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Field Crops Research 84 (2003) 57–77

Field Crops Research

www.elsevier.com/locate/fcr

# Crop management factors influencing yield and quality of crop residues

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Received 1 July 2002; accepted 30 March 2003

**Abstract**

In the semi-arid tropics, over two-third's of the world's people depend on agriculture within which livestock play a major role in building rural livelihoods. Crop residues (fodder/stover) are important feed resources for ruminants. This review was undertaken with the objective of improving understanding of the role of various crop management factors in affecting the productivity and quality of crop residues. Variability in productivity and quality of residues can be of both genetic and non-genetic origin. Recommended agronomic practices vary according to crop and cultivar and can release the maximum genetic potential determining quantity and quality of residues. Planting method and planting rate recommendations should be followed to maximise productivity. Although low density planting improved fodder quality, fodder yield declined. Time of sowing affected fodder yield in most of the crops, but fodder quality was not generally affected. It was common to observe that application of nitrogen (up to 120 kg ha$^{-1}$) in cereals and application of phosphorus (up to 60 kg ha$^{-1}$) in legumes improved the green and dry fodder yields, as well as crude protein (CP), crude fibre (CF) and other quality parameters. Inoculation of cereal seed with nitrogen fixing bacteria such as *Azotobacter* and seed of pulses with phosphate solubilising bacteria has been reported to decrease fertiliser needs and improve the CP and in vitro dry matter digestibility (IVDMD) of fodder. Irrigating at more frequent intervals by splitting the same quantity of irrigation water into smaller irrigations and at critical stages improved dry matter and CP yields. Hand weeding resulted in better weed control efficiency and stover yield than application of herbicides. However, application of herbicides resulted in the greatest benefit:cost ratio. Manual harvesting resulted in lower losses than mechanical harvesting, and may affect quality depending on the extent of loss of different fodder components. Drought stress yielded more digestible organic matter due to increases in the proportion of leaves compared to stems. Saline conditions affected seed germination and crop yields. Several methods are suggested to counteract the effects of salinity. Intercropping of cereals with legumes improved fodder nutritional quality (mostly protein content). In almost all crops, a positive association was found between fodder and grain yield indicating simultaneous improvement in both characters. In most cases, fodder yield and digestibility were positively correlated and showed positive association with plant height, leaf number and the number of tillers per plant, but there were limits and variation among crops.

The ICRISAT–ILRI partnership experiments were conducted with a diverse set of sorghum and pearl millet cultivars at ICRISAT, India. Planting density levels in both crops did not influence forage quality although some fodder yield traits were affected. A significant interaction of genotype with planting density was observed for grain and fodder yield in sorghum

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doi:10.1016/S0378-4290(03)00141-2

and grain yield and harvest index in pearl millet. Adherence to recommended crop management practices can potentially facilitate the release of the maximum genetic potential determining quality and yield parameters for improved animal production.


*Keywords:* Sorghum; Pearl millet; Neutral detergent fibre; Crude fibre; Lignin; Nutritive value; Crop residue; In vitro digestibility; Crude protein; Dry matter yield; Legumes; Fertiliser; Fodder; Stover

## 1. Introduction

Over two-thirds of world's 1.3 billion impoverished people live in rural areas and rely on agriculture for a significant part of their livelihoods. Livestock are important assets of this group and play a critical role in both sustainability and intensification of agricultural productivity in most farming systems. Increasing human population and changes in dietary habits associated with urbanisation and higher incomes are causing increased demands for food of animal origin.

Delgado et al. (1999) estimated that between 1993 and 2020, the demand for livestock products will double and meat and milk production in developing countries will grow at annual rates of 2.7 and 3.2%, respectively. The inability of producers to feed animals adequately throughout the year remains the major technical constraint in meeting future demands for meat and milk. Improving the feed supply, both in yield and quality, is an effective means to build assets and increase livestock productivity. The purpose of this paper is to assess briefly the role of crop residues among feed resources and to summarise the crop management factors that affect the yield and quality of crop residues.

## 2. Crop residues

### 2.1. Importance of crop residues among feed resources

Pastures (herbaceous plants, fodder trees/shrubs), crop residues, cultivated forages, concentrate feeds (agro-industrial by-products, grains, feed supplements, etc.) and household wastes are the main resources used as livestock feed. Availability of grazing land is decreasing due to expansion of cropping to meet the demands for food, urbanisation and land use for other activities such as industries.

The adoption of introduced forages in tropical developing countries has been limited due to lack of evidence of economic profitability or inadequate technical support, such as seed availability. Small farmers in rural areas will increasingly depend on crop residues to feed livestock among other feed resources for some time to come (t Mannetje, 1997).

Availability and use of crop residues as feed is increasing. Over one billion metric tonnes of residues are produced worldwide (Kossila, 1984) and provide much of the feed resources for ruminants in developing countries (Owen and Jayasurirya, 1989). The feed value of crop residues has been largely ignored and this has resulted in development of crop varieties and hybrids that produce less residues than unimproved varieties (Williams et al., 1997). However, crop residues are still the most important feed for ruminants in small-holder crop–livestock production systems of Asia and Africa. Although in the recent years, the use of cereal grains as feed has increased—Delgado et al. (1999) estimated that between 1982 and 1994, the global use of cereal grain as livestock feed increased at the rate of 0.7% annually. In spite of increased use of grain as feed, developing countries still use less than half the cereal grain proportions for feed compared to those used by developed countries and this is likely to continue. Crop residues still contribute substantially to the supply of nutrients for animals in mixed farms in the tropical and sub-tropical developing countries.

In the early days of cereal crop improvement, emphasis was placed on grain yield, and many dwarf, high-yielding varieties were released. However, in recent years, recognising the need for crop residues as feed for livestock, the emphasis has shifted to dual-purpose cultivars. In most crops, intermediate optima were observed for many traits including grain and fodder yield and quality. In sorghum, for example, grain and fodder (crop residue) yields increased positively up to 1.8 m plant height with 68–70 days to flowering but the relationship reversed beyond 2.0 m plant height (Rao and Rana, 1982).

### 2.2. Crops used as residues

The crops whose residues are commonly used as livestock feed and the area under each are given in Table 1 (also see FAO, 1999). Wheat (*Triticum aestivum* L.) occupies the highest acreage in the world followed by rice (*Oryza sativa* L.), maize (*Zea mays* L.), barley (*Hordeum vulgare* L.), sorghum (*Sorghum bicolor* (L.) Moench) and millets (includes pearl millet (*Pennisetum glaucum* L.) and several minor millets). Maize is prominently grown in Africa, while rice predominates in India. Worldwide, nearly 70.64 million hectares are covered by pulses with 24.75 million hectares under groundnut (*Arachis hypogaea* L.) (FAO, 1999).

The potential productivity of various crops for grain and fodder yield and estimated potential dry matter production are presented in Table 2. Maize contributed most to estimated potential dry fodder production globally followed by rice, wheat, sorghum, barley, millets and pulses. In Africa, estimated sorghum and maize dry fodder production are highest and almost equal while millets follow with half the contribution. Wheat, barley, groundnut and pulses made similar contributions of around 30 Mt with rice producing double this quantity. In India, crop dry matter production was mostly contributed by rice, sorghum, ranked second with only one-third of rice's total followed by wheat, millets, maize and pulses (Table 2).

Table 1
Area (in million hectares) grown under crops whose residues are used as livestock feed[a]

| Crop | World | Africa | India |
|---|---|---|---|
| Wheat | 215.27 | 8.42 | 27.40 |
| Rice | 155.13 | 7.84 | 44.80 |
| Maize | 139.21 | 26.08 | 6.30 |
| Barley | 56.41 | 4.36 | 0.78 |
| Sorghum | 43.66 | 22.74 | 10.40 |
| Millets | 36.16 | 19.90 | 11.93 |
| Oats | 13.91 | 0.18 | – |
| Groundnut | 24.75 | 9.37 | 8.00 |
| Pulses | 70.64 | 15.97 | 25.39 |

[a] Source: FAO (1999).

Table 2
Potential productivity ($t\ ha^{-1}$) of grain and dry matter yields and the estimated total dry matter production[a] (in million tonnes) of various crops whose residues are used as livestock feed

| Crop | Grain yield ($t\ ha^{-1}$) | Dry fodder yield ($t\ ha^{-1}$) | Estimated dry fodder production | | |
|---|---|---|---|---|---|
| | | | World | Africa | India |
| Wheat | 2.7–4.2 | 3.2–5.6 | 947.20 | 37.07 | 120.55 |
| Rice | 2.5–7.5 | 6.2–11.8 | 1396.15 | 70.58 | 403.20 |
| Maize | 4.8–10.1 | 10–16.1 | 1816.74 | 340.40 | 82.22 |
| Barley | 1.2–2.9 | 5.2–12.7 | 504.87 | 39.00 | 6.98 |
| Sorghum | 1.7–4.8 | 11–16.9 | 609.10 | 317.26 | 145.08 |
| Millets | 0.5–2.8 | 1.5–11.6 | 271.22 | 149.25 | 89.46 |
| Oats | 1.2–2.1 | 5.7–10.3 | 22.96 | 0.29 | – |
| Groundnut | 1.2–2.2 | 2.8–5.5 | 84.14 | 31.84 | 27.20 |
| Pulses | 0.53–1.5 | 0.9–4.9 | 176.60 | 39.93 | 63.49 |

[a] Grain and dry fodder yields are pooled from various references (quoting is beyond scope of the paper). Mean dry fodder yield $ha^{-1} \times$ area cultivated (from Table 1): estimated/potential dry fodder production.

Crop residue yields varied for each crop depending on genotype and environmental factors (Table 2). The data on the potential dry matter production of crops indicates that sorghum and maize possess maximum potential followed by barley, millets, rice, oats, wheat and pulses. But the use of crop residues as fodder depends not only on productivity but also on quality. Sorghum, for example, continues to synthesise new vegetative material even after physiological maturity thus potentially accumulating nutrient in stubble. Also, sorghum stubble does not decrease in quality as rapidly as maize after physiological maturity (Bolsen et al., 1977). Furthermore, sorghum productivity is higher in drier areas with rainfall less than 650 mm, while pearl millet is important in drier areas with less than 450 mm rainfall. Other cereal stovers are not available for maintenance rations for cattle under such climatic conditions. Legumes, which are rich in protein, are utilised not only for fodder but also for erosion control and green manure in rotation with other crops.

## 3. Role and influence of crop management factors on the yield and quality of crop residues

The yield and quality characteristics of residues are determined by the genetic makeup of the crop, growing conditions and harvesting, threshing and storage methods. For improvement in residue quality, efforts will have to be made to increase the soluble nutrient content (cell content) and the digestibility of the cell wall fraction. Studies during crop development indicate different rates of change in chemical composition and digestibility due to conditions of growth, which ultimately affect fodder nutritive value. Effects of these factors tend to be larger than the genetic effects on quality and quantity of crop residues. Thus it is very important to both identify and understand the optimum crop management factors that can contribute to the improvement of yield and quality of crop residues.

Various crop management interventions can be employed for improving the yield and quality of different crop residues for use as fodder. These include: crop husbandry factors (e.g. seeding rate, spacing/plant density, time of sowing, fertiliser application, other cultural practices); stress factors (abiotic: drought, salinity, temperature, day length; and biotic: diseases and pests); external chemical application; intercropping; and genotypic factors within each crop. The next sections review available literature on these factors.

### 3.1. Crop husbandry factors

#### 3.1.1. Planting method

Drilling sorghum at 40 kg $ha^{-1}$ gave higher dry matter yields compared to hand sowing and broadcasting (Kim et al., 1989). Planting in single rows gave the highest green fodder yields followed by double-row and triple-row strips (Nazir et al., 1997). Tillage system did not influence the organic matter and NDF content. In vitro organic matter digestibility (IVOMD) of maize was not influenced by tillage (Pudelko et al., 1995).

#### 3.1.2. Seeding rate and population density/spacing

In sorghum stover, CF and non-structural carbohydrate content were higher at higher seeding rate (Mohamed and Hamd, 1988), whereas height increased with increasing seeding rate for the first cut but decreased with increasing seeding rate for second cut. An optimum seeding rate of 30–40 kg $ha^{-1}$ is suggested for forage sorghum (Kim et al., 1989). Straw yield of wheat increased significantly up to a seeding rate of 125–150 kg $ha^{-1}$, however seeding rate had no effect on protein content and nutrient uptake by the crop (Pandey et al., 1999). In pearl millet seeding rate increase had little effect on total dry matter in experiments conducted at ICRISAT.

A decrease in plant density in sorghum i.e. increase of within row spacing from 5 to 60 cm decreased dry matter yield, total NDF and lignin concentrations moderately, while forage digestibility and protein content improved (Caravetta et al., 1990). Significant reduction in dry matter yields occurred as row spacing increased from 15 to 90 cm. Corleto et al. (1990) suggested an optimum plant density of 40–50 plants $m^{-2}$ in rows 25 cm apart for silage of highest quantity and quality. However, mixtures of sorghum and soybean (*Glycine max* L.) were most advantageous for obtaining greater dry matter yields under high planting densities according to Kawamoto et al. (1987).

ICRISAT–ILRI sorghum experiments were conducted at Patancheru, India with a diverse set of dual-purpose sorghums drawn from the germplasm collection and varieties released in India and elsewhere. Thirty-four dual-purpose sorghum cultivars were evaluated at two plant densities (80,000 and 160,000 plants $ha^{-1}$) and two fertility levels (80 kg N $ha^{-1}$ and 40 kg $P_2O_5$ $ha^{-1}$ (high) and 20 kg $P_2O_5$ $ha^{-1}$ and 40 kg N $ha^{-1}$ (low) in three replications (Experiment 1). Another experiment (Experiment 2) involving 20 landraces drawn from the core collection was conducted at two plant densities at high fertility. The effect of plant density (Table 3) showed that significant differences occurred for fodder weight in both the experiments and for sugar% in Experiment 1 only, while the differences for nutritive traits, in vitro digestibility (gas 24 h in millilitre) and NDF (%) were not significant.

The ILRI–ICRISAT partnership experiment at Patancheru, India also included 30 cultivars representing the full range of variability in the Indian pearl millet gene pool (traditional landrace cultivars from arid areas, improved dual-purpose open-pollinated varieties and grain type $F_1$ hybrids). The results are presented in Table 4 for two population levels (10 vs. 5 plants $m^{-2}$). The effects due to population densities were significant for harvest index and productive tiller number.

The treatment combination of 50 hills $m^{-2}$ (hill refers to a planting point) with a single seedling per

Table 3
Performance of sorghum dual-purpose cultivars at different plant density levels[a] across fertility levels[a] and genotypes in experiments conducted in the 1999 rainy season at ICRISAT, Patancheru, India

| Experiment | Density | Leaf number (PER plant) | Sugar (%) | Grain weight (t $ha^{-1}$) | Fodder weight (t $ha^{-1}$) | Gas 24 $h^2$ (ml)[b] | NDF (%)[c] |
|---|---|---|---|---|---|---|---|
| 1999 K Ex 1 | Low | 14 | 12.12 | 3.4 | 8.4 | 17.14 | 68.28 |
| | High | 13 | 12.92 | 3.6 | 10.7 | 18.10 | 68.55 |
| ±S.E. | | 0.22 | 0.13* | 0.13 | 0.20** | 0.19 | 0.39 |
| 1999 K Ex 2 | Low | 15 | 11.62 | 2.3 | 11.5 | 12.62 | 75.16 |
| | High | 13 | 11.9 | 3.1 | 16.7 | 12.61 | 75.52 |
| ±S.E. | | 0.39 | 0.35 | 0.21 | 0.08* | 0.05 | 0.33 |

[a] Fertility: high = $80N:40P_2O_5:0K$, low = $40N:20P_2O_5:0K$; and density: low = 80,000 and high = 160,000 plants $ha^{-1}$ in 1999 K Ex 1, and only density levels and high fertility in 1999 K Ex 2.
[b] Positively related to in vitro organic matter digestibility (IVOMD).
[c] Stem only.
* $P < 0.05$.
** $P < 0.01$.

hill is an economically feasible agronomic practice for rice (Rajarathinam and Balasubramaniyan, 1999). A closer spacing of 10 cm × 10 cm or 100 hills $m^{-2}$ proved to be a better spacing than 20 cm × 10 cm or 50 hills $m^{-2}$ (Siddiqui et al., 1999). However, from economical viewpoint, 50 hills $m^{-2}$ can be considered. Higher plant density (20 cm × 10 cm) was superior in wheat compared to plant densities obtained with 20 cm × 15 cm and 20 cm × 20 cm spacing (Patel, 1999). A plant density of 133,000 plants $ha^{-1}$ gave maximum net returns in pigeonpea (*Cajanus cajan*) (Nedunzhiyan and Sambasiva Reddy, 1993). In soybean, maximum dry matter yield was obtained with a plant density of 333,000 plants $ha^{-1}$ which was on par with a density of 444,000 plants $ha^{-1}$ (Halvankar et al., 1999). However, Veeramani et al. (2000) observed a density of 444,000 plants $ha^{-1}$ produced higher dry matter than 333,000 plants $ha^{-1}$ plant density. A spacing of 25 cm × 12 cm recorded higher haulm yields in groundnut than a spacing of 50 cm × 6 cm (Patra et al., 1999). From the above reports, it appears that fodder quality is not affected much by planting density compared to fodder yields. Therefore, depending on the crop, appropriate spacing which maximises fodder yields as depicted above should be chosen.

#### 3.1.3. Time of sowing

Managing planting date influences crop growth and development as well as the interaction between growth and development and stressful periods. Congenial factors such as favourable night temperature of 22.5 °C and mean daily sunshine of 8.5 h that contribute to higher fodder yield normally prevail when sorghum is sown during February and March and the first half of July (rainy season) in Tamil Nadu, India (Gururanjan, 1993). However, 10 May was suggested as the optimum sowing date of sorghum in most of the studies (Park et al., 1988 in Korea; Lee et al., 1992 in Korea; El-Hattab and Harb, 1991 in Jordan; Harb and

Table 4
Performance of pearl millet dual-purpose cultivars at different plant density levels[a] averaged across two fertility levels[a] and genotypes at Patancheru, during 2000 and 2001 rainy seasons

| Density | Biomass (g $m^{-2}$) | Harvest index | Grain weight (g $m^{-2}$) | Fodder weight (g $m^{-2}$) | Number of tillers ($m^{-2}$) | Leaf stem ratio |
|---|---|---|---|---|---|---|
| High | 571 | 33.6 | 196 | 303 | 17.9 | 27.0 |
| Low | 553 | 35.6 | 206 | 280 | 16.3 | 26.7 |
| *P* | NS | <0.001 | NS | NS | <0.001 | NS |

[a] Density: high = 10 plants $m^{-2}$, and low = 5 plants $m^{-2}$.

El-Hattab, 1991 in Jordan). When sorghum is sown in the post-rainy season, a sowing time around 5 November is suggested for greater dry matter yields in New Zealand (Causley, 1990). Sowing on 10 May resulted in greater plant height (Park et al., 1988), 1400 growing degree-days required for heading, greater number of cuts, and fresh and dry matter yields in sorghum (Lee et al., 1992). However, its digestibility, plant CP and fibre were not affected by sowing date (El-Hattab and Harb, 1991). Cross sowing of sorghum with cowpea on 30 July produced the highest sorghum fodder dry matter yield of 5.1 t $ha^{-1}$ (Rana et al., 1994). Maximum straw yield of wheat in Gujarat, India was obtained with sowings in first week of December (Patel et al., 1999) and in Madhya Pradesh, India in the fourth week of November (Tiwari et al., 1999). However, higher nitrogen mitigated adverse effects of delayed sowing. The optimum sowing time for rice in different seasons has been reported as 15 March and 25 June in Uttaranchal, India (Singh and Singh, 2000). Oats sown on the 15 November recorded maximum herbage (both fresh and dry). Herbage yield declined significantly with delayed sowing (Joshi et al., 1993). Planting date did not affect haulm yields significantly in groundnut (Patra et al., 1999). In Madhya Pradesh, N, P and K uptake in grain and straw were highest in late October/mid-November sowing dates in chickpea (*Cicer arietinum*) (Dixit et al., 1993). In Italy, plant height reduced from 80 to 50 cm with delayed sowing from late November to early March (Gristina et al., 1993). Chickpea sown at the end of December or in the middle of February in a Sicilian environment suffered less from the *Ascochyta rabiei* attacks and gave greater yield (Lombardo et al., 1993).

Limited literature is available for deducing the influence of sowing time on fodder quality. The available literature suggests that it has limited influence. However, for maximising fodder yields, the appropriate sowing date which creates optimal growing conditions for the crop and also reduces the risk of pest and disease attack should be chosen.

#### 3.1.4. Fertiliser

Nitrogen assumes greater importance in improving the yield and quality of fodder. In sorghum, nitrogen (N) application increased CP, ash and HCN content but decreased CF and non-structural carbohydrate content (Mohamed and Hamd, 1988). Application of N up to 120 kg $ha^{-1}$ increased the green forage, dry matter and CP contents and decreased NDF contents (Bebawi, 1988; Patil et al., 1992). While application of N at the rate of 100–120 kg $ha^{-1}$ was suggested as optimum in sorghum by Gill et al. (1988) and El-Hattab and Harb (1991), no advantage in using split application was observed (Gill et al., 1988; Bebawi, 1988). Even a marginal application of 50 kg N $ha^{-1}$ improved in vitro digestibility (Lourenco et al., 1993). The use of *Azospirillum* inoculant, can reduce N needs by almost 15 kg N $ha^{-1}$ (Pahwa, 1986), while the application of 80 kg N plus seed inoculation with *Azotobacter* gave a similar yield to that of an application of 120 kg N $ha^{-1}$ alone (Agrawal et al., 1996). Dry matter yields increased considerably with the application of an additional 80 kg N $ha^{-1}$ after the first and second harvest (Birch and Stewart, 1989). Pereira (1990) suggested inoculation of forage sorghums with nitrogen fixing bacteria. Growing sorghum at 80 kg N $ha^{-1}$ in clayey soils is recommended by Patel et al. (1992).

Phosphorus and potassium do not have similar significant effects on fodder yield and quality as nitrogen. Protein content and yield were unaffected by $P_2O_5$ application (Patel et al., 1993). Crude fibre decreased with increasing N but was unaffected by P application (Patel et al., 1994). However, a study by Kailash et al. (1993) noted that on application of phosphorous (P), N and K content in the shoot increased up to 30 days after sowing and decreased thereafter. While in the root, N and K content decreased continuously with P application. No such changes were observed in N and P content in stem and roots on application of K which reflects on the property of this nutrient (Kailash et al., 1993). Application of NaCl (41 kg Na $ha^{-1}$) enhanced Na content of plant tops from 0.014 to 0.018%, decreased S content and widened the N:S ratio (Wheeler et al., 1984). Application of Zn and FYM increased forage digestibility (Patel and Patel, 1992).

A 40 kg N and 10 kg $P_2O_5$ $ha^{-1}$ was found to be the optimal fertiliser dose by Das et al. (2000). Application of *Azospirillum*, 12.5 t sullage and 30:20:10 kg NPK $ha^{-1}$ gave highest fresh weight (36.45 t $ha^{-1}$) and also highest CP (7.9%), P, K, Ca and Mg contents in sorghum while 6.25 t FYM, 6.25 t sullage and 60:40:20 kg NPK $ha^{-1}$ gave highest dry matter yield

Table 5
Performance of sorghum dual-purpose cultivars at different fertility levels[a] across plant density levels[a] and genotypes in experiments conducted in different seasons and years at ICRISAT, Patancheru

| Season/experiment | Fertility | Leaf number (per plant) | Sugar (%) | Grain weight (t $ha^{-1}$) | Fodder weight (t $ha^{-1}$) | Gas 24 $h^2$ (ml)[b] | NDF (%)[c] |
|---|---|---|---|---|---|---|---|
| 1998 R Ex 1 | High | 7 | 12.62 | 1.2 | 5.9 | 25.07 | 66.48 |
| | Low | 7 | 10.62 | 1.1 | 4.4 | 25.25 | 64.81 |
| ±S.E. | | 0.12 | 0.07** | 0.06 | 0.18* | 0.16 | 0.48 |
| 1999 K Ex 2 | High | 14 | 11.5 | 4.3 | 10.6 | 17.26 | 69.51 |
| | Low | 13 | 13.54 | 2.8 | 8.6 | 17.98 | 67.32 |
| ±S.E. | | 0.36 | 0.09** | 0.05** | 0.02*** | 0.42 | 0.57 |
| 2000 K Ex 3 | High | 14 | 16.79 | 1.7 | 15.7 | – | – |
| | Low | 15 | 17.06 | 1.2 | 13.5 | – | – |
| ±S.E. | | 0.29 | 0.87 | 0.04* | 0.36* | – | – |

[a] Fertility: high = $80N:40P_2O_5:0K$, low = $40N:20P_2O_5:0K$; and density: low = 80,000 and high = 1,60,000 plants $ha^{-1}$ in 1999 K Ex 1, only fertility levels and normal density (1,20,000 plants $ha^{-1}$) in 1998 R.
[b] Positively related to in vitro organic matter digestibility (IVOMD).
[c] Leaf and stem in 1998 R and stem only in 1999 K Experiment 1.
* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$.

(22.41 t $ha^{-1}$) (Vasanthi and Venkatakrishnan, 1992). Highest DM yield (8.67 t $ha^{-1}$) and protein yield (0.64 t $ha^{-1}$) was obtained with the application of 120 kg N and 20 kg $P_2O_5$. The combination of N and Zn yielding maximum forage yield was 80 kg N $ha^{-1}$ and 2.5 kg Zn $ha^{-1}$ (Patel and Patel, 1994).

Three ILRI–ICRISAT experiments to investigate the effect soil fertility on yield and quality of crop residues were conducted in post-rainy season of 1998 and rainy seasons of 1999 and 2000 at high and low fertility levels (Table 5). Sugar% and fodder yields were significantly greater at high fertility. While there were no effects of fertility on nutritive quality traits in the post-rainy season (rabi) experiment (Experiment 1), in the rainy season (kharif) studies (Experiments 2 and 3), sugar% was significantly higher under low fertility. As expected grain and fodder yields were higher at the high fertility.

In pearl millet, increased nitrogen increased stover yield and quality. Application of nitrogen at 120 kg $ha^{-1}$ increased stover yields significantly and is considered the optimum rate (Kaushik and Mahendra, 1983; Dahiya et al., 1986; Sima Vyas et al., 1992). However, Desale et al. (2000) reported maximum green forage, dry matter and CP yields with application of 225 kg N $ha^{-1}$ in four splits. Response by pearl millet to as fertiliser levels as high as 600 kg each of N and $P_2O_5$, 400 kg $K_2O$ and 40 t compost $ha^{-1}$ has been reported (Choi et al., 1989).

The results of the ILRI–ICRISAT pearl millet experiments on fertility levels (87 kg N $ha^{-1}$ N and 28 vs. 21 kg $P_2O_5$ $ha^{-1}$) are presented in Table 6. The

Table 6
Performance of pearl millet dual-purpose cultivars at different fertility levels[a] across plant density levels[a] and genotypes at Patancheru, during 2000 and 2001 rainy seasons

| Fertility | Biomass (g $m^{-2}$) | Harvest index | Grain weight (g $m^{-2}$) | Fodder weight (g $m^{-2}$) | Number of tillers ($m^{-2}$) | Leaf stem ratio |
|---|---|---|---|---|---|---|
| High | 677 | 35.6 | 245 | 348 | 20.1 | 27.4 |
| Low | 451 | 33.6 | 158 | 237 | 16.3 | 26.3 |
| *P* | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.05 |

[a] Fertility: high = $87N:28P_2O_5:0K$, low = $21N:21P_2O_5:0K$; density: high = 10 plants $m^{-2}$, and low = 5 plants $m^{-2}$.

total above ground biomass, harvest index, grain dry mass, stover dry mass, tiller number and leaf% of stover were significantly higher at higher fertility. Grain and fodder quality was improved when half of the nitrogen was applied to the soil at sowing and the remaining half was sprayed on foliage over all the treatments. Mulching slightly improved the grain and fodder quality of pearl millet (Dahiya et al., 1986). Crude protein content and IVDMD increased through seed inoculation with *Azospirillum* or *Azotobacter* and further increased through nitrogen application (Tiwana et al., 1992).

In maize, green and dry fodder yields, and CP and CF yields increased significantly with increasing levels of N up to 100 kg N $ha^{-1}$. No differences were observed beyond applications of 100 kg N $ha^{-1}$(Sood et al., 1994). However, Singh et al. (2000) observed that total N uptake increased significantly up to 150 kg N $ha^{-1}$ in sole maize and up to 100 kg N $ha^{-1}$ in intercropped systems. Ninety kilograms $P_2O_5$ $ha^{-1}$ and 30 kg $ZnSO_4$ $ha^{-1}$ resulted in optimum dry matter production.

Highest stover yield was recorded with the treatment combinations of 30 kg N $ha^{-1}$, 40 kg $P_2O_5$ $ha^{-1}$ and 30 kg $K_2O$ $ha^{-1}$ in fox tail millet by Zaman et al. (2000). In wheat, maximum grain and straw yields were obtained with 120 kg N $ha^{-1}$, 60 kg $P_2O_5$ $ha^{-1}$ and 60 kg $K_2O$ $ha^{-1}$. *Azotobacter* reduced the nitrogen requirement (30 kg N $ha^{-1}$) for wheat (Nehra et al., 2001). Wheat responded by producing double the crop residue yield over the control (no application of fertilizer) at 160 kg N $ha^{-1}$, 80 kg P $ha^{-1}$ and 60 kg K $ha^{-1}$ and was on par with the application of 120 kg N $ha^{-1}$, 60 kg P $ha^{-1}$ and 40 kg K $ha^{-1}$ (Pandey et al., 2000). Response to N depended on the time of sowing in wheat (Verma et al., 2000). The method of fertilizer application did not significantly effect the fodder yields in wheat (Tiwari et al., 1999).

In rice, straw yield increased up to applications of 120 kg N $ha^{-1}$ with an optimum rate of 98.5 kg $ha^{-1}$ (Chopra and Chopra, 2000). Increases in straw yield have been reported at 200 kg N $ha^{-1}$. An application of 60 kg N $ha^{-1}$, 30 kg P $ha^{-1}$ and 30 kg K $ha^{-1}$ and 6 t FYM $ha^{-1}$ resulted in higher N, P and K uptake by rice. However, Bhowmick and Nayak (2000) recommended 150 kg N $ha^{-1}$, 75 kg P $ha^{-1}$ and 75 kg K $ha^{-1}$ to achieve the highest benefit and cost ratio. Higher straw CP yield in oats was obtained at a level of 120 kg N $ha^{-1}$, while dry matter yield increased up to 80 kg N $ha^{-1}$. Jagdev et al. (2000) recommended N rates 95.3 and 112.6 kg $ha^{-1}$ for maximum green fodder yield as with and without *Azotobacter*, respectively.

Farm yard manure at 10 t $ha^{-1}$ and 50 kg N $ha^{-1}$, 40 kg P $ha^{-1}$ and 25 kg K $ha^{-1}$ produced maximum grain and straw yields in finger millet (*Eleusine coracana* L.) (Singh, 1999). Application of N in the form of FYM improved dry matter digestibility. Nitrogen application did not affect digestibility, organic matter or NDF content of finger millet straws. In pigeonpea, 30 kg $P_2O_5$ $ha^{-1}$ increased grain and stalk yield, and harvest index (Singh et al., 1983a). Seed inoculation with phosphate solubulising bacteria and application of 30 kg $P_2O_5$ $ha^{-1}$ gave similar dry matter yields in chickpea as an application of 60 kg $P_2O_5$ $ha^{-1}$ (Shinde and Saraf, 1994). Increases in haulm yields in groundnut were recorded from an application of 30 kg N $ha^{-1}$, 60 kg P $ha^{-1}$ and 30 kg K $ha^{-1}$ (Kumar et al., 2000). Fertilizer source, however, did not influence haulm yields. Sulphur application did not influence haulm yield (Bandopadhyay and Samui, 2000).

Application of 60 kg $P_2O_5$ $ha^{-1}$ improved forage yield and quality in cowpea (Sheoran et al., 1994). While, in greengram, biomass yield increased with application of phosphorous i.e., an application of 75 kg $P_2O_5$ $ha^{-1}$ resulted in a biomass increase of about 55.4% (Chowdhury et al., 1999). Singh et al. (2001) reported increase stover yield of soybean, at 90 kg N $ha^{-1}$ and at 30 kg S $ha^{-1}$. Kumawat et al. (2000) recommended an N rate of 60 kg $ha^{-1}$ in soybean. An increase in grain and straw yields was reported with P applications up to 80 kg $P_2O_5$ $ha^{-1}$ (Nimje and Seth, 1988).

The importance of application of nitrogen for improving the yield and quality of crop residues of cereals as well as application of phosphorus for pulses (reduced need for nitrogen as it is fixed through symbiotic association with the plant) is clear from the various reports presented above. For most cereals, N application at 120 kg $ha^{-1}$ was found to be optimum for maximising the yield and quality of crop residues, while application of 60 kg $P_2O_5$ $ha^{-1}$ showed a similar response in pulses. However, soybean needed a N dosage of 60–90 kg $ha^{-1}$ and green gram needed a higher $P_2O_5$ dosage of 75 kg $ha^{-1}$.

P and K did not have much influence on fodder quality and a dosage of half that of N was generally recommended in cereals. Similarly, in pulses, N and K dosage of half that of P maximised the yields of crop residues. Nutrient fixing micro-organisms, organic matter (farm yard manure), and sullage decreased the fertilizer requirements.

### 3.1.5. Irrigation

Water is one of the essential inputs for crop production. It affects crop performance not only directly but also indirectly by influencing nutrient availability, timing of cultural operations, and other factors. Fresh weight yields of forage sorghum ranged from 38.3 t $ha^{-1}$ with no irrigation to 88.4 t $ha^{-1}$ with 56 mm of irrigation (Naescu and Nita, 1991). Greater benefit was observed from splitting the same quantity of irrigation water into more frequent irrigations Magid et al. (1982). Nitrogen, phosphorous, and potassium contents in sorghum leaves increased significantly. Increased dry matter yields were obtained by irrigating every 7 days instead of each 15 days (Mustafa and Abdel Magid, 1982).

In pearl millet, irrigating at a water:cumulative pan evaporation (IW:CPE) ratio of 10 (equivalent to 11 irrigations) is essential for maximum stover yields (Sima Vyas et al., 1992). However, although irrigating pearl millet is not a normal production practice, irrigating twice once at tillering and then at flowering resulted in high stover yields.

In wheat, Sarkar and Paul (2000) suggested that if a single irrigation is available, it should be applied at boot stage. If a second irrigation is available, it should be applied at crown root initiation. If three irrigations are available, then the water should be applied at 50% booting, 50% flowering and 50% grain formation stages. Thakur et al. (2000) observed that wheat receiving four irrigations at crown root initiation, maximum tillering, boot and milk stages resulted in maximum grain and straw yields and net benefit of Rs. 1.31 on each rupee investment. In rice, saturation till tillering and submergence till ripening resulted in the highest grain and straw yields which was on par with the treatment continuous submergence (Patel, 2000). Application of three to four irrigations (at active tillering, flag leaf and milk stages) in barley improved the N, P and K uptake and increased dry matter production (Wahab and Singh, 1983). Irrigating at 0.6 IW:CPE ratio resulted in maximum dry matter production in soybean (Veeramani et al., 2000). The N and P uptake of stover was maximum at 0.8 IW:CPE ratio in soybean (Kumawat et al., 2000). For obtaining higher haulm yields of groundnut, two irrigations at the first phase of flowering and at pod initiation were recommended, or irrigation at the 0.8 IW:CPE ratio (Kumar et al., 2000). Two irrigations applied at branching and pod initiation stages in chickpea improved the plant growth and dry matter production and recorded more grain and straw yields, N and Zn uptake and protein yield (Reddy and Ahlawat, 1998; Naik et al., 1993).

The various studies show that maximum fodder yields and good quality fodder can be obtained with more frequent irrigations. When water is limited, it should be applied at critical stages as identified above for various crops. It is desirable to split the irrigation water available rather than to apply a large amount as a single irrigation.

### 3.1.6. Weed control

Weeds compete with the crop for all essential nutrients and cause stunted growth and reduction in grain and fodder yield. Their timely control can augment the yields. Fresh and dry weight of sorghum was increased by atrazine with maximum plant height achieved with the application of 1.0 kg a.i. atrazine $ha^{-1}$ (Singh et al., 1988). However, in another study, application of 0.25 kg a.i. atrazine $ha^{-1}$ proved effective (Tomer et al., 1983). Hand weeding at 15, 30, and 45 days after sowing gave higher control efficiency (82%) than pre-emergence and post-emergence application of atrazine. Manual weed control was effective in maximising additional stover yield, increased plant height, number of green leaves per plant, stem diameter, leaf area per plant, and leaf:stem ratio at anthesis (Rathore et al., 1985). Similarly, no difference in dry matter yields between paraquat application and rotary hoeing before ploughing was observed (Causley, 1990).

Application of atrazine at 0.5 kg a.i. $ha^{-1}$ and terbutryne at 0.5–0.75 kg a.i. $ha^{-1}$ effectively controlled the major weeds (*Echinocloa colonum* (L.) and *Trianthema monogyna* L.) and resulted in significantly higher grain and stover yields in pearl millet (Singh et al., 1983b). Propazine was the most effective pre emergence herbicide in pearl millet. Maximum weed control efficiency (69.5%) and increased maize stover yields was achieved with atrazine 1.0 kg $ha^{-1}$ applied at 30–35 days after sowing, similar to yield achieved with pre-emergence application (60.4%) in maize (Porwal, 2000).

Pendimethalin at 0.75 kg $ha^{-1}$ produced the highest green fodder and dry matter yields of maize. In wheat, though hand weeding resulted in higher yields, weed control through herbicides recorded a significant benefit cost ratio (Pandey et al., 2000). Butachlor and 2,4-D (1 kg $ha^{-1}$) in 60:40 proportion and Anilofos (0.4 kg $ha^{-1}$) were equally effective in controlling weeds and increasing both grain and straw yields of rice (Gogoi et al., 2000). Hand weeding gave greater grain and straw yields in rice compared to mechanical and chemical weeding (Sahadeva Reddy and Rami Reddy, 2000). Weed-free conditions up to 45 days after sowing was sufficient to achieve higher grain and straw yields of rice.

Pre-emergence application of alachlor at 1.25 kg $ha^{-1}$ and hand weeding 40 days later controlled weeds and increased dry matter production of soybean (Veeramani et al., 2000). Two interrow cultivations along with one hand weeding gave the minimum weed count and weed dry weight and also gave significantly higher grain and stover yields compared to other chemical and cultural treatments in finger millet (Singh and Arya, 1999).

Manual weeding effectively controls weeds. But chemical weeding proved to be the most economical method. The chemicals differed for different crops as mentioned above. Taking account of the cost and non-availability of labour, use of chemicals for weed control and mechanical weeding at critical stages is suggested as an appropriate strategy for most crops. In the case of rice and finger millet, manual and mechanical weeding were found to control weeds effectively.

### 3.2. *Stress factors*

#### 3.2.1. *Drought*

Investigation of various cropping systems has shown that in drought years, mono-cropping with drought tolerant crops such as pearl millet or forage sorghums are appropriate strategies (Ali and Rawat, 1986). Whenever water is limiting, emphasis should be given to maximum economic production per unit of applied water rather than to maximum yield. However, unless a change in quality affects price, 95% of maximum yield is the most economic level of production (Ibrahim, 1995). Sorghum exhibits drought avoidance mechanisms (Ludlow, 1989) and under drought conditions, yields more digestible organic matter per hectare than maize (Meeske and Basson, 1995).

Water-stressed sorghum plants had higher a proportion of leaves and a lower proportion of stems, were more digestible and had lower percentage of lignins (Akin et al., 1994).

In a study involving seven tropical grain legumes (Wilson and Muchow, 1983), growth was severely affected by water stress with dry matter yield and leaf area of the various species reduced between 49 and 62% of the irrigated controls, This indicated that significant improvement in dry matter yield could be obtained by timely irrigation. Water-stressed plants were similar to or had higher digestibility and nitrogen content but had less phosphorus content than irrigated plants. Delayed senescence allowed cowpea to survive and recover from mid season drought.

Occurrence of drought during crop growth stages improved fodder quality but reduced fodder yield. Cultivation of drought tolerant crops (sorghum and millets) with emphasis on economical yield per unit of applied water is proposed as the best possible alternative.

#### 3.2.2. *Salinity*

Green forage yield data indicated that barley was most tolerant to soil salinity followed by oats, sorghum, pearl millet, Egyptian clover and maize (Yadav and Kumar, 1997). In sorghum, salinity decreased seed germination and early seedling growth. Chlormequat and dry and wet seed irradiation treatments counteracted the adverse effects of salinity even at the highest level (6000 ppm). $CaCl_2$ and $ZnSO_4$ pre-treatments also increased germination rate and percentage of sorghum (Ismaeil et al., 1993). Planting on the shoulders of the ridge proved to be a superior practice to avoid salinity hazards affecting the early stages of growth (Abusawar, 1994). He reported an application of FYM alone or in combination with urea to salty soils significantly increased forage fresh and dry yield and improved forage quality.

Waste water can successfully be used to grow maize and sorghum as forage crops, provided 15–20% excess water is applied to meet leaching requirements to maintain soil salinity within acceptable limits for optimal agricultural production (Al-Jaloud et al., 1993). Sand mulching decreased salinity in the root zone of sorghum, increased root growth and dry matter accumulation. Salt stress reduced sorghum leaf weight and CP content but sand mulching alleviated these effects (Kim et al., 1988). Biological reclamation with *Leptochloa* is a good substitute for chemical reclamation with gypsum (Kumar et al., 1994). Investigation of 45 differentially maturing rice cultivars revealed that mean plant height and number of tillers of early maturing cultivars were less affected by salinity followed by late and medium cultivars (Cheong Jin et al., 1995).

Salinity reduced both the yield and quality of crop residues. In saline soils, stress tolerant crops like barley and oats should be cultivated. Otherwise, necessary measures should be followed to counteract the hazards of salinity as suggested by many studies reported above.

### 3.2.3. Pests and diseases

Several pests and diseases are known to reduce the productivity and quality of grain and crop residues in several crops. This topic is dealt with in Pande et al., this volume.

## 3.3. Intercropping

The low CP of crop residues is a serious constraint to livestock nutrition. Integration of forage legumes into cereal-based cropping systems is considered a promising option for addressing this constraint and for developing sustainable cropping systems. Soil fertility parameters such as pH, CEC, organic carbon and total nitrogen accumulation accounted for 83.3% of total variation in dry matter production in seven cropping sequences involving rice, wheat, green gram, ground nut, oat, maize, cowpea, and berseem (*Trifolium alexandrium* L.) (Prasad et al., 1991). Hence, while selecting a multiple cropping sequence for increased biomass harvest, due emphasis must be given to the crops that contribute positively towards soil fertility which might also improve grain and fodder yields and quality.

For good dry matter production, various intercrop combinations have been investigated such as sorghum with cowpea and sorghum with pigeonpea (Reddy et al., 2001), sorghum with lablab bean, sorghum with soybean (Oliveira and de Garcia, 1990) and sorghum with chickpea (Ali and Rawat, 1986). Sorghum in rotation with any legume crop produced high yields without N fertilizer. The forage CP increased in the presence of the legume (soybean in several studies) in the mixture (Oliveira and de Garcia, 1990). Sunhemp contributed to maximum CP content, but to achieve both high dry matter yield and CP content, cowpea is suggested as a the best associate for sorghum (Kumbhar et al., 1994). Crude protein contents of legume, cereal-legume, and cereal fodder crops were in the ranges of 15.2–16.4, 11.5–12.4 and 7.9–8.1%, respectively (Sharma et al., 1993). However, several have observed that sorghum in pure stands gave more green fodder yield than intercropped sorghum (Singh and Hazra, 1988; Singh et al., 1990).

Intercropping plays an important role in satisfying the nutritional needs of livestock. A cereal legume intercrop (e.g. sorghum with cowpea) tends to achieve this objective. Such an intercrop also improves soil fertility parameters.

## 3.4. Genetic factors controlling fodder yield and quality

The contribution of genetic as opposed non-genetic factors (environmental factors, crop management and post-harvest techniques) to grain and fodder yields and to straw digestibility varies between crop species and among genotypes within a crop species. It may be possible to select or breed varieties which have good grain and fodder yield coupled with better quality straw, but this has not been conclusively demonstrated. Varietal differences for crop residue quality have been reported in wheat (Doyle et al., 1987), rice (Walli et al., 1988), barley (Ramanzin et al., 1986), oats (Shand et al., 1988), finger millet (Subba Rao et al., 1993), sorghum (Badve et al., 1993) and maize (Harikar and Sharma, 1994). Certain traits such as brown midrib have been found to be associated with lowering of NDF, hemicellulose and acid detergent lignin (ADL) concentrations and increase of IVOMD in crops such as sorghum (Fritz et al., 1990) and pearl millet (Cherney et al., 1990; Akin et al., 1991; Gupta et al., 1993).

Straw quality is often expressed as digestibility. Studies with varieties of rice, wheat, barley, sorghum and millets grown under similar conditions have

Table 7
Genetic variation in quality and quantity of straws and stovers

| | Finger millet[a] | Sorghum[b] | Wheat[c] |
|---|---|---|---|
| OMD range | 53–56 | – | 30–45 |
| NDFD range | 38–46 | 50–60 | – |
| Correlation between grain yield and OMD | 0.64 | 0.02 | 0.08 |
| Correlation between straw yield and OMD | 0.08 | 0.45 | – |
| Correlation between plant height and OMD | 0.55 | 0.05 | 0.02 |

[a] Subba Rao et al. (1993).
[b] Badve et al. (1993).
[c] Doyle (1994).

indicated wide differences in in vitro digestibility by as much as 10–15% units (Table 7). In many studies, straw digestibility has not been related to grain yield and indications are that higher grain yield does not necessarily mean low straw digestibility.

A very important determinant of chemical composition and digestibility of straw in some crop species is the leaf to stem ratio. This is not only because of the generally higher nutritive value in leaves compared to stems, but leaves are also more acceptable to animals as they are easier to chew and more digestible. Occasionally in rice, leaves are of lower quality than stems (Walli et al., 1988). The differences in composition and digestibility of plant parts of some cereal crops are presented in Table 8. The coarse stemmed straws (finger millet, sorghum, pearl millet and maize stover) differ from slender straws (rice, wheat, barley and oats) in having a higher leaf:stem ratio, higher nitrogen content, cell solubles, dry matter intake and nutrient digestibilities.

### 3.4.1. Cereals

In sorghum, Jayamani and Stephen Dorairaj (1994) reported that the dry matter content was negatively associated with brix value and CP content, while it did not show any significant relationship with ash content, fat content, CF content and green fodder yield per plant. Crude protein was negatively related to CF content. A study involving 158 exotic and 12 indigenous (Indian) sorghum accessions by Singh and Lata (2000) revealed that correlations between days to flowering, days to maturity, number of leaves per plant, leaf area per plant and flag leaf area per plant were positive and significant. Plant height and leaf area per plant had positive and direct effects on stover yield while other traits contributed indirectly via leaf

Table 8
Chemical composition and in vitro organic matter digestibility of plant parts from crop residues

| | Wheat[a] | | Rice[b] | | Sorghum[c] | | Finger millet[d] | |
|---|---|---|---|---|---|---|---|---|
| | Leaf | Stem | Leaf | Stem | Leaf | Stem | Leaf | Stem |
| OM[e] (g/kg DM) | – | – | 820 | 850 | 874 | 945 | – | – |
| NDF[f] (g/kg DM[g]) | 671 | 848 | 810 | 760 | 591 | 636 | 663 | 706 |
| N (g/kg DM) | 6.5 | 2.9 | 7.4 | 4.3 | 7.1 | 4.2 | – | – |
| OMD[h](%)/IVNDFD[i] | 52[h] | 31[h] | 44h | 42[h] | 58[i] | 55[i] | 51[i] | 33[i] |

[a] Doyle (1994).
[b] Doyle et al. (1986).
[c] Badve et al. (1993).
[d] Subba Rao et al. (1993).
[e] Organic matter.
[f] Neutral detergent fibre.
[g] Dry matter.
[h] Digestible organic matter.
[i] In vitro neutral detergent fibre digestibility.

Table 9
Estimates of correlation coefficients of sorghum dual-purpose cultivars for important traits rabi season, 1998 and kharif season, 1999, Patancheru, India

| | Rabi experiment | | Kharif experiment 1 | | Kharif experiment 2 | | Kharif experiment 3 | |
|---|---|---|---|---|---|---|---|---|
| | Gas 24 h[a] | NDF (%)[a] | Gas 24 h[b] | NDF (%)[b] | Gas 24 h[b] | NDF (%)[b] | Gas 24 h[b] | NDF (%)[b] |
| Gas 24 h | – | – | – | – | – | – | – | – |
| NDF (%) | −0.89* | – | −0.89** | – | −0.76** | – | −0.84 | ** |
| Leaf number (per plant) | 0.37 | −0.22 | 0.12 | −0.10 | 0.26 | −0.19 | 0.42* | −0.58** |
| Sugar (%) | 0.77* | −0.67* | 0.64** | −0.61** | 0.37 | −0.44 | 0.32 | −0.40* |
| Grain weight ($t\,ha^{-1}$) | −0.74* | 0.77* | −0.19 | 0.16 | −0.36 | 0.22 | −0.49** | 0.28 |
| Fodder weight ($t\,ha^{-1}$) | 0.46 | −0.37 | 0.57** | −0.49** | 0.39 | −0.37 | 0.42* | −0.46** |

[a] Leaf and stem.
[b] Stem only.
* $P < 0.05$.
** $P < 0.01$.

area per plant. Apart from above traits, dry fodder yields were correlated with stem girth and weight. Selection for improved dry matter based on plant height and number of broad leaves was suggested. A significantly positive association existed between acid detergent fiber (ADF) and plant height.

In a study conducted at ICRISAT, Patancheru, India in partnership with ILRI during the 1998 post-rainy

Table 10
Performance of sorghum dual-purpose cultivars across different plant densities[a] and fertility[a] levels

| Experiment | Leaf number (per plant) | Sugar (%) | Grain weight ($t\,ha^{-1}$) | Fodder weight ($t\,ha^{-1}$) | Gas 24 h[b] (ml) | NDF (%)[b] |
|---|---|---|---|---|---|---|
| 1998 R | | | | | | |
| Mean | 7 | 11.62 | 1.1 | 5.2 | 25.16 | 65.65 |
| Range | 6–9 | 7.91–15.28 | 0.9–1.5 | 3.6–5.9 | 22.37–29.16 | 60.19–69.93 |
| ±S.E. | 0.18*** | 0.77*** | 0.06*** | 0.27*** | 0.19*** | 0.55*** |
| 1999 K Ex 1 | | | | | | |
| Mean | 13 | 12.52 | 3.5 | 9.6 | 17.62 | 68.42 |
| Range | 11–18 | 7.20–19.69 | 1.0–7.1 | 4.8–19.3 | 12.37–22.86 | 59.73–80.38 |
| ±S.E. | 0.54*** | 0.64*** | 0.23*** | 0.55*** | 0.83*** | 1.38*** |
| 1999 K Ex 2 | | | | | | |
| Mean | 14 | 11.76 | 2.7 | 14.1 | 12.61 | 75.34 |
| Range | 10–19 | 7.58–18.35 | 0.4–4.9 | 5.3–27.7 | 10.94–15.70 | 59.24–84.05 |
| ±S.E. | 0.81*** | 1.19*** | 0.30*** | 1.00*** | 0.89 | 1.81*** |
| 1999 K Ex 3 | | | | | | |
| Mean | 12.4 | 7.00 | 2.7 | 8.4 | 13.94 | 72.03 |
| Range | 10–15 | 5.2–11.0 | 0.6–5.9 | 2.6–14.2 | 8.88–20.03 | 59.72–80.17 |
| ±S.E. | 0.65*** | 1.12 | 0.71*** | 1.41*** | 0.57 | 0.80 |
| 2000 K Ex 4 | | | | | | |
| Mean | 14 | 16.93 | 1.4 | 14.6 | – | – |
| Range | 11–18 | 12.03–22.72 | 0.1–4.1 | 7.1–25.0 | – | – |
| ±S.E. | 0.58*** | 0.91*** | 0.10*** | 0.81*** | – | – |

[a] Fertility: high = 80N:40$P_2O_5$:0K, low = 40N:20$P_2O_5$:0K; and density: low = 80,000 and high = 1,60,000 plants $ha^{-1}$ in 1999 K Ex 1, for fertility levels and normal density (1,20,000 plants $ha^{-1}$) in 1998 R and 2000 K Ex 4 experiments, two density levels and high fertility in 1999 K Ex 2, and high fertility and normal density (1,20,000 plants $ha^{-1}$) in 1999 K Ex 3.
[b] Leaf and stem in 1998 R and stem only in 1999 K experiments.
*** $P < 0.001$.

and 1999 rainy seasons involving diverse sorghum lines, the grain and fodder yield and nutritional quality assessment trials revealed that tall and late genotypes had better digestibility and less NDF. Higher leaf number was associated with greater digestibility and less NDF% in stems. High sugar content or longer stay-green in stems was positively correlated with high digestibility and low stem NDF%. Leaf to stem ratio, contrary to expectation, showed a negative correlation with digestibility and a positive correlation with stem NDF% which could be explained by the fact that entries with high leaf dry weight might have less stem dry weight and high grain yield. As a result, the high-yielding entries had poor digestibility. Stem weight and fodder weight were positively correlated with digestibility and negatively with NDF%, while head weight and grain yield showed a reverse trend as expected (Table 9). Again, significant differences were observed among sorghum genotypes in ICRISAT–ILRI studies for various traits for leaf number, sugar%, grain and fodder yield and crop residue nutritive traits (digestibility and NDF%) (Table 10).

Greater fodder yield can be obtained in pearl millet from early maturing plants with more productive tillers, greater plant height, greater ear girth and grain weight. Also fodder yield possessed high positive correlation (direct effect) with grain yield. Therefore, direct selection for fodder yield should also contribute to improved grain yield (Navale et al., 1995). In ICRISAT–ILRI studies, significant differences were observed among pearl millet genotypes for total above ground biomass, harvest index, grain dryness, stover dry matter, productive tiller number, and leaf% stover (Table 11).

In the ICRISAT–ILRI studies, interactions of sorghum and pearl millet genotypes across different fertility and density levels for fodder yield and quality traits were assessed. The results of one post-rainy season experiment and four rainy season experiments (three conducted during 1999 and one during 2000) in sorghum and of 2000 and 2001 rainy season experiments in pearl millet were analysed. In sorghum grown in the post-rainy season, the interaction between genotype and fertilizer were significant for digestibility and NDF%, but not significant for leaf number per plant, sugar% content, and grain and fodder weight. This indicated that genotypes can be selected for high fodder yield and sugar% content irrespective of the response of genotypes to fertilizer. The significant interactions for digestibility and NDF indicated that there is less chance of progress through selection for greater digestibility and less NDF% among genotypes under different fertilizer levels. Significant genotype and fertilizer interactions were obtained for sugar% content and grain weight in Experiment 1 and for grain and fodder weight in Experiment 4 of the 1999 rainy season. There was no genotype $\times$ density interaction for all the traits in Experiment 1, while significant interactions were found for grain and fodder yields in Experiment 2. Sugar% content was affected by an interaction between fertilizer and plant density, while the combined interaction of genotype, fertilizer and density was non-significant (Table 12).

In pearl millet, among the traits studies, biomass, harvest index, number of tillers, leaf:stem ratio, grain and fodder weights, genotype interacted significantly with year for all the traits while for fertility, it was also significant for all traits except leaf stem ratio. Genotype interacted significantly with density for the harvest index and grain weight (Table 13).

In wheat, significant positive association was found between biomass yield and flag leaf area, glume per weight, spikes per plant and yield per plant. The

Table 11
Performance of pearl millet dual-purpose cultivars across different fertility levels[a] and plant density levels a at Patancheru, during 2000 and 2001 *kharif* seasons

| Genotype | Biomass ($g\ m^{-2}$) | Harvest index | Grain weight ($g\ m^{-2}$) | Fodder weight ($g\ m^{-2}$) | Number of tillers ($m^{-2}$) | Leaf stem ratio |
|---|---|---|---|---|---|---|
| Minimum | 391 | 26.5 | 118 | 215 | 10.7 | 24.2 |
| Maximum | 688 | 44.0 | 267 | 349 | 25.3 | 28.5 |
| *P* | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |

[a] Fertility: high = 87N:28$P_2O_5$:0K, low = 21N:21$P_2O_5$:0K; density: high = 10 plants $m^{-2}$, and low = 5 plants $m^{-2}$.

Table 12
Interactions of sorghum dual-purpose cultivars across different fertility levels[a] and plant density levels[a]

| | Leaf number (per plant) | Sugar (%) | Grain weight (t ha$^{-1}$) | Fodder weight (t ha$^{-1}$) | Gas 24 h[b] (ml) | NDF (%)[b] |
|---|---|---|---|---|---|---|
| 1998 R | | | | | | |
| Trial mean | 7.0 | 11.62 | 1.1 | 5.2 | 25.16 | 65.65 |
| S.E. ± fertility (F) | 0.12 | 0.07** | 0.06 | 0.18* | 0.16 | 0.48 |
| Geno (G) | 0.18*** | 0.77*** | 0.06*** | 0.27*** | 0.20*** | 0.55*** |
| F × G | 0.26 | 0.98 | 0.10 | 0.39 | 0.30*** | 0.84* |
| CV (%) | 6.6 | 16.3 | 12.4 | 12.9 | 1.9 | 2.0 |
| 1999 K Ex 1 | | | | | | |
| Mean | 13.4 | 12.52 | 3.5 | 9.6 | 17.61 | 68.46 |
| S.E. + fertility (F) | 0.36 | 0.09** | 0.05** | 0.02*** | 0.31 | 0.47 |
| Dense (D) | 0.22 | 0.13* | 0.13 | 0.20** | 0.14* | 0.43 |
| Geno (G) | 0.54*** | 0.64*** | 0.23*** | 0.55*** | 0.83*** | 1.39*** |
| F × D | 0.42 | 0.16* | 0.14 | 0.20 | 0.34 | 0.64 |
| F × G | 0.83 | 0.90* | 0.33*** | 0.77 | 1.19 | 1.99 |
| D × G | 0.78 | 0.91 | 0.35 | 0.80 | 1.16 | 1.98 |
| F × D × G | 1.14 | 1.28 | 0.48 | 1.11 | 1.66 | 2.80 |
| CV (%) | 13.8 | 17.8 | 22.8 | 20.0 | 13.3 | 5.70 |
| 1999 K Ex 2 | | | | | | |
| Mean | 14.0 | 11.76 | 2.7 | 14.12 | 12.61 | 75.34 |
| S.E. + dense (D) | 0.39 | 0.348 | 0.21 | 0.08* | 0.05 | 0.03 |
| Geno (G) | 0.81 | 1.187*** | 0.30*** | 1.00*** | 0.89 | 1.81*** |
| D × G | 1.18 | 1.673 | 0.46* | 1.38*** | 1.23 | 2.50 |
| CV (%) | 11.6 | 20.2 | 22 | 14.1 | 14.2 | 4.8 |
| 1999 K Ex 3 | | | | | | |
| Mean | 12.4 | 7.0 | 2.7 | 8.4 | 13.94 | 72.03 |
| S.E. ± geno (G) | 0.65*** | 1.12 | 0.71*** | 1.41*** | 0.57*** | 0.80*** |
| CV (%) | 7.4 | 22.6 | 37.6 | 23.7 | 23.26 | 6.25 |
| 2000 K Ex 4 | | | | | | |
| Mean | 14.4 | 16.9 | 1.42 | 14.61 | – | – |
| S.E. + fertility (F) | 0.29 | 0.87 | 0.04* | 0.36* | – | – |
| Geno (G) | 0.58*** | 0.91*** | 0.10*** | 0.81*** | – | – |
| F × G | 0.86 | 1.53 | 0.15*** | 1.18** | – | – |
| CV (%) | 9.9 | 13.1 | 17.7 | 13.6 | – | – |

[a] Fertility: high = 80N:40$P_2O_5$:0K, low = 40N:20$P_2O_5$:0K; and density: low = 80,000 and high = 1,60,000 plants ha$^{-1}$ in 1999 K Ex 1, only fertility levels and normal density (1,20,000 plants ha$^{-1}$) in 1998 R and 2000 K Ex 4 experiments, only density levels and high fertility in 1999 K Ex 2, and high fertility and normal density (1,20,000 plants ha$^{-1}$) in 1999 K Ex 3.
[b] Leaf and stem in 1998 R and stem only in 1999 K Experiments.
* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$.

positive correlation of total biomass with grain yield per plant, grain yield per spike and number of grains per spike indicated that selection for total biomass could have simultaneous improvement in yield per se (Mishra et al., 2001). Dry matter production per plant in rice showed a significantly positive association with number of vegetative tillers, number of productive tillers, panicle length, number of unfilled grains, grain weight and grain yield per plant while also showing a non-significant relationship with harvest index, number of filled grains and plant height (Ravindra Babu, 1996). The fodder yield in oats can be increased by selecting for greater plant height, more number of leaves per plant, greater leaf area per plant, more number of tillers per plant and more stem thickness (Dubey et al., 1995).

Table 13
Interactions of pearl millet dual-purpose cultivars across years[a], different fertility levels[a] and plant density levels[a] at Patancheru, India during 2000 and 2001 kharif seasons

| Interactions | Biomass ($g\ m^{-2}$) | Harvest index | Grain weight ($g\ m^{-2}$) | Fodder weight ($g\ m^{-2}$) | Number of tillers ($m^{-2}$) | Leaf stem ratio |
|---|---|---|---|---|---|---|
| Year | 0.016 | 0.001 | 0.001 | 0.040 | 0.001 | 0.029 |
| Year × fert | 0.055 | 0.015 | 0.026 | 0.002 | NS | 0.001 |
| Year × pop | NS | 0.07 | NS | NS | NS | 0.05 |
| Fert × pop | NS | 0.001 | NS | NS | NS | NS |
| Geno × year | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| Geno × fert | 0.001 | 0.006 | 0.001 | 0.005 | 0.008 | NS |
| Geno × pop | 0.108 | 0.002 | 0.020 | NS | 0.057 | NS |

[a] Years: 2000 and 2001 kharif seasons. Density: high = 10 plants $m^{-2}$, and low = 5 plants $m^{-2}$; and fertility: high = $87N{:}28P_2O_5{:}0K$, low = $21N{:}21P_2O_5{:}0K$.

Associations amongst the crop residue yield and quality traits, their interaction with the environment will help in guiding future research strategies. Negative association between grain yield and fodder quality in sorghum and positive association between fodder yield and grain yield in pearl millet, wheat, rice have been observed. Variability present in the crops can be utilised for selection and extensive crossing can be made to break undesirable linkages.

### 3.4.2. Pulses

In pigeonpea, dry matter at maturity exhibited positive and significant correlation with plant height, number of primary branches, number of secondary branches, number of pods per plant and seed yield per plant and negatively with harvest index (Paul et al., 1996). An improved chickpea plant type can be designed by increase in biomass through increased number of pod bearing nodes, pods per plant, branches per plant and also by increase in harvest index through shift of first pod to lower nodes, increased number of pod bearing nodes and reduced extra unpadded nodes at the tip (Bhatia et al., 1993). Jirani and Yadavendra (1988) reported positive associations between number of branches per plant, 100 seed weight, number of pods per plant and harvest index. Maintaining a fairly high total dry matter production with simultaneous enhancement of harvest index contributed to increased seed yield in mungbean (Natarajan and Palanisamy, 1988). Improvement in shoot:root ratio, plant height, number of seeds per plant and grain yield caused an improvement in dry weight of plants at maturity, while no relationship was found between dry weight of plants and length of roots, weight of nodules, $N_2$ content in plants, number of clusters per plant, number of pods and 100 grain weight in green gram (Ebenezer et al., 2000).

## 4. Summary and conclusions

This review discussed the importance of crop residues as livestock feed and the influence of crop management factors on the yield and quality of crop residues and the genetic factors governing them. Management factors such as planting method, seeding rate, population density, sowing time, fertilizer, irrigation, weed control, intercropping and abiotic stresses such as drought and salinity were discussed in detail. Sowing by drilling coupled with optimum seed rate recommendations gave higher fodder yields though crop residue quality was not affected. Time of sowing varied between regions and provided optimum growth conditions and an escape mechanism against pests and diseases. The nitrogen rate in cereals and the phosphorus rate in legumes should be given importance and were discussed in detail for various crops. Critical stages for irrigation and herbicide applications were also specifically given for each crop. Drought and salinity affected fodder yields while drought stress improved the quality of crop residues. Different methods to overcome salinity stress were discussed briefly. Some successful intercropping sequences which improved crop residue quality as a whole were presented. Genetic associations were illustrated between yield (grain and fodder) and quality traits and most crops showed simultaneous improvement of characters. Thus, this review has shown that when optimum management principles are followed there is great possibility for realising the genetic potential of the crop for residue yield and quality.

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