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REVIEW ARTICLE

The sustainable utilization of saline resources for livestock feed production in arid and semi-arid regions: A model from Pakistan

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Abstract

Degraded land area is increasing in many arid and semi arid countries (UNEP, 2010). Additionally, fresh water resources are becoming limited and routine irrigation practices in conventional agriculture are causing a steady increase in soil salinity. This will lead to further desertification of affected areas in the future with concomitant reduction in the yield of crops known for human and animal consumption. Consequently it has become imperative to search for suitable alternatives and develop ecologically sustainable and economically sound biological systems that can use low quality water and drought affected saline lands to produce plants of economic importance. A large number of halophytes could be used as animal forage/fodder without encroaching upon arable lands and irrigation water. This paper emphasizes the agricultural importance of these salt tolerant plants in a world where most of the water is saline at any given moment. However, the economic use should be in accordance with the ecological demands suited to particular biomes. Pakistan for example, is spread over an area of 800,000 square kilometers with varied climatic conditions ranging from temperate to sub-tropical desert, eventually displaying a high biodiversity in local flora including halophytes. About 16% of the world halophytic flora is distributed in Pakistan with more than 410 species and among them >100 have potential economic usages as cattle feed. A number of these species are also distributed in the regions between the Atlantic coasts of Africa to western India. The Sindh/Balochistan coast of Pakistan extending from Seer Creek to Jiwani and from coast to mountains including Indus basin are rich sanctuaries for many of these plants. There is a need to conduct systematic survey of this flora, ascertain their chemical characteristics for nutritive value and subsequently identify the species suited to particular conditions through animal feeding trials. Some of these trials have already indicated a promise for ecologically sustainable use of perennial grasses such as *Panicum antidotale*, formerly identified as *Panicum turgidum* and *Desmostachya bipinnata* that may be taken to commercial scale. The system that was developed in Pakistan may serve as a model to other semi-arid sub-tropical countries of the region.

Key words: Animal feed, Brackish water, Non-conventional crop, Salinity

Introduction

A general surge in human population of the world has been registered over the past several decades which continues to rise, especially in developing / under developed countries from arid and / or semi arid regions (Koyro et al., 2008). Conventional agriculture in these areas is threatened by salinisation or desertification resulting from high evapo-transpiration, faulty irrigation practices and intense land utilization (Qadir et al., 2008). Vast areas of good agricultural land are already saline due to natural or man-made causes, resulting in reduced or no productivity. This is evident in declining trends of yields of major agricultural crops like wheat, cotton, rice in the affected areas (FAO, 2008). Scarcity of water for agricultural, industrial and domestic use looms on the horizon and the future scenario suggests that the acquisition of water could be a major source of conflict among nations. Such situations have already developed in several parts of the world and straining relations between countries like India-

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Pakistan, Turkey-Iraq, Sudan-Egypt, USA-Mexico (Qadir et al., 2008).

Saline land and salty water, which are present in abundance both inland and along the sea coast, are conventionally considered as non-productive resources but there is a need to utilize them to reduce pressure on fresh water and arable lands. Hydro- and xero- halophytes, with the remarkable ability to thrive in salt-affected lands irrigated with brackish water, may provide a viable and sustainable option (Khan and Qaiser, 2006).

2. The strategies of halophytes to be successful in saline habitats

Halophytes are a group of plants that survive and reproduce in environments where the salt concentration is around 200 mM or more, whereas the non-halophytes, to which most of our crop plants belong, are sensitive to lower levels of salinity (Flowers and Colmer, 2008). The key to survival under saline conditions is the ability and capacity of a plant to minimize the effect of sodium and other harmful ions. This can be achieved by restricting salt buildup in plant tissue (exclusion) or allowing it to a certain limit (inclusion). Plants, depending on their genetic makeup, have the ability to do both (Marschner, 1995; Koyro and Lieth, 2008). Classification of 'includer' and 'excluder' is only of limited validity however, it shows two contrasting mechanisms of plants to counter one and the same problem.

In case of exclusion, the plant suffers from water deficit (physiological drought) and adverse effect on gas exchange. On the other hand, if it takes up salts (i.e. inclusion); it needs to manage ion toxicity and imbalance: Both cases can ultimately lead to production of Reactive Oxygen Species (ROS) creating further problems (Geiβler et al., 2009a, 2009b, 2010; Koyro, 2003; Koyro et al., 2009). The 'excluders' are generally less tolerant as their capacity to exclude breaks earlier whereas the 'includers', which are also prone to damage above certain limit, continue to survive at considerably higher salt concentrations. There is need for plants to maintain a constant flow of water (and mineral nutrients needed for sustenance) from the rhizosphere to the shoots by decreasing osmotic potential through accumulation of osmotically active substances such as salts. If the plant is effectively managing this excess ion uptake to its advantage, most of these salts ultimately end up in the vacuoles. The lower osmotic potential thus developed in the vacuole is usually balanced by compatible osmotic solutes which may also provide protection to enzyme systems from osmotic damage and oxidative burst (Flowers and Colmer, 2008).

The ability of halophytes to survive saline habitats is dependent mainly on regulating conventional mechanisms optimally rather than using any secondary approaches. The halophytes have acquired a wide range of physiological adaptations to survive in habitats like coastal marshes, dunes, sabkha and inland salt flats, marshes, playa etc (Breckle and Veste, 1995). The strategies employed by these plants of saline habitats for survival and sustained growth under adverse conditions include stem succulence, leaf succulence, secretion of salt, and a number of biochemical and molecular adaptations that vary with a variety of environmental conditions (Flowers and Colmer, 2009; Marschner, 1995; Laüchli and Luttge, 2002).

3. The strategic advantages of using halophytes

The primary idea that halophytes could be used as non-conventional crops utilizing saline land and water is, however, not new. Nomads in the Euphrates region experience problems of high soil salinity due to intense cultivation and they used to replace crops with *Alhaji maurorum* for some period to decrease the soil salinity before replanting the crops. Although some halophyte are reported to be used as human food by certain communities (Yensen, 2006), for the time being at least, halophytes do not seem to have much potential in contributing to world human food mainly because of our established culinary preferences. Using these plants as turf to check land erosion and desertification in saline areas (DePew and Tillman, 2006), source of edible oilseeds (Glenn et al., 1991), fodder (Khan et al., 2009) among other usages (Lieth et al., 1999) however, needs to be exploited. In addition, their potential in reforestation or revegetation leading to ecological recovery of saline areas that have fallen into disuse, coastal development and protection, production of inexpensive biomass for renewable energy, environment conservation through carbon sequestration cannot be denied (Lieth et al., 1999; Abdelly et al., 2008). They may also serve as a source of essential oils and various chemicals of medicinal importance, wood for building purposes and furniture, boat and canoe making etc. For instance, out of some 410 halophytes reported from Pakistan about 51 could be used as medicine, 48 as forage, 47 as fodder, 38 as food, 34 as ornaments, and others as fiber, timber, fuel wood and miscellaneous chemicals, etc. (Khan and Qaiser, 2006).

4. The global challenges

In the frame of significant global changes such as increasing world population, ageing society, decreasing acreage, climate change, decrease of natural resources, there is a high demand to stabilize and to increase the availability of food and fodder (FAO, 2008). In many developing countries including Pakistan, there has been a substantial increase in livestock and meat/milk production during the last two decades (Anonymous, 2008). However, supplies failed to meet the fodder demand leading to the exorbitant increase in the prices. Further analysis indicates a change in the composition of food away from grain and towards livestock occurring in many countries particularly less developed ones (Bruinsma, 2003; Popkin, 2001). In the wake of such projections, livestock production such as cattle farming has to be geared up within each country to increase its output both for high quality meat/milk and for industrial raw materials like wool, hair, hides, etc., without compromising the environment.

An important factor for growth and health of animals is the diet fed to them, which also depends on whether the animals are being raised for meat or milk production. Feed is mainly composed of dry (usually wheat/rice straw) and green (maize/sorghum) fodder along with an energy ration. These fodders need good quality water and agricultural land thereby competing with food crops of human consumptions (El-Shaer, 2010); this necessitates a search for alternatives. Utilizing brackish water or partial substitution of fresh water with salty water to produce halophytic fodder in saline or dry lands seems to be one promising solution if a sustainable non-destructing system can be applied.

5. Pits and falls of using cash crop halophytes as animal feed

Halophytes have long been known to be a valuable resource for utilizing saline lands and brackish water but their potential as animal fodder has remained relatively under-explored. Wild herbivores are known to graze a number of halophytic species and domesticated animals have been fed some of these under conditions of shortage or non-availability of regular fodder.

Toward the latter half of the twentieth century, papers on the effect of salt in drinking water and feed on animal health and meat quality/quantity began to appear (Wilson, 1966; Walker et al., 1971; Hopkins and Nicholson, 1999; Thomas et al., 2007) also indicating the difficulties encountered (Weston et al., 1970; Weston, 1996;Wilson and Kennedy, 1996; Norman et al., 2004). Subsequently, scattered reports appeared in the literature where scientists from Australia, Indo-Pakistan, the Middle East, Africa and North/South America working in relevant fields have attempted replacing partially/completely the regular fodder with a variety of halophytes. There is however still a need for more integrated studies to carefully monitor the variations in the live weight of animals (Morecombe et al., 1996).

In most of the trials, halophytes fed to goats and sheep were high salt includers with heavy loads of secondary metabolites in their foliage (Swingle et al., 1996; Khan et al., 2000; Koyro et al., 2008; Rabhi et al., 2010). Excessive salt contents not only reduce palatability, cause difficulty in the digestion process (Hemsley et al., 1975) but also increase the thirst of the animals who consume water in larger quantities after the feed (Marai et al., 1995). In a water scarce environment this may be a major limitation. Furthermore, most of the halophytes mentioned above were short lived annuals with a requirement of reseeding and recurring expenses associated with high mortality that occurs during recruitment and early seedling growth.

An even more important issue in the domestication of wild halophytic plants to crops is that of taking the product from the laboratory to the experimental station and from there to the farmer as part of a system which is economically beneficial. This difficult and crucial process has not been addressed properly in most cases (Khan et al., 2009) and often resembles a practice of trial and error with unfortunate consequences for the end user and the environment. Therefore, the aim of this paper is to present a reliable model for the development of halophytic fodder plants using a sustainable saline irrigation/soil management system.

Perennial halophytic grasses for instance *Distichlis palmerii* or *Leptochloa fusca* have an excellent relation between costs and benefit because they do not require annual re-seeding and their successful use as cattle feed is in practice worldwide (Ashour et al., 1997; Malik et al., 1986; Masters et al., 2007; Yensen, 2006). The latter species (*L. fusca*) tolerates salinity/water logging, accumulates little salts even at high substrate salinities and recovers well from cutting and grazing. Several other perennial halophytic grasses are also reported to have similar potential and most of them are used when there is shortage of conventional fodder/forage and fresh water.

6. Basic requirements for a halophytic fodder crop

It is generally agreed that in addition to its ecological compatibility, a good fodder/forage should be leafy, nutritious, palatable and digestible; preferably containing > 5-6% protein and < 9-10% ash (Badri and Hamed, 2000). Whereas many halophytes can fulfill the protein requirement, it is rather difficult to meet the ash limit even by the non-accumulators. High ash contents (up to 35-50% of the dry weight) indicate accumulation of large quantities of salts in foliage which may be harmful for plants as well as cause ill effects on the health of animals fed such material. However, one way to overcome this problem is avoiding halophytes as a sole feed for extended periods. Species with 10-15% ash may safely be used as supplements to regular feed (El-Shaer, 2010).

Halophytes may contain toxic amount of undesirable compounds including phenolic acids, glycosides, alkaloids, and nitrates that may have a negative impact on animal health and growth (Abd El-Rahman, 2008). Oxalates in halophytes such as those from the family Amaranthaceae, particularly *Atriplex* spp., may lead to kidney failure (Osmond et al., 1980; Karimi and Ungar, 1984) unless the animals are gradually conditioned; ruminants, especially sheep adopt better (Attia-Ismail, 2003). Glenn et al., (1991) reported saponins in the seed cake of *Salicornia bigelovii* left after oil extraction in such quantities that rendered it unfit for feeding chickens and recommended it for swine or ruminant feed. A betaine-enriched diet for instance did not help in weight gain of lambs but showed a significantly lower sub-cutaneous fat thickness (Fernandez et al., 1998). Sheep fed with *Lotus corniculatus* have higher live weight gain, weaning live weight and wool production and were free from internal parasites which save the expenses of anthelmintic drenching (Ramirez-Restropo et al., 2004) and this response attributed to the presence of 2.4 - 2.7% condensed tannins on dry weight basis.

The methods to optimize the quality of halophytic feed are numerous. High content of ash and/or toxic chemicals can be reduced through chopping, soaking and washing with brackish water followed by washing with fresh water, air drying, ensiling, etc. The halophytic feed can also be supplemented with high energy fodder and protein rations for this purpose (Attia-Ismail, 2003).

There is ample choice for halophytic fodder crops in spite of the limitations discussed above. Halophytes reported from Pakistan constitute about 16% of the world flora (Lieth and Menzel, 1999) and many of them have the potential for use as animal feed (Table 1). A glance at this table shows an overwhelming presence of family *Poaceae* (47 species), followed by *Amaranthaceae* (20) and *Papilionaceae* (13) while 19 families are represented by three or less species. In Karachi (Pakistan) and its vicinity there are about 30 species of halophytic grasses which can be used as forage or fodder (Table 2, Khan, unpublished data). Some of these species are widely distributed inland also, but so far very little data are available on their palatability, nutritive value, growth responses and salt tolerance. These lists are not exhaustive and many other, even better species may exist. Therefore, there is a need to survey the local flora of the area and select best suited candidates for a particular environment. Some of the species can be fed directly (Table 3) while some other (Table 4) may be used as silage.

Table 1. Alphabetical listing of halophytes of Pakistan with forage/fodder potential. (extracted from Khan and Qaiser, 2006).

Genus, Species and Author	Distribution	Plant Type	Life Form	Economic Uses
Aizoaceae				
Trianthema portulacastrum L.	CO	Xeroh	TH	1, 2
Trianthema triquetra Rottl.ex Willd.	CO, IP, PP, BP	Xeroh	TH	1
Amaranthaceae				
Arthrocnemum indicum (Willd.) Moq.	CO	Hyphal	NP	1
Arthrocnemum macrostachyum (Moric.) C. Koch	CO	Hyphal	NP	1
Atriplex canescens James	BP	Xerohal	NP	1
Atriplex dimorphostegia Kar. & Kir.	BP	Psamm.	TH	2
Atriplex griffithii Moq.	ASM	Xerohal	NP	1
Atriplex halimus L.	Des	Xerohal	MIP	1
Atriplex leucoclada Boiss.	CO, IP	Xero	NP	1
Atriplex tatarica L.	MM	Xero	TH	1

Table 1. Contd..

Genus, Species and Author	Distribution	Plant Type	Life Form	Economic Uses
Beta vulgaris ssp *maritma* (L.) Arcangeli	BP, IP	Weedy	NP	
Bienertia cycloptera (Bunge ex Trautv.) Bunge ex Boiss.	CO	Xerohal	TH	1
Camphorosma monspelictum L.	ASM, BP, IP	Xero	NP	1
Halocharis hispida (Schrenk ex C. A. Mey) Bunge	ASM, BP	Xerohal	TH	2
Halocnemum strobilaceum (Pall.) M. Bieb.	CO, BP	Xerohal	NP	1
Haloxylon persicum Bunge ex Boiss	ASM	Psamm.	NP	2
Haloxylon stocksii (Boiss.) Benth. & Hook.	Cosm.	Xerohal	NP	1
Kochia scoparia (L.) Schrad	Cosm	Xerohal	TH	2
Salsola imbricata Forssk	Cosm	Xerohal	NP	2
Salsola tragus L.	ASM, MM, BP	Xerohal	TH	1
Seidlitzia florida (M. Bieb.) Boiss.	BP	Xerohal	TH	1
Suaeda fruticosa (L.) Forssk.	Cosm.	Xerohal	NP	1
Asteraceae				
Artemisia scoparia Waldst. & Kit.	MM, IP, PP, BP	Psamm.	NP	1
Seriphidium brevifolium (Wall. ex DC) Ling & Y.R. Ling	MM	Psamm.	NP	1
Seriphidium quettense (Podlech) Ling	BP	Psamm.	NP	1
Avicenniaceae				
Avicennia marina (Forssk.) Vierh	CO	Hyphal	MP	1
Brassicaceae				
Lobularia maritima (L.) Desv.	IP	Psamm.	NP	1
Raphanus raphanistrum L.	ASM, PP, BP	Psamm.	TH	1
Caesalpiniaceae				
Caesalpinea bonduc (L.) Roxburgh.	IP, CO	Hyphal	NP	1
Convolvulaceae				
Cressa cretica L.	Cosm.	Hyphal	SFC	1
Cyperaceae				
Bolboschoenus affinis(Roth.) Drobov	PP, CO, IP	Hyphal	NP	1
Bolboschoenus glaucus	Cosm.	Hyphal	SFC	1
Carex divisa Hudson	BP, MM	Hyphal	NP	1
Juncaginaceae				
Triglochin maritima L.	MM	Hyphal	NP	1
Triglochin palustris L.	MM	Hyphal	NP	2
Mimosaceae				
Acacia nilotica (L.) Delile ss *hemispherica*	CO	Xero	MSP	1
Prosopis cineraria (L.) Druce	PP, IP, CO, Des	Xero	MSP	1
Prosopis farcta (Banks & Sol.) Macbride	IP	Weedy	MSP	1
Molluginaceae				
Glinus lotoides L.	CO, BP, IP	Psamm.	TH	1
Myrsinaceae				
Aegiceras corniculatus (L.) Blanco	CO	Hyphal	NP	1
Neuradaceae				
Neurada procumbens L.	ASM, BP, IP	Psamm.	TH	1
Papilionaceae				
Alhaji maurorum Medic.	Cosm.	Hyphal	NP	1
Dalbergia sissoo Roxb.	IP, BP	Xero	MSP	1
Medicago falcata L.	MM	Chasm	NP	2
Melilotus alba Desr.	MM	Chasm	TH	2
Melilotus indica (L.) All.	Cosm.	Chasm	TH	2
Melilotus officinalis (Li.) Pall.	MM	Chasm	TH	2
Pongamia pinnata (L.) Merrill	IP	Hyphal	MSP	2
Sesbania grandiflora (L.) Poir	CO	Xero.	MSP	2
Sesbania sesban (L.) Merrill	IP	Xero	MSP	1,2
Trifolium fragiferum L.	MM	Psamm.	AC	1
Trifolium repens L.	ASM, MM, BP	Psamm.	AC	1

Table 1. Contd..

Genus, Species and Author	Distribution	Plant Type	Life Form	Economic Uses
Vicia sativa L.	Cosm.	Hyphal	TH	1
Vigna trilobata (L.) Verdc.	CO, Des	Xero	TH	2
Poaceae				
Aeluropus lagopoides (L.) Trin. ex Thw.	CO, Des, IP, BP	Hyphal	SFC	2
Aeluropus littoralis (Gouan) Parl.	BP	Hyphal	SFC	2
Aeluropus macrostachys Hack.	BP	Hyphal	SFC	2
Agrostis stolonifera L.	MM, PP	Psamm.	NP	2
Aristida mutabilis Trin. & Rupr	MM, ASM, IP, BP	Psamm.	NP	2
Aristida adsceshoines L.	Cosm.	Weedy	SFC	2
Cenchrus biflorus Roxb.	Cosm.	Psamm.	TH	2
Cenchrus ciliaris Rich.	Cosm.	Psamm.	NP	2
Cenchrus pennesettiformis Hochst. & Steud. Ex steud.	IP, CO	Psamm.	SFC	2
Chloris gayana Kunth	MM, IP	Psamm.	MIP	1
Chloris virgata Sw.	BP	Psamm.	TH	2
Cynodon dactylon (L.) Pers.	Cosm.	Weedy	SFC	2
Dactyloctenium aegyptium (L.) Willd.	Cosm.	Weedy	TH	2
Dactyloctenium aristatum Link	IP, CO, Des, BP	Psamm.	TH	2
Dactyloctenium scindicum Boiss.	Cosm.	Xerohal	SFC	2
Desmostachya bipinnata (L.) Stapf	Cosm.	Xerohal	NP	2
Dichantheum annulatum (Forssk.) Stapf	Cosm.	Xero	NP	2
Diplachne fusca (L.) P. Beauv.	IP	Hyphal	NP	2
Echinochloa colona (L.) Link	Cosm.	Hyphal	TH	2
Echinochloa crusgalli (L.) P. Beauv.	Cosm.	Hyphal	TH	2
Eleusine indica (L.) Gaertn.	MM, IP, CO	Hyphal	TH	2
Eragrostis curvula (Schrad.) Nees.	MM, BP, IP	Psamm.	NP	2
Eragrostris japonica (Thunb.) Trin.	Cosm.	Psamm.	NP	2
Eragrostis superba Peyr.	IP	Psamm.	NP	2
Festuca rubra L.	MM	Psamm.	NP	2
Halopyrum mucronatum (L.) Stapf	CO	Psamm.	SFC	2
Lasiurus scindicus Forssk.	Cosm.	Psamm	NP	2
Lolium multiflorum Lam.	MM, BP	Psamm.	NP	2
Orthochloa compressa (Forssk.) Hilu	Cosm.	Hyphal	SFC	1
Panicum antidotale Retz.	Cosm.	Psamm.	NP	1
Panicum turgidum L.	CO, BP, Des	Xeroh	NP	2
Paspalum pasploides (Michex) Scribner	Cosm.	Hyphal	SFC	1,2
Phalaris arundinacea L.	MM	Hyphal	NP	2
Phalaris minor Retz.	MM, IP, BP, PP	Hyphal	TH	2
Phragmites karka (Retz.) Trin. ex. Steud.	Cosm.	Hyphal	NP	2
Poa bulbosa L.	MM, BP	Psamm.	SFC	2
Poa pratensis L.	MM, BP	Psamm.	SFC	2
Puccinellia gigantia (Grossh.) Grossh.	BP	Hyphal	NP	2
Sacchraum bengalense Retz.	PP, IP, Des	Hyphal	MIP	2
Sporobolus coromandelianus (Retz.) Kunth	IP	Psamm.	SFC	2
Sporobolus helvolus (Trin.) Dur. & Schinz.	PP, IP	Psamm.	SFC	2
Sporobolus ioclados (Nees ex Trin.) Nees	BP, CO	Psamm.	SFC	2
Sporobolus kentrophyllus (K.Schum.) W.D. Clayton	CO	Psamm.	SFC	2
Sporobolus tourneuxii Coss.	Des	Psamm.	SFC	2
Sporobolus tremulus (Willd.) Kunth.	PP	Hyphal	SFC	2
Sporobolus virginicus (L.) Kunth.	CO, CT	Psamm.	SFC	2
Urochondra setulosa (Trin.) C.E. Hubb.	CO	Xerohal	SFC	2
Primulaceae				
Anagallis arvensis L.	MM	Xero	TH	2
Resedaceae				
Oligomeris linifolia (Vahl) Macbride	CO, IP, BP, PP	Xero	SFC	1,2

Table 1. Contd..

Genus, Species and Author	Distribution	Plant Type	Life Form	Economic Uses
Rhamnaceae				
Zizyphus nummularia (Burm. f.) Wight and Arn.	MM, CO	Xero	MIP	1,2
Rhizophoraceae				
Ceriops tagal (Perr.) C.B. Robinson	CO	Hyphal	MSP	1,2
Rhizophora mucronata Poir.	CO	Hyphal	MSP	1,2
Salicaceae				
Populus euphratica Olivier	IP, BP, PP	Xero	MSP	1
Salvadoraceae				
Salvadora oleoides Dne.	CO, IP	Xero	MIP	1
Salvadora persica L.	Des, IP	Xero	MIP	2
Zygophyllaceae				
Nitraria retusa (Forssk.) Aschers	CO	Xero	SFC	2
Zygophyllum simplex L.	Des, BP, IP, CO	Xerohal.	TH	1

Distribution: 1. Coast (CO), 2. Balochistan Plains (BP), 3. Indus Plains (IP), 4. Potwar Plateau (PP), 5. Deserts (Des) including Thal, Thar and Cholistan, 6. Arid and Semi-arid Mountains (ASM) including the northern Balochistan, Sulemania range, Waziristan, Kurram agency, Gilgit, and Chitral (Hindukush) and 6. Moist Mountains (MM) including the Western Himalayas, Swat, Kaghan, Kashmir, Muree and Kaghan.

Plant type: This category is based on the habitats in which the taxon is distributed. Hyphal = hydrohalophytes (present in salt marshes), Xeroh = Xerohalophyte = salt desert species, Psamm = Psammophytes (sand loving plants found on littoral or inland sand dunes), Xero = Xerohalophytes (desert species suspected as halophytes), Chasm = Chasmophytes (cliff-dwelling species), Weedy = Fugitive species.

Life form: Only one life form is assigned per species, even though many species show a certain amount of plasticity in this regard. Phanerophytes are further divided into a. Mesophanerophytes (MSP, 8 – 30 m tall); b. Microphanerophytes (MIP, 2 – 8 m tall) and c. Nano-Phanerophytes (NP, < 2 m tall). Chamaephytes (≤ 25 cm tall) could be further sub-divided into a. Sub-Fruticose Chamaephytes (SFC, erect shoot fruit at base), and b. Active Chamaephytes (AC, erect shoot absent), and Therophytes (TH).

Economic use: Fodder (1) and Forage (2)

7. Fodder species which can be used without processing

This group of species primarily consists of perennial grasses and a few species from non-grass families with worldwide distribution in arid and semi-arid regions but particularly found in the area extending from Rajasthan desert in India to dunes of Morocco (Table 1). A large number of them are high quality fodder and could be produced with brackish water irrigation on desert sand or saline part of the arid land. They are also known for high productivity and many could produce a biomass to the tune of 40,000-50,000 kg/ha/year (Khan et al., 2009). They usually have low anti-nutrient compounds and acceptable (low) ash content. The more promising ones among this group of species include *Cenchrus ciliaris*, *Dactyloctenium scindicum*, *Dichanthium annulatum*, *Kochia scoparia*, *Panicum antidotale*, *Phragmites karka* and *Sporobolus ioclados*. Even *Hibiscus cannabinus*, *Urochondra setulosa* and *Desmostachya bipinnata* can be used as a fodder after cutting and drying (Table 3, Khan, un-published data).

Table 2. Ethno-botanical information on perennial halophytic grasses with potential as animal Fodder/forage form Karachi and its vicinity.

Species	Distribution	Uses
PERENNIALS		
Aeluropus lagopoides	Sandy saline usually wet soils near the sea.	Forage by cattle.
Cenchrus ciliaris	Cosmopolitan distribution in Pakistan. It extends from Africa to India in addition to widely introduce in the old world.	It is valuable fodder grass especially for hay. It could also be used as turf
Chloris barbata	Pakistan (Sind); widespread throughout the tropics	Good forage grass.
Dactyloctenium sindicum	Pakistan (Sind, Punjab, N.W.F.P. & Kashmir); widely distributed in tropical and warm temperate regions of the Old World; introduced in America	It is a very nutritious fodder grass for cattle

Desmostachya bipinnata	Pakistan (Sind), native to the Sudanian region; from Morocco to India	It is considered to be a good fodder grass, especially when young
Dichanthium annulatum	Pakistan (Cosmopolitan); throughout the Middle East to Indo-China; North and tropical Africa	The species is an excellent fodder grass for camels.
Eleusine indica	Pakistan (Punjab); throughout Africa and in India.	A good fodder and pasture grass.
Halopyrum mucronatum	Very common in sandy areas near sea. Distributed in west Africa, Arabia and India.	It is used as forage when young
Lasiurus scindicus	Pakistan (Cosmopolitan); Northwest India, Iraq; tropical Arabia; Egypt up to Mali.	A valuable fodder grass said to be relished by camels, sheep and cattle.
Panicum antidotale	It extends from Somalia westward through Ethiopia and the Sudan to Morocco, and eastwards from Egypt through Arabia and southern Jordan to Pakistan (Sindh and Balochistan)	Palatable and frequently heavily grazed particularly by cattle and camels
Paspalum paspaloides	Pakistan (Cosmopolitan); tropics and sub-tropics throughout the world	Excellent turf grass
Phragmites karka	Tropical Africa, Polynesia, northern Australia and tropical Asia, Pakistan (Cosmopolitan)	It could be used as fodder particularly in silage.
Sporobolus ioclados	Pakistan (Punjab); throughout Africa and in India.	Excellent fodder / forage grass.
Urochondra setulosa	Pakistan (Cosmopolitan); tropical and subtropical regions throughout the world	Good grass for landscape development.
Sporobolus tremulus	Pakistan (Sindh,Punjab); India, Burma, Sri Lanka; Indo-China.	Soil binder and useful fodder grass
Sporobolus helvolus	Pakistan (Sind, Punjab & K.P.); tropical Africa, Arabia and India.	Desert grass making good fodder for camels
Paspalidium paspaloides	Pakistan (Sind): Old World tropics.	Good grazing grass
Digitaria pennata	Pakistan (Sind & Baluchistan); tropical East Africa, Ethiopia, Eritrea, Somalia, Arabia and northern India	Good as a fodder
Chrysopogon aucheri	Pakistan (Sind, Baluchistan, Punjab, N.W.F.P. & Kashmir); Egypt, Arabia, Iran, Afghanistan and northern India.	Fodder
Cymbopogon jwrancusa	India, west Pakistan, to tropical Africa	Fodder/forage
Cynodon dactylon	Pakistan (Sind, Baluchistan, Punjab, N.W.F.P. & Kashmir); tropical and warm temperate regions throughout the world.	An excellent fodder
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Sporobolus coromandelianus	Pakistan (Sind & Punjab); Old World tropics but mainly in Pakistan, India and South Africa	Not preferred
Cenchrus biflorus	Pakistan (Sind, Punjab & Kashmir); tropical Africa, extending through Arabia to India.	This grass is acceptable.
Cenchrus pennisetiformis	Pakistan (Sind & Baluchistan); tropical East Africa through Arabia to India; introduced to Australia	Valuable fodder grass
Leptothrium senegalense	Pakistan (Sind); Tropical East Africa and Senegal	Grazed by cattle
Dactyloctenium aegyptium	Pakistan (Sind, Punjab, K.P. & Kashmir); widely distributed in tropical and warm temperate regions of the Old World; introduced in America	it is a very nutritious fodder grass for cattle
Poa annua	Pakistan (Baluchistan, Punjab, K.P. & Kashmir); cosmopolitan, but avoiding deserts and hot climates	Sometime grazed
Eragrostis ciliaris	Pakistan (Sind, Baluchistan & Punjab); tropical and South Africa, extending through Arabia and the Mascarene Islands to India; tropical America	Grazed by cattle

Table 3. Some halophytes with potential use as fodder/forage.

S. No.	Name of species	Family	Type	Ash (%)	Protein (%)
1	*Cenchrus ciliaris*	Poaceae	C4	08.0	05.5
2	*Dactyloctenium scindicum*	Poaceae	C4	08.0	15.5
3	*Desmostachya bipinnata*	Poaceae	C4	14.0	10.3
4	*Dicanthium annulatum*	Poaceae	C4	11.0	07.7
5	*Kochia scoparia*	Amaranth	C4	14.2	14.6
6	*Hibiscus cannabinus*	Malvaceae	C3	10.6	25.7
7	*Panicum antidotale*	Poaceae	C4	11.0	18.9
8	*Phragmites karka*	Poaceae	C3	12.0	20.0
9	*Sporobolus ioclados*	Poaceae	C4	13.0	17.5
10	*Urochondra setulosa*	Poaceae	C4	10.0	05.91

Table 4. Some halophytes with potential use as silage.

S.No	Name of species	Family	Type	Ash (%)	Protein (%)
1	*Atriplex stocksii*	Chenopod	C4	35.0	13.3
2	*Salvadora oleoiodes*	Salvadoraceae	C3	40.0	11.6
3	*Salsola imbricata*	Chenopod	C4	45.1	09.7
4	*Suaeda fruticosa*	Chenopod	C4	48.7	11.5

8. Fodder species which could be used after processing

There are plant species which are distributed in salt marshes and in the deserts across Asia and Africa with high potential to be used as fodder after processing (Table 4). These species include among others *Alhaji maurorum, Athrocnemum macrostachyum, Atriplex stocksii, Haloxylon salicornicum, Halocnemum strobilaceum, Kochia indica, Limonium stocksii, Salsola drummondii, Salsola imbricata*, *Salvadora oleoides*, *Suaeda fruticosa*, *Zygophyllum simplex and Z. propinqum*. Most of these species either have high ash content, high anti-nutrient factors (tannins, oxalates and nitrates) and/or high lignin. Therefore, they could not be fed alone but need to be supplemented with leguminous fodder like berseem (*Trifolium alexandrinum*) and high energy supplements. It has also been demonstrated that quality of such fodder is better in young leaf in comparison to old, and during the winter compared to summer (El-Shaer, 1981, 1999, 2010; El-Shaer et al., 1990). Furthermore, they could be processed to form either feed blocks or silage by mixing molasses, wheat straw, etc. and then fed directly (Khan, unpublished data). The detail of the possible utilization of highly succulent halophytes is discussed elsewhere (El-Shaer, 2010).

9. Co-cultivation of low ash salt excluders and high ash salt accumulators for sustainable productivity

Irrigated agriculture on arable lands using good quality water but without proper care has often been a cause for turning arable lands saline (Abrol et al., 1988). When dealing with saline lands and brackish water, there is a need to be more careful to avoid any permanent damage to the soil where the lands become saline beyond repair. Suitable approaches and applications are required to strike a balance between salt input and removal from the system. Salt accumulators may be grown alongside fodder crop to remove the salt from the system. Removal of the leaves of the accumulators regularly could help removing extra salt added from salt water irrigation (Rabhi et al., 2010). In an independent study (Khan et al., 2000), it was estimated that salt accumulating species e.g. *Suaeda fruticosa* could remove about 20,000 kg/ha/year salts from the system.

In a field trial on growth maximization of *Panicum antidotale,* the salt accumulating halophyte – *S. fruticosa* was grown together with the main crop to remove the salt from the soil (see Khan et al., 2009 for details). The ash percentage of dry matter of the leaf of *S. fruticosa* may vary from 35 to 50% (Khan et al., 2000). Levels of soil salinity (8 dS m^{-1}) and water salinity (12 dS m^{-1}) in the above trial was favorable for the growth of *Panicum antidotale*, however, it was low for *S. fruticosa* which grew more rapidly than the grass crop, and the aerial part of the plants (6 inches above the ground) was cut and removed from the site regularly to prevent competition with the main crop. Using *S. fruticosa* has proved to be quite effective here as there has not been a significant increase in soil salinity after three years of irrigation with brackish water.

In addition to its role as a salt remover, *S. fruitcosa* has other economic benefits, for example in Pakistan this plant is burned by local villager to obtain soda ash used in soap production (Chaudhri et al., 1964; Khan et al., 2000). Suaeda seeds could be a valuable source of high quality edible oil and biodiesel (Weber et al., 2007; Khan, unpublished data). El-Shaer (2010) reported that members of this species (*S. fruticosa* and *S. imbricata*) could be processed to form silage and fed directly without any harm.

10. Sustainability of saline irrigation system

The potential of using halophytes as cash crop is tremendous. However, as shown with the combined action of a salt accumulator with the main fodder crop (Khan et al., 2009); it requires special attention and knowledge to make the system sustainable. This requires several precautions that must be taken for the utilization of brackish water on saline lands:

a) The approach envisages close monitoring of salt balance in the soil under the skilful supervision to avoid buildup of salts and maintain productivity.

b) Saline water contains several essential nutrients such as K, Ca and Mg but only low amounts of P and N. Therefore, the demand for additional fertilization needs to be monitored regularly.

c) The soil need to be checked regularly at short intervals for pH and EC. Organic matter level may be maintained in soil through burying fresh biomass and farm yard manure to help improve soil fertility.

d) Soil must be prevented from drying and gypsum may be applied if needed, i.e. avoid making it sodic.

e) More frequent and less intense irrigation is required to prevent soil from drying and keeping a check on upward movement of salts.

The field trials on growth maximization of *Panicum antidotale* were followed by a number of animal feeding trials to ascertain the utility of these halophytes as suitable fodder for cattle (for details of initial trials see Khan et al., 2009) while yet unpublished findings show similar potential of *Desmostachya bipinnata*. There was no difference between the water requirement of the animals fed diet having either conventional (non-halophyte) or halophytic fodder. These findings indicate the potential of halophytic plants for use as animal fodder suggesting that they may be able to replace the conventional fodder such as maize/wheat, etc.

In the above study, replacing conventional green and/or dry fodder with halophytic grasses (*Panicum* and *Desmostachya*) was not harmful for animal growth, there was no difference in yield (Fig. 1) or taste of meat from the animals fed either diet as compared to a conventional diet, and there are indications that the venture can be economically viable, especially if a large number of animals is raised. Finding suitable replacements of other components of the diet, e.g. legume fodder and a source for concentrate which could be produced using the available saline resources of land and water needs further investigations. With proper management, this will open a new field of saline agriculture.

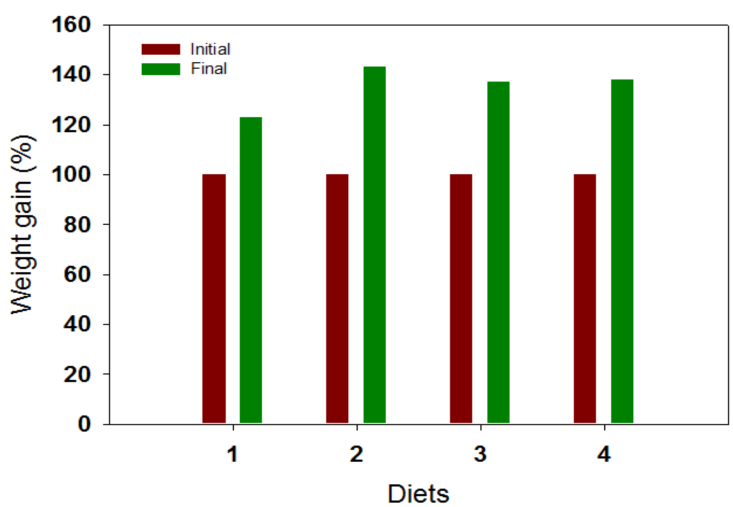

Figure 1. Change in weight of animal during the feeding trial. Animal diet consisted of several combinations of green fodder, straw and energy ration. Diet 1 has maize and straw only while in diet 2-4 energy rations were also included. In diet 3 maize and *Panicum* were equally mixed while diet 4 consisted of only *Panicum*.

11. General outcome of the studies

The potential of halophytes as cash-crop is great and if managed as proposed, it could serve to rehabilitate ecosystem, alleviate poverty and make the degraded saline areas into productive land:

1. Planting halophytes in highly saline area where hardly any plant could grow, may improve the soil conditions substantially.

2. Co-cultivation of a salt accumulator (for instance *S. fruticosa)* with main fodder crop could help in preventing soil to become more saline and to achieve sustainable system.

3. An irrigation system with low intensity and high frequency prevents soil from drying and keep the soil fit for any saline agriculture. Occasional intense washing of the soil with saline irrigation water also prevents build up of salinity in root zone.

4. Perennial grasses like *Panicum* and *Desmostachya* make system more economically efficient because they offer the advantage of sowing once and continued harvesting for several years.

5. Salt tolerant grasses are also a better fodder for direct feeding because most of them do not generally accumulate high amount of salt.

6. Secondary metabolites like alkaloids, flavonoids, terpenes and oxalates are present in only trace amounts in most of the grasses and therefore are of little threat to feeding animals.

Most of the developing countries are distributed in arid and semi-arid regions and face severe shortage of food which needs to be imported at exorbitant price. The rate of the increase of human population is also high in these regions. These countries have plenty of underground brackish water resources, vast acreages of saline wasteland and a number of useful salt tolerant plants. If these resources are utilized to produce high quality fodder thus providing opportunities for cattle farming, it would address the shortage of meat and dairy products to a great extent. This would not only meet food requirement but reduce the burden on the economy.

12. Conclusion

Salinity of soil and water are major threats to agriculture, especially in arid and semi-arid regions. Crops that are used for human and animal consumptions do not have the ability to survive even 1% salt (NaCl). Livestock production in particular, suffers, because feeding the human population gets priority and consequently, forage and fodder production for animals has to rely on substandard lands and irrigation water. The situation could be improved if more salt tolerant plant species were introduced. Increasing marginal salt resistance of our current crops through conventional breeding and molecular techniques have, however, brought correspondingly small benefits, requiring a shift from conventional to new approaches.

Halophytes are plants of saline habitats capable of tolerating high salinities, some of which can thrive even in seawater, but whose usages have remained relatively under-explored. Halophytes with low salt content (up to 15% of dry weight) may be fed directly to animals while those with undesirably high salts but ample protein may be used after processing. Animal feeding trials have proved the efficacy of *Panicum antidotale* Forssk. and *Desmostachya bipinnata*, perennial grasses distributed in highly arid and/or saline areas of the Sindh and Balochistan provinces of Pakistan, as suitable alternatives to conventional green and dry fodder. These are comparable to conventional fodder in terms of nutritional value and body weight gain of calves. Their suitability is further supported by the fact that the concentration of secondary metabolites in these species is much lower than the limits considered harmful for animals. The problem of salt buildup in soil over time can be partially reversed by co-cultivation with a halophytic salt accumulator leading to long lasting agronomical productivity. The system that was developed in Pakistan could serve as a model to other semi-arid sub-tropical countries of the region. However it needs to be adjusted to the specific conditions in each biome or country.

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