



Importance of crop residues in crop–livestock systems in India and farmers' perceptions of fodder quality in coarse cereals

P. Parthasarathy Rao^{a,*}, A.J. Hall^{b,1}

^aInternational Crops Research Institute for Semi-Arid Tropics (ICRISAT), Patancheru 502324, Andhra Pradesh, India

^bNatural Resources Institute, University of Greenwich, Chatham, Kent ME4 4TB, UK

Received 2 August 2002; accepted 30 January 2003

Abstract

The mixed crop–livestock systems of India are underpinned by the crop residues which contribute on an average 40–60% of the total dry matter intake per livestock unit. There is however considerable regional variation in the dominant type of crop residue: rice and wheat straws in irrigated regions compared to coarse cereal straws and hay from leguminous crops in the drier, semi-arid regions. This paper synthesizes a series of recent studies on the role and importance of crop residues and farmers' perceptions of fodder quantity and quality in coarse cereal and groundnut based feeding systems. Crop improvement programs for sorghum, pearl millet and groundnut have traditionally focused on grain/pod yield improvement, pest and water stress tolerance. Only relatively recently have dual-purpose (grain and fodder) plant types been developed. While the nutritive value of fodder from dual-purpose crops can be determined through *in vivo* and *in vitro* analysis, such experimental procedures cannot necessarily capture the often-subjective quality attributes that farmers (and their animals) value. Results indicate that farmers perceive a range of quality traits, some of which could be screened for relatively easily, whereas others may be more difficult to assess. These findings highlight the importance of farmer participatory evaluation of fodder traits in the development of improved dual-purpose varieties. However the impact of these varieties on poor farm households will be contingent on the complementary improvement in the effectiveness of seed systems.

© 2003 Elsevier B.V. All rights reserved.

Keywords: Dual-purpose crops; Farmer perceptions; Quantity; Quality; Disease and pest incidence

1. Introduction

Mixed crop–livestock systems are the dominant form of agricultural production in India. Integrating crops and livestock on the same farms helps smallholder farmers to diversify the sources of income and

employment. Livestock act as a storehouse of capital and an insurance against crop production risks, a coping mechanism against livelihood shocks as well as a vital source of dietary protein. Development of the livestock sector provides new livelihood opportunities for women who otherwise often lack access and control over land-based means of production (Deshingkar, 2002). In these systems, livestock holdings are more equitably distributed compared to land holdings (Birthal and Parthasarathy Rao, 2002). For the majority of smallholders, crop residues from dual-purpose crops constitute 40–60% of total dry matter intake. The rest is made up from

* Corresponding author. Tel.: +91-40-329-6161;
fax: +91-40-241-239.

E-mail address: p.partha@cgiar.org (P. Parthasarathy Rao).

¹ Presently stationed at ICRISAT, Patancheru 502324, Andhra Pradesh, India.

homegrown feeds and grasses from common property resources. Owing to cash constraints smallholder farmers in the drier, semi-arid regions generally do not purchase compound feed and agro-industrial by-products (AIBPs) in the market. In the dry months, particularly the 2–3 months prior to the onset on next monsoons, they face considerable feed shortages that adversely affect animal productivity. One potential avenue for improving feeding systems is to enhance the nutritive value of cereal and legume stovers and straws. However, while the nutritive value of genotypes can be determined through *in vivo* and *in vitro* analysis, such experimental procedures cannot necessarily capture the often-subjective quality attributes that farmers (and their animals) value.

This paper explores this issue by reviewing recent research conducted in India. Not only is the scope of this issue significant in the context of the sub-continent but also the purpose of this paper is to synthesize the results of a diverse set of studies conducted at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) over the last decade or so. The paper begins by reviewing the role and importance of crop residues from dual-purpose crops in mixed crop–livestock systems in India. It then goes on to present a summary of recent studies on farmer perceptions of grain and stover yields and preferred quality characteristics for coarse cereal straws and groundnut haulms. The results presented provide an indication of the range of traits valued by farmers and their perceived importance. These findings are discussed in the context of global research and intervention options relevant to ongoing efforts to improve the nutritive value of crop residues through genetic enhancement.

2. Role and importance of crop residues in livestock feed in India

Livestock feed resources in India can be divided into the following six major groups:

- cereal straw/stover: slender straws from rice and wheat, coarse stover from coarse grains such as sorghum, millets and maize;
- haulms from legume crops such as pulses and oilseeds;
- grasses from pastures, wastelands, forests and fallow lands;

- green fodder from forage crops;
- AIBP from cereals, legumes and oilseeds;
- cereal grains including, sorghum, millets, broken rice.

Kelley and Parthasarathy Rao (1996) found that the availability of feed on a dry matter basis from the above groups has varied during the last two decades. Overall, at the all-India level, feed availability per livestock unit has increased. They found, however, considerable variation across the major states in India. The driving force leading to an overall increase in feed availability is the increase in area and production of rice and wheat, and consequently slender straws, particularly in the better endowed regions² of the country. In contrast, in the semi-arid tropics the availability of stover from coarse cereals (mainly sorghum and millets) has stagnated due to a decline in area under these crops and the adoption of improved cultivars with a higher grain to straw ratio. This was compensated for to some extent by haulms from legume crops, the area of which increased during the late 1980s and early 1990s due to changing price policy for oilseeds.

Owing to competition for land for food crops the relative area under forage crops has remained stagnant during the last 25 years at around 5–6% of gross cropped area, however, the irrigated area under fodder crops increased faster (Kelley and Parthasarathy Rao, 1994a). Due to a decline in area under fallow lands, pasture and common lands, the availability of grasses has declined. Increasing population pressure on existing arable lands has led to encroachment of the area under common property resources. The quantity and quality of grasses from the above sources also declined due to overgrazing, and lack of proper maintenance (Jodha, 1992).

Recent estimates by Parthasarathy Rao and Bhownik (2001),³ support the above findings. They found

² Better-endowed regions are typically the high rainfall regions (above 1200 mm) and the large irrigated cropping areas extending across northwest India, including much of Punjab, Haryana and Uttar Pradesh.

³ In this study district-level data on livestock numbers, land use, area and production under crops were assembled from secondary sources. Using standard conversion factors availability of crop residues, green fodder, grasses from grazing lands and AIBPs were calculated for each district and aggregated on a dry matter basis. Livestock numbers were converted into standard livestock units and feed availability per livestock unit was estimated.

Table 1
Feed availability^a (dry matter basis) per livestock unit

| Tonnes per LSU | No. of districts | |
|----------------------------------|------------------|------|
| | 1972 | 1995 |
| <1.0 | 64 | 43 |
| 1.0–1.54 | 122 | 89 |
| 1.55–1.99 | 52 | 51 |
| >2.00 | 73 | 127 |
| All district average (t per LSU) | 1.61 | 2.05 |

^a Total feed included feed from crop residues, forage crops, grasses from common lands, and AIBPs. Source: Parthasarathy Rao and Bhowmick (2001).

that at the all-India level the availability of feed on a dry matter basis per livestock unit (LSU) between 1972 and 1997 has increased from 1.61 to 1.95 t. The number of districts with >1.55 t per LSU has increased from 125 to 187 (Table 1). However, there is considerable regional variation in the availability of feed across districts/regions in India (Fig. 1).

Crop residues from dual-purpose crops including rice, wheat, sorghum, pearl millet and oilseeds are by far the most important source of feed. At the all-India level they account for 61% of the total feed on a dry matter basis, up from 50% in the early 1970s (Table 2). In more than a third of the districts crop residues account for more than 60% of the total feed per livestock unit. Variation in their importance across regions is shown in Fig. 2. The dependence on crop residues is higher in the more marginal and semi-arid districts where alternative sources of feed are limited. These findings at the district level are supported by studies at the micro/household level (McDowell, 1988; Thole et al., 1988; Kristjanson and Zerbini, 1999; Hall, 1999).

Table 2
Share of crop residues in total feed^a (dry matter basis)

| Percentage | No. of districts | |
|-----------------------|------------------|------|
| | 1972 | 1995 |
| <35 | 72 | 55 |
| 35–60 | 140 | 110 |
| >60 | 99 | 128 |
| District averages (%) | 51 | 60 |

^a Total feed included feed from crop residues, forage crops, grasses from common lands, and AIBPs. Source: Parthasarathy Rao and Bhowmick (2001).

There is considerable variation in the availability of crop residues from dual-purpose crops by type across districts (Fig. 3). In the irrigated northern districts and high rainfall eastern districts of India slender straws dominate while in the low rainfall arid and semi-arid districts coarse cereal straws, and haulms from legumes dominate.

3. Economic importance of crop residues

In the arid and semi-arid regions of India, owing to a decline in the area under coarse cereals, the availability of stover from these crops has reduced. This is reflected in the rising real straw prices and declining grain to straw price ratios. In the heart of sorghum growing areas in Maharashtra the sorghum grain to straw price ratio decreased from 8:1 in the early 1970s to around 3:1 by the mid-1990s. Similar trends are noticeable for pearl millet in Rajasthan where pearl millet straw constitutes an important source of feed (Kelley and Parthasarathy Rao, 1996; Marsland and Parthasarathy Rao, 1999).

The faster increase in straw prices is reflected in the increase in the value of straw in the total value of production (grain + straw). This has implications for breeding programs. Historically, breeding programs for coarse grains have tended to concentrate on grain quantity (mostly) and quality (less so) at the expense of straw. This has slowed the adoption of new improved cultivars particularly in mixed crop–livestock production systems where farmers value dual-purpose grain and fodder yielding plant types (Hall, 1999; Underwood et al., 2000). Since the early 1990s this trend has been reversed to some extent as breeders have started to also emphasize stover quantity and quality.

4. Improving the nutritional value of crop residues

Crop residues are low in metabolized energy and crude protein. Since crop residues are the most important feed resources in the arid and semi-arid regions of India, considerable research effort has gone into improving their nutritional value through crop management, and physical, biological and chemical treatment of straws, as well as supplementation through high

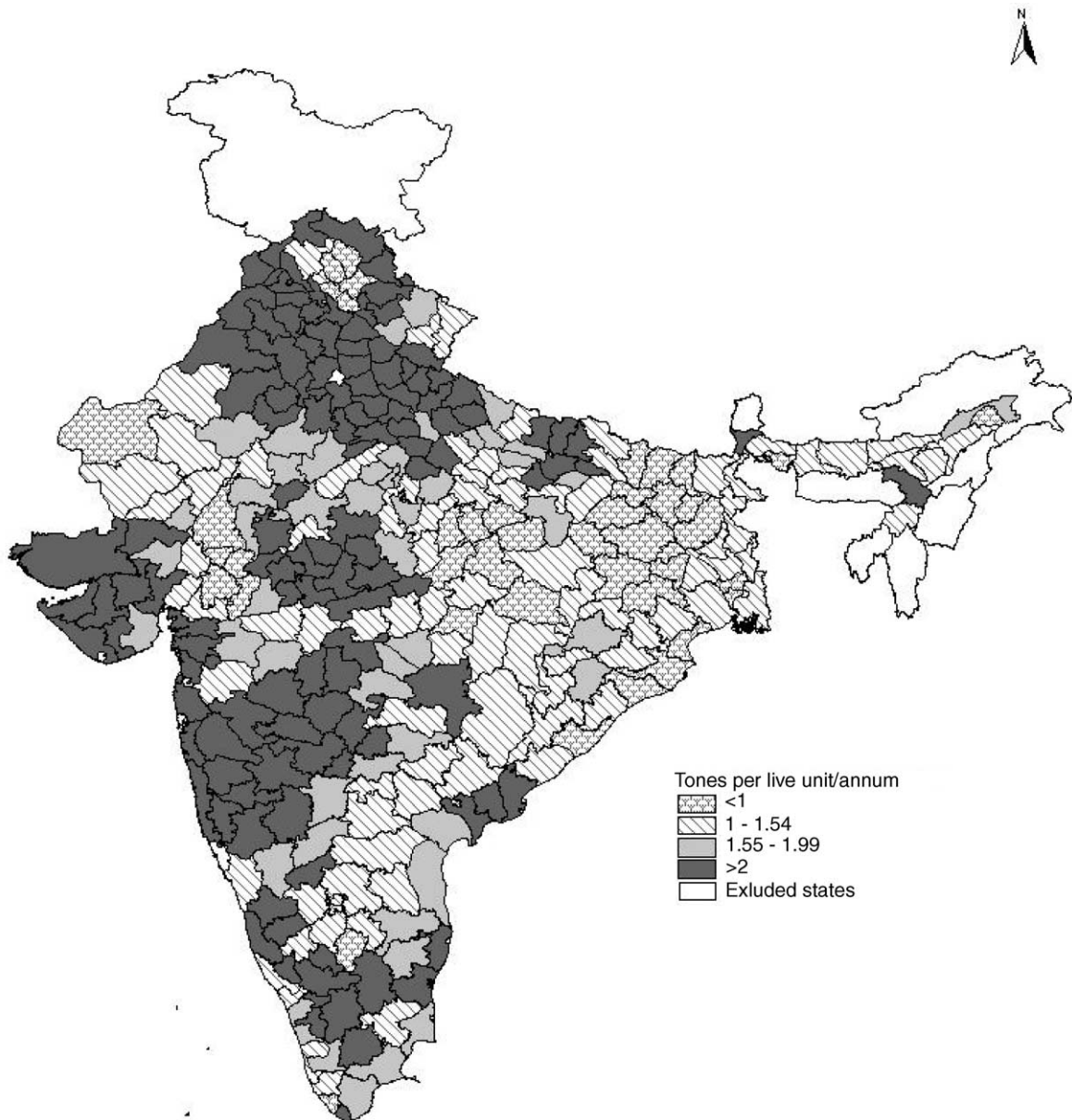


Fig. 1. Total feed (dry matter basis) per livestock unit, 1997.

protein oil cakes, green fodder, and tree leaves. However, the on-farm adoption of these technologies has been low due to improper fit of the technology in the farming system, low resource availability, high opportunity cost of land, labor and capital in alternative uses, and lack of significant and visible economic benefits (Devendra et al., 2000; Thomas et al., 2002). As already

mentioned, only in recent years have crop improvement programs initiated breeding for dual-purpose crops with emphasis on grain and straw yield and quality. In an ex ante assessment of returns to research on improving sorghum stover quality, Kristjanson and Zerbini (1999) found that a 1% increase in digestibility of sorghum stover would lead to a 5% increase in milk production.

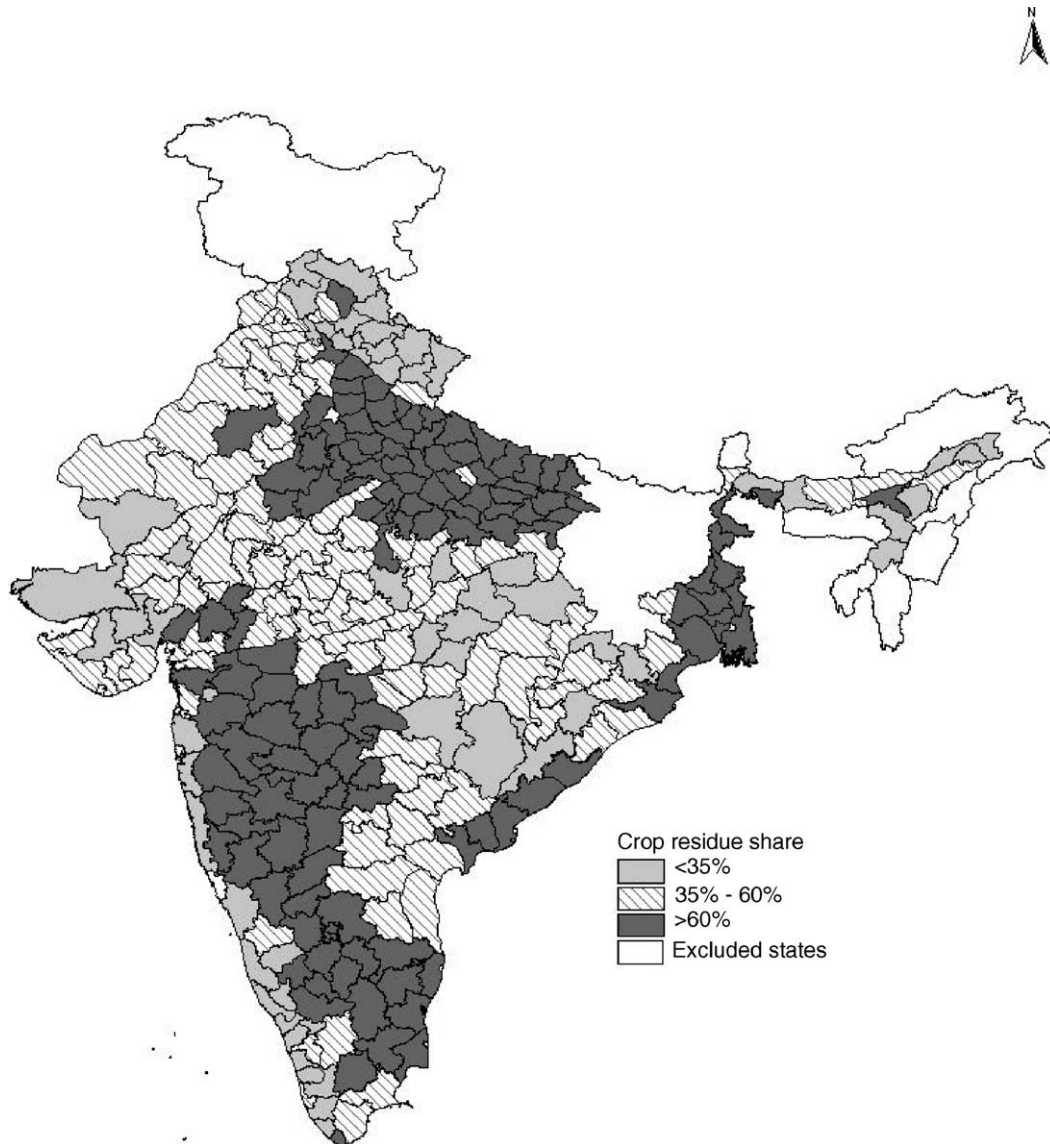


Fig. 2. Share of crop residues in total feed availability (dry matter basis), 1997.

5. Farmer perceptions

5.1. Grain and straw yield for sorghum and pearl millet

One determinate of farmers' perceptions of grain and straw yield of coarse cereals is their prediction of rainfall probability. Kelley et al. (1996) and Kelley and Parthasarathy Rao (1994b) found that in the

semi-arid tropics of India farmers generally perceive 3–4 years out of 10 to be low rainfall or drought years. It is 5 years in arid regions (see Table 3). Risk in production, particularly in low rainfall years, is a major consideration in the adoption of new varieties. Farmers perceive and, indeed, observe higher grain and straw yield from local varieties in low rainfall years. In the arid villages of western Rajasthan, since pearl millet straw plays such a fundamental role in

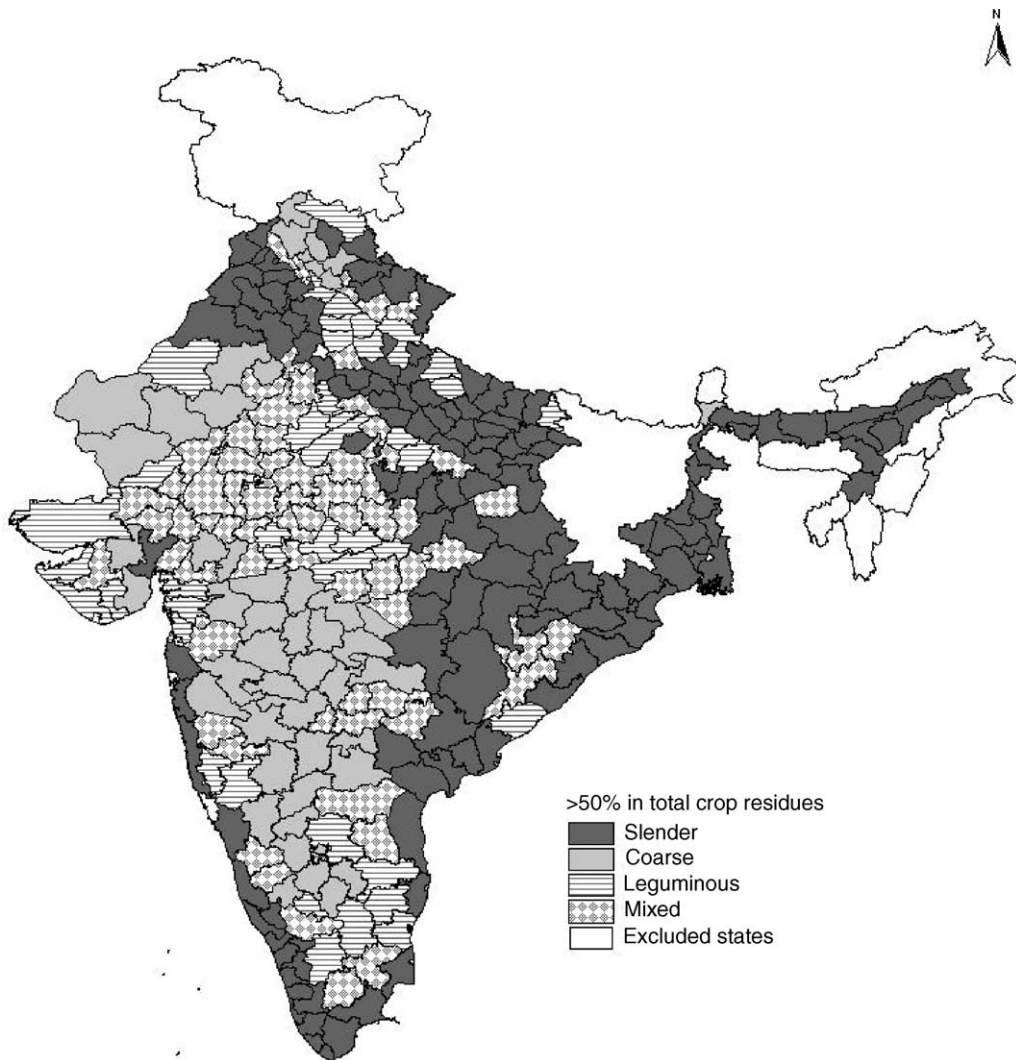


Fig. 3. Crop residues by dominant type, 1997.

the crop–livestock systems, this is likely to influence farmers’ decision about adopting new cultivars. In low rainfall/drought years, grains are generally available in the market from neighboring states and government relief programs. This is generally not the case with fodder.

There are also other considerations that determine farmers’ preferences for straw yield. For example, straw yield is considered important in those villages/regions with good markets for milk and/or fodder and/or non-availability of alternative sources of feed (Underwood et al., 2000).

5.2. *Quality of crop residues: recent farm level studies*

While the studies reported in the previous sections provide a broad picture of fodder utilization and fodder quality issues, this section looks in greater detail at the precise nature of farmers’ preferences and the contextual issues in production and marketing systems that inform these preferences. This section draws from two recent sources. First, the study by Rama Devi et al. (2000) examined farmers’ perceptions of sorghum and groundnut residues in the context

Table 3

Farmer perceptions on rainfall probability (semi-arid and arid villages of India) (source: Kelley et al., 1996; Kelley and Parthasarathy Rao, 1994a)^a

| Village | Years per decade ^b | | | |
|-----------------|-------------------------------|----------------------|-------------------|--------------|
| | Good rainfall year | Normal rainfall year | Low rainfall year | Drought year |
| S. India (SAT) | 1.7 | 5.0 | 2.4 | 0.9 |
| W. India (SAT) | 1.5 | 3.2 | 3.8 | 1.0 |
| W. India (SAT) | 3.7 | 4.3 | 2.1 | – |
| W. India (Arid) | 1.0 | 4.0 | 3.0 | 2.0 |

^a Mean value, i.e. averaged across village sample.

^b Farmers were asked to classify rainfall with reference to crop yields, as follows: (i) good rainfall year = good or high yields; (ii) normal rainfall year = average yields; (iii) low rainfall year = low yields; (iv) drought year = zero or negligible yields.

of plant diseases and their implications for nutritive value. Secondly, the study of Underwood et al. (2000) explored farmers' perceptions of fodder quality as part of the genetic enhancement program at ICRISAT which is targeted at improving the nutritive value of sorghum and millet residues.⁴

These studies identified a number of general points that give greater perspective to a discussion of farmers' perceptions. These points included:

- Livestock play a key role in agricultural production systems in the Indian semi-arid tropics and are closely interlinked with cropping patterns.
- Richer households tend to keep larger animals and greater numbers.
- Poor and rich households with their different livelihood strategies value fodder in different ways and give different emphasis to the importance of grain-stover trade offs.
- Goats are an important source of milk and income for poor households in particular.

⁴ Both these empirically based studies resulted from extensive field and market surveys. In the case of the former study surveys were conducted in four villages in the Indian state of Andhra Pradesh. In the case of the latter study surveys were conducted in 13 villages across the Indian states Andhra Pradesh, Karnataka, Gujarat, Rajasthan, and Maharashtra. Both studies used combinations of semi-structured interviews with key informants and participatory rural appraisal techniques, triangulated with secondary information sources.

Table 4

Farmers' preferences for sorghum and millet stover plant types^a

| Characteristic | Sorghum | Millet |
|--|---------|--------|
| Leafiness/plant keeps leaves | X | X |
| Light green/golden yellow, no blackening | X | X |
| Thin/soft/tall well-filled stems | X | X |
| Sweet taste/animal eats the whole plant | X | X |
| Less susceptible to fungus attack/no observable pest and disease | X | X |
| Traditional varieties preferred to new | X | X |
| Less lodging | X | X |

^a Source: adapted from Underwood et al. (2000) and Rama Devi et al. (2000).

- Good markets (price, demand, ease of access), especially for milk play a key role in stimulating increased animal production and the intensification of production systems (for example, supplementary feeding).
- Decreasing numbers of animals in many areas are attributed to changing production patterns (tractORIZATION, changes to cash crop production, and the reduced availability of stover).
- Sorghum and millet are almost always grown as a dual-purpose crop.
- Local markets exist for both sorghum and millet stover, but not for groundnut haulms. There is a particularly strong market for fodder from urban-based dairy production systems.
- Farmers and fodder markets recognize a range of quality characteristics that relate to both specific plant types as well as quality issues related to infestation, particular by foliar diseases.
- Farmers assess feed value/quality based on a range of parameters including visual observation of stover/straw, its palatability, effect on milk production, strength to animals (draft animals), effects on animal health, availability and cost relative to other feeds.
- Farmers often perceive output characteristics of fodder quality without being able to relate them to precise variety traits.

Table 4 summarizes the key quality characteristics valued by farmers in sorghum and millet varieties.⁵ However the importance of these characteristics needs to be viewed in the context of a wider set of variety characteristics of different cultivars. Table 5

⁵ Comparable information is not available for groundnut varieties.

Table 5
The wider range of variety characteristics preferred by farmers^a

| Sorghum and millet | Groundnut |
|--|--|
| Grain yield | Pod yield |
| Less susceptible to grain mould | Less susceptible to pests and diseases |
| Acceptability of fodder to animals | Water stress tolerance |
| Fodder yield | Fodder yield/more leaves |
| Human consumption characteristics of grain | Grain characteristics (oil content) |
| Suitability to local soils | Short duration |
| Water stress tolerance | Fodder quality |
| Less susceptible to other plant diseases | Suitability to local soils |

^a Source: adapted from Underwood et al. (2000) and Rama Devi et al. (2000).

summarizes the wider set of variety characteristics, including fodder quality that farmers value in sorghum, millet and groundnut varieties.

The production and marketing context and the household resource endowment context are also important in conditioning farmers' fodder practices and preferences. For example, it was found that in villages with weak links to milk markets, low prices for sorghum stover damaged by foliar diseases had a greater impact on farm households as the majority of stover was sold to urban fodder markets. In villages where the links to milk markets was stronger, such income impacts were not perceived by farmers who fed the stover to their own animals. There were also differences between rich and poor households with the latter having fewer animals and selling the stover from crops primarily grown for food. Conversely the rich, often with more animals, had to grow more sorghum for stover, selling grain as a by-product. Access to milk markets and the relative degree of production intensification also influences the comparative importance of stover in animal diets and hence influenced the overall importance that farmers attributed to different quality parameters. Rainfall patterns and soil types add further complexities to discussions and also influence perceived preferences for different plant types, grain-stover trade offs and other quality parameters. So in one sense the answer to the question of what are farmers' preferences is that *it all depends* (Underwood et al., 2000).

A further issue that was investigated in conjunction with farmers' preferences for sorghum and millet

stover quality was the issue of farmers' access and adoption behavior towards new varieties. The relevance of this is that if genetic enhancement of the nutritive value of crop residues is to be translated into production and livelihood gains, effective processes must link technology development, production and supply. As would be expected, farmers reported that they were always interested in testing new varieties, but that naturally they were keen to minimize risk. They also had a set of criteria that they would use to evaluate new varieties that included stover quality, but only as one of a large number of attributes (see Table 5). Perhaps what was most surprising was that the most limiting factor was access to new varieties, particularly for poorer households but also for the rich. The study revealed that it was not uncommon to find farmers who had been growing the same variety for 20 years.

This component of the study seemed to suggest that rather than farmers having access to a suite of new varieties from which they could choose, the key constraint was the lack of access to improved materials. So although risk-averse behavior and unsuitable varieties have been a constraint to the introduction of new varieties and, consequently, productivity gains (an underlying rationale for more participatory plant breeding), seed supply, extension and knowledge flows have been an equal if not more significant failing (see Tripp (2001) for an extensive treatment of this issue).

6. Implications for future research strategies

A number of specific points arise out of these studies of farmers' preferences that need to be borne in mind in future genetic enhancement and technology transfer strategies:

- Farmers value both specific plant types as well as well as animal output qualities (milk yield, animal health, etc).
- While this suggests that a greater degree of farmer participation is required in the planning and testing of genetic enhancement strategies for nutritive value, this should not be at the expense of in vivo and in vitro evaluation of improved material.
- A related point concerns the highly contextual nature of farmers' preferences and the relative

degree of importance that is given to different traits in different production and market systems and in households of different resource endowments. Demand for different varietal characteristics will evolve along with the developments and changes that are taking place in the production system in which they are used.

- While the selection of fodder quality traits should not compromise grain and fodder yields, if a variety is to be acceptable to farmers, there may be a range of trade offs with other characteristics that are acceptable (for example, single purpose fodder crop varieties are acceptable in some northern Indian production systems).
- The only way that the diversity of options can be accommodated is to pursue more decentralized and participatory breeding strategies.
- The implication of this for international research is that efforts should be made to understand more fully the physiological and genetic basis for the range of plant and animal output characteristics that farmers value. This should underpin the development of greater diversity of breeding lines. Public and private sector breeding programs seeking to fill niche demands for specific varietal types could then exploit this pool of characteristics.

Neither participatory research, nor better adapted and more appropriate varieties will by themselves lead to the improvement in the nutritive value of crop residues in farmers fields and the improvement in the efficiency of animal production systems. Greater thought needs to be given to find ways that link farmers into the parts of the innovation system responsible for setting research priorities and undertaking research, as well as parts of this systems which can deliver research products—new seeds—to farmers. This requires stronger integration of research systems and seed systems and partnerships between public and private sectors.⁶

The work reviewed in this paper has dealt solely with India and many of the patterns of crop residue use and variety characteristics are specific to that context. Nevertheless crop residues do form an important part of animal feeding systems in many developing

countries around the world and efforts to improve nutritive value offer an important route to productivity and livelihood gains. The message from this paper is that not only do crop improvement programs need to engage directly with farmer priorities but also complementary developments are required in the wider innovation systems—input supply mechanisms in the public and private sector and output market developments for animal and crop products. Embedding research in this wider canvas remains a significant challenge for many of the countries where the worlds poorest live.

7. Farmer perceptions: conclusions

Crop residues from dual-purpose crops, particularly from coarse cereal and leguminous crops, are by far the most important feed source available to farmers in semi-arid, tropical India. On average about 50–60% of total feed is obtained from crop residues. A shift in breeding strategy towards the development of dual-purpose plant types could increase the adoption of improved varieties. Such an approach offers opportunities to improve the nutritive value of crop residues and could potentially lead to improvements in the productivity of animal production systems. The exploration of farmers' perceptions of fodder quality characteristics reveals both the large scope of farmer knowledge on these issues, as well as its complexity and contextual nature. For the genetic enhancement of crop residues to be a successful route to improve animal production, ways of dealing with this complexity and diversity need to be devised in the research and technology delivery systems in India.

References

- Birthal, P.S., Parthasarathy Rao, P., 2002. Economic contributions of the livestock sub-sector in India. In: Birthal, P.S., Parthasarathy Rao, P. (Eds.), *Technology Options for Sustainable Livestock Production in India*, Proceedings of ICAR-ICRISAT Collaborative Workshop on Documentation, Adoption, and Impacts of Livestock Technologies in Mixed Crop–Livestock Farming Systems in India, ICRISAT, Patancheru, India, pp. 12–19.
- Deshingkar, P., 2002. Goats, poor women's rights, conservation and policy. Draft. ODI Livelihood Options study, Andhra Pradesh, Hyderabad, India.

⁶ For further discussion of this perspective see Hall et al. (2001).

- Devendra, C., Thomas, D., Jabbar, M., Zerbini, E., 2000. Improvement of Livestock Production in Crop–Animal Systems in Agro-Ecological Zones of South Asia. ILRI, Nairobi, Kenya, 108 pp.
- Hall, A.J., 1999. Sorghum utilization and the Indian poor: a review of findings and recommendations. In: Hall, A.J., Yoganand, B. (Eds.), Summary Proceedings of a Workshop on Sorghum Utilization and the Livelihoods of the Poor in India, ICRISAT, Patancheru, India, February 4–5, 1999, pp. 5–41.
- Hall, A.J., Sivamohan, M.V.K., Clark, N., Taylor, S., Bockett, G., 2001. Why research partnerships really matter: innovation theory, institutional arrangements and implications for the developing new technology for the poor. *World Dev.* 29, 783–797.
- Jodha, N.S., 1992. Common property resources—a missing dimension of development strategies. Discussion Paper 169. The World Bank, Washington, DC, 87 pp.
- Kelley, T.G., Parthasarathy Rao, P., 1994a. Trends in cultivated green fodder crops in India. In: Joshi, A.L., Doyle, P.T., Oosting, S.J. (Eds.), Proceedings of a National Seminar on Variation in the Quantity and Quality of Fibrous Crop Residues, BAIF Development Research Foundation, Pune, India, pp. 98–100.
- Kelley, T.G., Parthasarathy Rao, P., 1994b. Yield and quality characteristics of improved and traditional sorghum cultivars: farmers' perceptions and preferences. In: Joshi, A.L., Doyle, P.T., Oosting, S.J. (Eds.), Proceedings of a National Seminar on Variation in the Quantity and Quality of Fibrous Crop Residues, BAIF Development Research Foundation, Pune, India, pp. 133–145.
- Kelley, T.G., Parthasarathy Rao, P., 1996. Availability and requirement of different sources of livestock feed in India with special reference to sorghum and millet straw. In: Global Agenda for Livestock Research Proceedings of the Consultation for the South Asia Region, ICRISAT Asia Center, Patancheru, June 8–6, 1995. ILRI, Kenya, pp. 53–65.
- Kelley, T.G., Parthasarathy Rao, P., E. Weltzein, R., Purohit, M.L., 1996. Adoption of improved cultivars of pearl millet in an arid environment: straw yield and quality considerations in western Rajasthan. *Exp. Agric.* 32, 161–171.
- Kristjansson, P.M., Zerbini, E., 1999. Genetic enhancement of sorghum and millet residues fed to ruminants: an ex ante assessment of returns to research. ILRI Impact Assessment Series 3. International Livestock Research Institute, Kenya, 44 pp.
- Marsland, N., Parthasarathy Rao, P., 1999. Marketing of rabi and kharif sorghum in Andhra Pradesh, Karnataka, and Maharashtra. Working Paper Series No. 1, 38 pp.
- McDowell, R.E., 1988. Importance of crop-residues for feeding livestock in small holder farming systems. In: Reed, J.D., Capper, B.S., Neate, P.J. (Eds.), Proceedings of a Workshop on Plant Breeding and Nutritive Value of Crop-residues, ILCA, Addis Ababa, Ethiopia, December 7–10, 1987. ILCA, Addis Ababa, pp. 3–27.
- Parthasarathy Rao, P., Bhowmick, T., 2001. Database development, typology construction, and spatial temporal analysis of crop-livestock systems in India. Progress Report 1. Submitted to System Wide Livestock Program (SLP), ILRI, Ethiopia. International Crops Research Institute for Semi-Arid Tropics, Patancheru, India, 56 pp.
- Rama Devi, K., Bandhyopadhyay, R., Hall, A.J., Indira, S., Pande, S., Jaiswal, P., 2000. Farmers' perceptions of the effects of plant diseases on the yield and nutritive value of crop residues used for peri-urban dairy production on the Deccan Plateau. Information Bulletin No. 60. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, India, 35 pp.
- Thole, N.S., Joshi, A.L., Rangnekar, D.V., 1988. Feed Availability and Nutritional Status of Dairy Animals in Western Maharashtra. Fibrous Crop Residues as Animal Feed. Indian Council of Agricultural Research, New Delhi, India, pp. 207–212.
- Thomas, D., Zerbini, E., Parthasarathy Rao, P., Vaidhyathan, A., 2002. Increasing animal productivity on small mixed farms in south Asia: a systems perspective. *Agric. Syst.* 71, 41–57.
- Tripp, R., 2001. Seed Provision and Agricultural Development: The Institutions of Rural Change. James Currey Ltd., Oxford, 174 pp.
- Underwood, M.P., Hall, A.J., Zerbini, E., 2000. Genetic enhancement of sorghum and millet residues fed to ruminants: farmer perception of fodder quality in livelihood systems. Summary Report of PRA Case Studies in Andhra Pradesh, Gujarat, Maharashtra, Karnataka and Rajasthan States. ILRI, Nairobi, Kenya and ICRISAT, Patancheru, India, 68 pp.