is often rotated in a double crop sequence. In recent years, forage production has declined due to increasing urbanisation, competition with cash crops (Ul-Allah et al 2015) and salinity.

Nomadic, transhumant, and sedentary are the three major grazing systems in Balochistan (Mirza et al 2009). Out of the total area of Balochistan, 21 million ha of Balochistan (~60%) is used for grazing small ruminants (Mirza et al 2009). More than half of this area is classified as 'poor' with forage yields of only 30-50 kg dry matter/hectare, whereas only 14% of the area is classified as 'better' rangeland with forage yields of 250-280 kg dry matter/hectare (Mirza et al 2009). Lack of biomass and severe nutritional deficits in autumn and winter limit livestock production (Akbar et al 1990). Overgrazing of rangelands and semi-arid areas has led to a decline in species diversity and forage quality. In addition, the expansion of dryland farming into marginal areas and the use of trees and shrubs for household fuel has led to a decline in the natural resource base. As is the case for rangelands worldwide, over grazing has led to a decline in the quality of the feedbase for ruminants as palatable species are replaced with low-quality vegetation. Inadequate forage during the dry periods combined with drought events results in heavy stock losses.

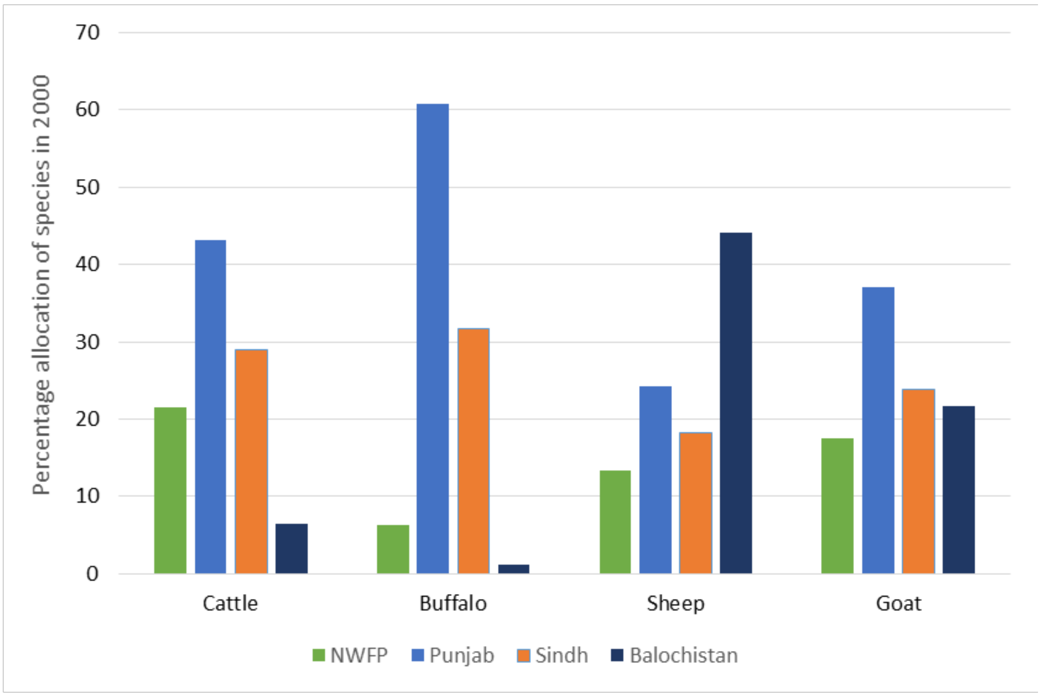

Fig. 3. Allocation of ruminant species across provinces of Pakistan in 2000 (% of the total number). Data calculated from Afzal and Naqvi (2003)

The 'Smallholder goat value chains in Pakistan; challenges and research opportunities' project team explored sheep and goat production systems in Punjab and Sindh. The authors concluded that poor supply (quantity, quality and consistency) of animals from farms is the major restriction in many value chains. Contributing factors were thought to include ill thrift and mortality of young animals, inappropriate nutrition and poor health of adult stock. Further, extension services are limited and poorly coordinated, so improvements are slow and supply cannot match demand. Interestingly, the project found that women and men identified slightly different constraints to small ruminant farming. Women ranked nutrition as the major issue, followed by animal health. Men ranked the issues in reverse order. Villages with low resource availability considered nutrition to be the most significant issue affecting small ruminant production, and as resource availability increased this declined and health became the most significant issue.

In both the Punjab and Balochistan, livestock production tends to be integrated with crop production in mixed farming systems; livestock utilise crop residues and forages are produced in a crop rotation cycle (Iqbal and Ahmed 1999). As in Australia, integration of crops and livestock is a way that farmers can improve flexibility and manage risk. The availability of sufficient high-quality seed remains a constraint to sown forages (Anwar et al 2012). There is a clear need to improve the productivity and feeding value of sown forages and to diversify the feed-base to allow for future increases in livestock production. Identification of new forages and better forage management has been a very active area of research (for example; Ross et al 2004; Ul-Allah et al 2014, 2015). Waste- and fallow-lands are also heavily utilised in Pakistan. Feeding systems vary at a regional scale and with production systems.

While feeding systems vary at a local and regional level, Pakistan has two periods of acute fodder deficiency, one in summer and the other in winter; ruminants typically lose condition during these times. Lack of nutrients, along with poor disease management, are considered the largest constraints to production (Dossa et al 2018). Studies suggest that only 75% of livestock receive the required amount of total digestible nutrients, and there is a 60% deficiency of digestible crude protein (Akram 1990; Devendra and Sevilla 2002). It has been estimated that an improvement in forage quantity and quality could increase livestock growth in up to 50% from the remaining genetic pool of animals (Hasnain 1983, as cited by Rehman 2017). The AVCCR 'Smallholder goat value chains in Pakistan; challenges and research opportunities' project found that nutritional limitations were most acute at the start of the summer (April-May), and during winter (Oct-Dec) when growing crops cannot be grazed by animals. Farmers stated they received poor prices if animals were sold to traders or butchers during these periods. Mortality of young stock was a critical issue at these times of the year, with 25-80% of young animals dying.

6.2.5 Halophytes to complement ruminant feeding systems in Pakistan

The highest proportion of saline areas of the world are found in arid and semi-arid environments (FAO/AGL, 2000). Halophytic shrubs from the Chenopodiaceae family are particularly well-adapted to saline and arid agriculture as they are perennial, drought resistant and tolerant of grazing (Masters et al 2007). These shrubs include saltbushes, bluebushes (*Maireana* spp), *Kochia* spp., glassworts (*Salicornia* spp.) and *Suaeda* spp. (Le Houérou, 1994; Masters et al., 2001). Le Houérou (1992) reported that edible forage production from a range of saltbush species to be 5–10 kg dry matter per ha each year for each mm of rainfall in areas without large salinity or waterlogging constraints. This means that with favourable soils and 200 mm rainfall, yields of 2 t dry matter per hectare per year could be expected. Under ideal growing conditions in Pakistan, saltbushes have demonstrated leaf yields of 5-6 tonnes fresh weight (1-2 tonnes DM) per hectare per year (ACIAR project 8619). Saltbush productivity depends on harvesting management and soil conditions (soil compaction/hardpans, flooding, soil salinity, moisture deficiency and waterlogging).

The feeding value of halophytic shrubs as a sole diet for ruminants is generally poor, due to a combination of: (1) low to moderate biomass production, (2) low to moderate digestibility of the organic matter, (3) excessive salt and/or sulphur accumulation, and (4) the presence of excessive plant secondary compounds such as oxalate (Norman et al 2004; Al Daini et al 2013). In Australian systems, it is therefore recommended that farmers use shrubs such as saltbush as a 'supplement' for livestock grazing crop residues – not a feed in its own right (Norman et al 2008). Saltbush leaf may have a role as a maintenance feed during periods of feed shortage (Hanjra and RasooI 1993), however salt accumulation in leaves will restrict voluntary intake to levels below maintenance. Mixing feeds to optimise productivity is not a novel concept in Pakistan where farmers mix cereal straw with other higher quality feeds like berseem clover to produce diets useful for ruminants. Despite nutritional limitations, saltbush is a valuable source of crude protein, sulphur, vitamin E and minerals within meat, milk and wool production systems (Ben Salem et al 2010; Pearce et al 2010).

Work in Australia has demonstrated the benefit of the antioxidants in saltbush. For example, Fancote (2013) found that lambs with access to saltbush had higher vitamin E levels and reduced incidence of subclinical nutritional myopathy during summer and autumn. Pearce et al (2010) found improvements in carcass and meat characteristics of lambs that grazed saltbush prior to slaughter.

6.3 Previous Salinity and Saltbush Research in Pakistan

Australian saltbush cultivars were introduced to Pakistan in the 1980's from the Department of Agronomy at the University of Western Australia. *Atriplex anmicola* (called *Atriplex rhagodioides* at the time) was imported by Dr Zahoor Aslam as part of his PhD studies. Seed from the plants were subsequently used for a series of salt tolerance studies (Mahmood and Malik, 19787).

Two ACIAR-funded projects (#8619 and #9302) have investigated the use of forage shrubs and woody species for saline areas of Pakistan. The projects ran consecutively for 8 years from 1986.

6.3.1 ACIAR project #8619. Forage shrub production from saline and/or sodic soils in Pakistan

Project #8619 was led by Dr Ed Barrett Lennard (Department of Primary Industries, Western Australia) and Prof Riaz Qureshi (University of Agriculture, Faisalabad). The focus of the project was on plant adaptation, with a series of experiments to identify options for saline areas that are subject to waterlogging. Ten species of halophytic shrubs were examined and five species of saltbushes were found to offer a significant opportunity for farmers with saline land. Due to the focus on shallow water-tables and waterlogging, old man saltbush was not included in the experiments. Fig. 4 shows the distribution of the five project research sites.

Fig. 4. Map of Pakistan showing the key research sites from the previous ACIAR salinity projects

Overall, saltbush survival after 12 months was highest at Bhawani (89%), and decreased in the following order: Dingarh (48%), Sujawal (41 %), Pindi Bhattian (23%) and Sadhoke (8%). This suggested that the shrubs were well adapted to arid conditions, but were less well adapted to salt, waterlogging and flooding. The only genotypes that survived at the most severely affected sites (Pindi Bhattian and Sadhoki) were from the group of saltbushes adapted to saline soils in Australia. The two species from within this group with highest survival were river saltbush (*Atriplex amnicola*) and quailbrush (*Atriplex lentiformis*). River saltbush is shallow rooted and relatively waterlogging tolerant for a saltbush species. Quailbrush was deep rooted and was thought to have roots that penetrated below the saturated zone. The project team concluded that the forage shrubs were well adapted to arid conditions, but were less adapted to salt, waterlogging and flooding. Under ideal growing conditions in Pakistan, saltbushes had leaf yields of 5-6 tonnes fresh weight (1-2 tonnes DM) per hectare per year. Saltbush productivity was related to harvesting management and soil conditions (soil compaction/hardpans, flooding, high soil salinity, moisture deficiency and waterlogging).

Oldman saltbush was not incorporated into these trials, because at that time it was not being used for the re-vegetation of saltland in Australia.

It is promising that the project demonstrated that river saltbush genotypes that were superior in Australia, also ranked highly in Pakistan but there were some failures. This is evidence that superior genotypes that have been selected for Australian conditions should perform well in Pakistan, however, this needs to be confirmed under field conditions.

6.3.2 ACIAR Project #9302 Forage shrub production from saline and/or sodic soils in Pakistan

Project #9302, involved Dr Ed Barrett Lennard (Department of Primary Industries, Western Australia), Dr Zahid Hussain (Director Land and Water Resources, Pakistan Agricultural Research Council, Islamabad), Prof Riaz Qureshi, Prof M. Aslam, Dr Shafqat Nawaz, Prof Raza Gill and Prof Kishwar Ijaz (all from University of Agriculture, Faislabad) and Prof Abdur Rashid (Agricultural University Peshawar). This project concentrated on plant propagation and agronomy; biomass production, harvest times, planting density and waterlogging. The project team conducted social surveys exploring the impact of salinity on communities in Satiana area. Economic modelling was undertaken to assess the impact of saltbush on farm profit. The team also conducted experiments with livestock to demonstrate complementarity between saltbush leaves and cereal straw.

6.3.3 Other saltbush research in Pakistan

Nawaz and Hanjra (1993) investigated the productivity of goats offered mixed diets of *Atriplex amnicola* leaves and kallar grass . They found that 25% saltbush and 75% kallar grass was the optimal diet (determined on a fresh weight basis). 100% saltbush did not support liveweight maintenance (as we would expect from the Australian experience). Water intake increased with the proportion of saltbush in the diet.

Bhatti et al (2009) compared intake and productivity of buffalo heifers offered combinations of grass, clover and saltbush *(Atriplex anmicola)*. They found that the addition of clover and saltbush to the diet improved productivity. They concluded that saltbush can be incorporated in the conventional diets of Nili-Ravi buffalo heifers at up to 50% as an alternate forage source when conventional fodders are in short supply, and when their nutrient contents are low during the severe winter and summer seasons.

6.4 Oldman saltbush improvement in Australia

Old man saltbush (*Atriplex nummularia*) is a woody perennial shrub that occurs as a dominant species in widespread communities over a 4 000 km range in arid and semi-arid zones of Australia where it has evolved with heavy predation by macopods, and (more recently) sheep. Oldman saltbush is very tolerant of saline conditions but has little tolerance to persistent waterlogging in the root zone (Barrett-Lennard 2003). It is utilised in arid and saline systems in Australia and across the world. The drought tolerance mechanisms of old man saltbush include deep roots (can be > 4 m), osmotic control and slow growth when water is scarce (Barrett-Lennard 2003). Being both perennial and in active growth through the summer and autumn period, saltbushes have the potential to reduce leakage of rainwater to water-tables thus potentially reducing the effects of dryland salinity (Barrett-Lennard et al 2005). In Australia, there is evidence of oldman saltbush utilising summer rainfall and allowing for natural rehabilitation of saline soils (Bennett et al 2012). This was shown to quadruple the livestock productivity of salt-affected land.

Until 2006, there had been little systematic effort to domesticate oldman saltbush and the majority of commercial plantations were derived from seed collected from native stands. In 2006, a project was initiated after comprehensive whole-farm economic modelling to assess the limitations and opportunities provided by saltbush within the mixed crop/livestock farming system of southern Australia (Norman et al 2015). The modelling, based on an average farm in several rainfall zones indicated that improving the energy value (digestibility of organic matter), of old man saltbush would substantially increase farm profitability (O'Connell et al 2006, Monjardino 2010). Sensitivity analysis predicted that improving shrub digestibility by 10% would increase profits by three times the increment associated with increasing biomass production by 10%, or reducing the cost of establishment by 10% (O'Connell et al 2006). The project team therefore initiated a program to improve the feeding value of old man saltbush, with a primary focus on digestibility of organic matter. The economic benefits rely on sheep choosing to incorporate the more digestible plants into their diets. Other studies had shown that sheep preferentially graze some individual shrubs before others, and some shrubs are not eaten (Norman et al 2004). These differences in relative preference by sheep were likely to be associated with both nutritive factors and the presence of plant secondary compounds with obnoxious and/or antinutritional characteristics, and excessive sulphur (Norman et al 2004, Norman et al 2011). A secondary aim of the project was to select a cultivar with higher preference by sheep. The final selection criterion was an improved proportion of 'edible' dry matter production (Norman et al 2015).

Old man saltbush was collected from populations across its native range and 60 000 seedlings were planted in replicated blocks at three experimental sites, across southern Australia (Hobbs and Bennell 2008). All plants were assessed for a range of agronomic traits and nutritive value was investigated at the provenance level. Nursery sites were grazed with Merino sheep to assess relative palatability. Assessing the energy value of the saltbush was complicated by high levels of soluble salt and uncertainty about the suitability of traditional laboratory methods for predicting digestibility (Masters et al 2007; Norman et al 2010a). To generate samples with known *in vivo* organic matter digestibility, a two-year program of animal house sheep feeding experiments was undertaken. Through a series of animal house and laboratory experiments, near infrared spectroscopy (NIRS) calibrations were developed to predict *in vitro* organic matter digestibility, crude protein, ash, neutral detergent fibre and acid detergent fibre of saltbushes (Norman and Masters 2010). Use of NIRS allowed for rapid and inexpensive screening of large numbers of plant samples.

In 2011, the best 12 genotypes were identified; they had 20% higher organic matter digestibility, higher relative palatability and produced up to 8 times more edible biomass than the mean of the original collection. Organic matter digestibility ranged from 62-66% and crude protein was 18-22%. These plants were vegetatively cloned and planted in replicated block experiments at 13 sites across southern Australia. These sites varied in location, salinity, soil type and rainfall and represented the majority of sites where saltbush may be grown. Plants were again assessed for survival, productivity and nutritional value. The top 4 genotypes and an industry standard were harvested and fed to sheep in a final metabolism feeding experiment; this was done in order to measure in vivo organic matter digestibility and nitrogen balance. The saltbush was fed with cereal hay as 50% of the diet. Based on these results, the first cultivar, named Anameka™, was commercialised in 2014. Anameka™ must be propagated by vegetative cuttings as the breeding system of saltbush means that plants grown from seed may not be phenotypically similar to the parents. Adoption has been high and over 2 million Anameka shrubs have been planted across Australia.

CSIRO are now working with a range of partners to develop elite seed lines and direct seeding methodologies. Although speculative, coated seeds have a significant potential to revitalise degraded rangelands. In a recent ACIAR project, the CSIRO saltbushes were introduced to Afghanistan. To date they are persisting well. The team are working with six Afghan women to explore the opportunity for women in villages to develop saltbush propagation small enterprises.

6.5 Conclusions and future research and development opportunities

The climatic conditions, in terms of rainfall (total and length of within-season drought) and temperature are similar to the semi-arid zone of Australia, where old man saltbush is endemic. The major difference is the rainfall in Pakistan tends to be associated with the hot season while in Australia it is associated with winter (with some significant but unpredictable summer events). The soils in southern Australia are predominantly old, highly weathered and naturally infertile. Previous research with saltbush species suggests that species that persist in Australia are also successful in Pakistan.

The distinction between assessment of salinity and salinity *associated with* shallow water-tables is an important distinction, as recent work in Australia has demonstrated that the saltbush species that are best adapted to shallow water-tables are not the best species for ruminant production. Extension activities are assisting Australian producers to select the saline/waterlogged soils, saline soils without waterlogging and arid areas. The improved genotypes of old man saltbush are suited to arid and saline areas but not waterlogged areas. Understanding land capability and the needs of livestock within the farming system will be a critical component of understanding the potential of old man saltbush within this project.

Although causes of salinity may differ, it is also a major problem in Australia. CSIRO and its industry partners have been investigating salt-tolerant forages for ruminant production on land that is too saline for food crops. These projects have developed a better understanding of the utilisation of saline land for halophyte production and the filling of nutrient gaps within ruminant production systems. Old man saltbush is a native Australian shrub that is well-adapted to arid, infertile and saline environments. The Anameka™ cultivar of oldman saltbush was commercialised by CSIRO in 2015, having been selected for improved digestibility and palatability. Anameka averages 64% digestibility of organic matter and 20% crude protein, a significant innovation for agricultural profitability in Australia. CSIRO also has other high-value genotypes of saltbush that offer an opportunity for livestock production to be part of the solution to environmental problems. With a focus on small ruminants in small-holder systems and opportunities for women in shrub propagation enterprises, this project could lead to significant long term benefits to the rural poor, especially women

Investment in saltbush research and development also benefits Australian rural communities. Economic modelling indicates that improved saltbush varieties can double the profitability of grazing systems on marginal land (Monjardino 2010). Lessons learnt in Pakistan will feed back into Australian research and extension activities. The project may open opportunities for Australian businesses to export saltbush seedlings and associated machinery for seed processing and on-farm planting to Pakistan.

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