Chapter IV. Production technologies for enhancing sweet sorghum yields

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Adoption of good crop and soil management practices are important for maximum productivity and to make the system sustainable in the long run. This chapter describes the cultivars and good cultural practices that are to be followed to raise successful crops in farmers' fields thereby achieving higher yields.

I. Adaptation and growing conditions

Sweet sorghum is a warm-season crop that matures earlier under high temperatures and short days. It tolerates drought and high-temperature stress better than many crops and hence adapts well to sub-tropical (Rego et al. 2003) and temperate regions of the world and is highly efficient in biomass production, with a low water requirement (Girma 1989 and Mastrorilli et al. 1990) and short growing season (Roman et al. 1998). Rainfall of 500-600 mm distributed ideally across the growing period is best, unless the soil can hold much water. The crop does not prefer high rainfall as high soil moisture or continuous heavy rain after flowering may hamper its sugar content. Air temperatures suitable for its growth vary between 15 and 37°C. Sorghum being a C4 tropical grass is adapted to latitudes ranging from 40°N to 40°S of the equator.

II. Rationale for development of improved cultural practices

Sweet sorghum yields vary considerably depending on the varieties, location grown, soil, water, climate, pests and diseases, inputs and agronomic practices. Significant research has taken place during past two decades, not only limited to ethanol production (Linton et al. 2011; Massoud and Abd El-Razek 2011), but also to improve crop yield and resources utilization efficiency (Zegada-Lizarazu and Monti 2012). These point to an option of a potential cash crop that can be cultivated with marginal input resources. Sweet sorghum can transform the available water more efficiently into dry matter than most of the other C_4 crops (Dercas and Liakatas 2007) and may uptake water from as deep as 270 cm soil depth (Geng et al. 1989). The major constraints in sweet sorghum production include non-availability of a suitable cultivar which can fit well in to the available growing season window coupled with poor agronomic management practices. This chapter elaborates the concept of good agronomic practices (GAPs) which will lead to bridge the yield gap between potential yield and on-farm yield.

III. Land preparation

Sweet sorghum is particularly well suited for cultivation on marginal lands. It is a C4 crop plant with tolerance to drought, water logging, high salinity and acidic soils. For the rainy season crop, with onset of rains in May-June, the field is plowed once or twice to obtain a good tilth. Harrowing of soil should invariably follow after each plowing to reduce the clod size. After the initial plowing, the subsequent plowing and harrowing are carried out when the moisture content of the clods are reduced. Field preparation depends on the system of sorghum sowing. The carrier Tropicultor has the provision of attaching different implements to a tool bar for field operations such as plowing, cultivator and blade harrow operation by which different operations are carried out. Similarly operations like broad-bed and furrow (BBF) formation and ridge and furrow (R&F) land configurations are possible with the attachment of ridger and chain (Fig. 1).

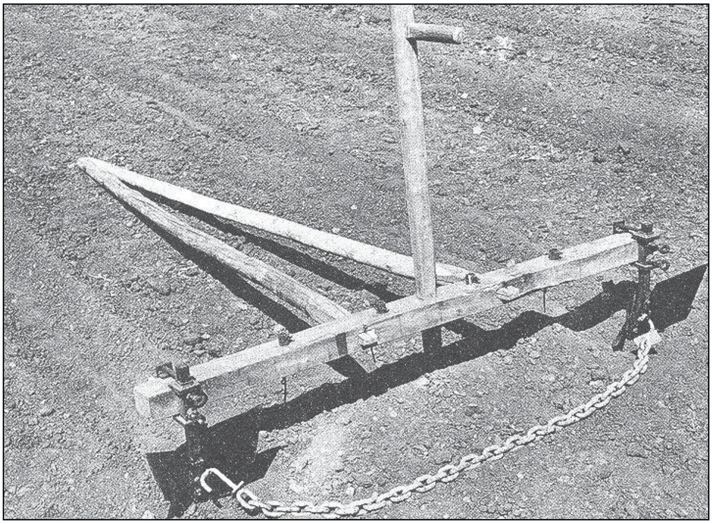

Fig.1. Chain attached to a wooden frame of a plow to level the land.

Three systems of sorghum sowing are followed: a) sowing on a flat surface, b) using ridge-and-furrow system and c) broad bed-and-furrow system.

The broad bed-and-furrow system is highly suitable for vertisols whereas flat sowing followed by the opening of furrow in every row/alternate by ridger at inter-cultivation (20 DAS) is effective for alfisol or lateritic soils under rainfed situations or conservation furrows along with contour sowing. If sowing is done on a flat surface, the land should be leveled after final plowing using bullock-drawn or tractor-drawn levelers (Fig. 1).

The R&F system (Fig. 2) is effective under irrigated conditions. Here ridges are made using either tractor or animal drawn ridge plows at 60-75 cm spacing (Fig. 3, 4 and 5).

Fig. 2. The ridge-and-furrows system.

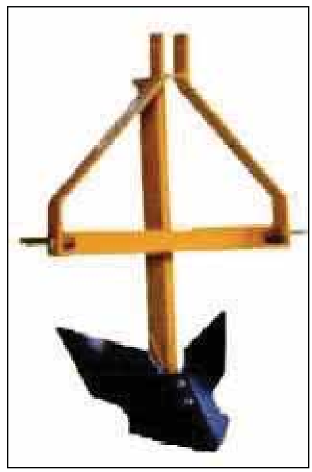

Fig. 3. Tractor-drawn ridger.

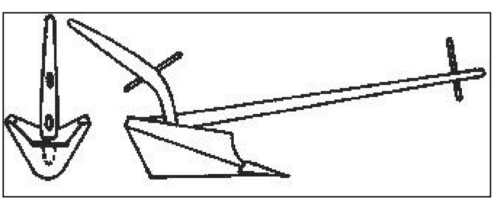

Fig. 4. Animal drawn wooden ridge plow.

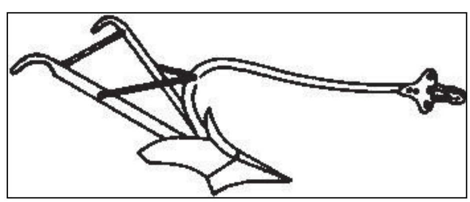

Fig. 5. Animal drawn iron ridge plow.

IV. Tropicultor – multi-tool carrier for rainfed systems

The carrier Tropicultor can be used for all field operations with bullock or tractor power. It has the provision of attaching different implements to a tool bar with simple flexible U-clamp system with a handle for lowering and raising the implements. Field operations such as plowing, cultivating and harrowing are done by changing the required implements (Fig. 6). The tool bar of the tropicultor is attached with 2 ridgers at 150 cm apart with a chain attachment to both the ridgers behind to form a bed approximately 100 cm and furrow of 50 cm continuously after one key line with required gradient (Fig. 7). Since the furrow is exclusively for the traffic zone where the bullock and wheels of tropicultor will move, all field operations like sowing, fertilizer application at required depths, row spacing with optimum population and required fertilizer rate for sorghum crop is possible. Inter cultivation is done with different size duck-foot shoes based on the crop row spacing that is attached to toolbar for inter row tilling and ridger (without wings to shape the furrow).

Fig. 6. Set of implements for the Tropicultor.

Fig. 7. Land preparation & BBF formation with the Tropicultor.

Fig. 8. A bullock-drawn Tropicultor bearing a fertilizer-cum-seed drill.

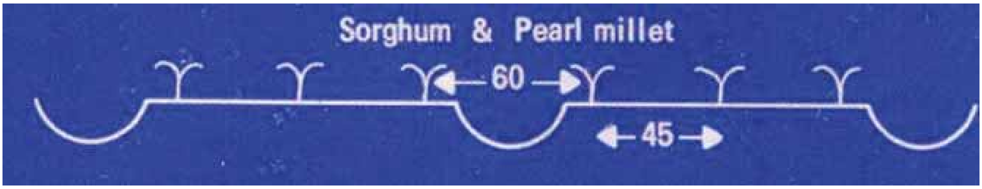

Fig. 9. An illustration of the broad bed-and-furrow method.

- The Tropicultor covers 2 ha in a day whereas it plows 1 ha for BBF formation and tilling with left and right plows. (Fig. 9 and 10).
- There is great reduction of cost for planting, fertilizer application and seed by 50%, and labor cost by 40% for weeding. (Fig. 8).
- Sorghum (2 rows) with pigeonpea (1 row) intercrop is possible with the Tropicultor.
- It is possible to place seed and fertilizer at required depth in the moisture zone for good crop establishment.
- There are lower operational costs for sowing and inter-culture operations and higher income with increased crop yields. The operations are very efficient, economical and time saving. As a bonus the operator can sit on tropicultor and carry out all field operations.

Fig. 10. (Contd. on next page).

Fig. 10. Sweet Sorghum at various growth stages raised on the broad bed-and-furrow system.

V. Planting time

Sweet sorghum can be grown during rainy season (kharif), postrainy season (rabi) and summer season depending upon the availability of soil moisture/ irrigation sources and with suitable temperature regimes (Rao et al. 2008).

1. Kharif crop (June–October): Sowing should be undertaken immediately after the onset of monsoon, preferably from first week of June to first week of July (depending on the onset of monsoon). The seeds (two to three) must be sown in a furrow opened by the bullock-drawn plow or locally available implement. In the ridges and furrow method, planting is done on the top or at the side of the ridge at 5 cm depth at a distance of 10-15 cm by planter as hand sowing is laborious, time consuming and a costly exercise. In this method, the rainwater is conserved in the furrow and avoids water logging. The farmer must make sure that soil has fully charged with rainwater or irrigation at least in the top 15 cm soil (plow layer) to ensure good and uniform germination and seedling emergence.

2. Rabi crop (October–February): Planting should be done from the last week of September to the end of October. The night temperature should be above 15°C at the time of sowing. The farmer must irrigate the crop if there is no rainfall at the time of sowing to ensure uniform germination and establishment. Ridges and furrow method of planting should be followed to conserve irrigation water just as with the rainy/kharif crop.

3. Summer crop: Planting is done from mid-January to February-end under supplemental irrigated conditions. The night temperatures should be above 15°C at the time of sowing. Summer planting on ridges and furrow will realize excellent cane yield provided irrigation water is available.

The following are the instructions to farmers in order to raise optimum crops of sweet sorghum.

A. Sowing

- Deep black soil (vertisol) or deep red loamy soil (alfisol) with a soil depth of 1 m is preferred. Seed rate is 8-10 kg ha^{-1}.

- Treat the seed with Carbendazim or Thiram @ 2 g per kg of seeds and with Azospirillum @ 600 g per 10 kg of seeds.
- Spacing: 45-60 cm_12-15 cm; (Row to row distance: 45-60 cm; plant to plant distance: 12-15 cm).
- Two to three seeds are dibbled in each hill/planting hole and the seedlings are to be eventually thinned to one per hill.
- If a planter is used, then the seed rate must be reduced to 8 kg.
- Pre-monsoon sowing or dry sowing of sweet sorghum is effective in improving rainfall use efficiency as the crop takes advantage of early monsoon without considerable effect on germination.
- Sowing starts in June for rainy season; and in October for the postrainy season. However, sowing should be avoided during cold months. For summer irrigated crops, sowing during February is feasible.
- Delayed sowing of sweet sorghum beyond 5th July attracts shoot fly.
- Crop rotation with legumes is necessary for sustainability of yields on a long term basis.
- Sweet sorghum/pigeonpea (2:1) intercropping is also viable in vertisols.
- Dry sowing cum fertilizer application with Tropicultor is advised.
- Planting on light shallow soils should be avoided.
- The ideal pH range is 5.0-8.5.

B. Thinning

The first thinning is to be done at about 12-15 days after planting (DAP) to retain two seedlings per hill at 15 cm apart. The second (and final) thinning is done at about 20-25 DAP to retain single plant per hill. The thinning operation is very essential for uniform stand establishment and the growth of plants. If this is not done, very thin stalks of uneven size are produced leading to crop lodging and low yields. Lack of crop uniformity will also pose problems in deciding when to harvest as well.

C. De-tillering

Remove the basal tillers that occur at the base of the plant manually if they occur within 20-25 DAP. Tillers are produced mainly due to planting in late rabi (Oct-Dec) coupled with low temperatures during the early vegetative stage, as well as due to shoot fly attacks.

D. Plant population

A good crop may have about 1,20,000 to 1,40,000 plants ha^{-1} (40000 to 48000 plants/acre). Maintain a minimum of about 10 plants per sq m. Cultivating sweet sorghum with greater plant population than recommended will result in thin stalks that may lodge due to heavy winds and/or rains.

VI. Nutrient management

- It is necessary to apply nutrients based on soil testing.
- Application of nitrogen @ 90 kg ha^{-1} is recommended for sweet sorghum along with 40 kg ha^{-1} P2O5. In lateritc soils, application of K2O is also necessary at 40 kg ha^{-1}.
- ICRISAT realized that there was widespread deficiency of S, Zn and B in the soils and therefore recommended per hectare application of 200 kg Gypsum, 50 kg Zinc sulfate and 1.25 kg of Agribor or 2.5 kg Borax (Boron) as a treatment once in three years to correct the deficiencies in the soil.
- Half of total N, entire P and K must be applied as basal dressing and the remaining N applied at 30 DAS.
- Micronutrients and secondary nutrient to be applied as basal dressing.

1. Importance of improved management practices

Studies conducted by ICRISAT under on-farm and on-station situations clearly revealed the importance of improved management practices including clean cultivation and balanced nutrient management. The data presented in Table 1 highlighted that grain yield and green stalk yield of sweet sorghum are higher with improved practice (90:40:40 kg NPK ha^{-1} along with 30 kg Sulphur, 10 kg Zn and 0.5 kg Boron ha^{-1}) compared with farmers practice (1 bag Urea + 1 bag di -ammonium phosphate ha^{-1}).

Table 1. Comparison of mean grain and stalk yields of sweet sorghum under improved management (IP) versus farmers' practices (FP).

Particulars/ Year	Average grain yield ($q\ ha^{-1}$)		Green stalk yield ($t\ ha^{-1}$)	
	IP	**FP**	**IP**	**FP**
On Station				
2008	11.80 (8.62-14.09)*	9.60 (7.5-12.7)	26.40 (18.84-31.89)	19.60 (15.6-22.4)
2009	24.20 (17.41-27.83)		52.70 (40.5-61.3)	
2010	22.39 (15.94-28.96)		33.58 (23.9-43.4)	
On farm				
2009	11.80 (9.2-14.7)	8.70 (4.8-11.1)	28.40 (21.1-35.8)	23.30 (17.3-27.3)
2010	11.50 (5.9-16)		37.70 (29.8-47.1)	
2011	18.50 (10.8-23.5)		48.60 (39.7-57.6)	

VII. Weed management and intercultivation

- Weed management is critical in sweet sorghum.
- Intercultivation with blade harrow or cultivator or Tropicultor (Fig. 11) once or twice between 25 and 35 days after sowing (DAS) followed by hand weeding is essential.
- The second interculture is to be followed by the earthing up of crop rows with bullock or tractor drawn implements to prevent lodging especially after flowering.
- Application of selective pre emergence herbicide Atrazine is recommended @ 0.2 kg ai ha^{-1} or Atrataf R @ 1 kg ha^{-1}.

Fig. 11. Intercultural operation with Tropicultor.

VIII. Irrigation/rainwater management

1. Kharif

Normally the crop raised under rainfed conditions in areas receiving rainfall of 550-800 mm does not require additional irrigation if the rains are adequate and well distributed during the crop growth period. In the case of late onset of monsoon, plant the crop and irrigate immediately. Also, irrigate the crop if the dry spell continues for more than two weeks especially at critical crop growth stages such as panicle initiation (35-40 DAS) and boot stages (55-65 DAS). Maintain soil moisture profile at or near field capacity. Always drain out the excess irrigation water or rainfall from the fields to avoid water logging. By and large, 2-3 irrigations may be required for a kharif crop depending on the planting time, soil type and rainfall distribution at a particular location.

2. Rabi and summer crops

Arrange first irrigation immediately after sowing if no rainfall occurs. Subsequently, irrigate the crop at 15 DAS, 30 DAS, 55 DAS and 75-80 DAS for realizing good stalk yields. Thus, a total of 4-5 irrigations are required for rabi and summer crops. Apply irrigation water of about 50 mm each time. During the initial stages of crop, up to 30 DAS sprinkler irrigation is preferable to flood since the crop needs less water compared to later stages – which helps save the precious resource.

IX. Harvesting

Harvest the crop at about 35-40 days after flowering of the plants ie, at physiological maturity of grain (Fig. 12 B) where the black spot appears on lower or hylar end of the grain.

Fig. 12. Physiologically matured seed show a black spot at the hilar end (B) and immature do not show the spot (A).

Alternately, the Brix of standing crop can be measured using a hand refractometer just as with the sugarcane crop. The methodology of pre-harvest crop quality survey and assessment as followed for sugarcane (ie, use of refractometer) is recommended for sweet sorghum also. Harvest the crop if stalk Brix reaches about 16-18% at physiological maturity of the grain. Additionally, the plants can also be sampled for small mill test (SMT) to know the juice Brix and other quality parameters as with sugarcane. Cut the plants to the ground level using sickle or knife and remove the leaves including sheaths. Remove the panicle with the last internode and thresh the grains separately followed by drying. The freshly cut canes can be made into small bundles of 10-12 kg and must be transported within 24 hours of harvesting to the mill for crushing.

X. Detrashing

Detrashing refers to removal of unwanted bottom dry and green leaves at regular intervals as with the sugarcane crop (Fig. 13). Sweet sorghum stalk bears more number of leaves (10-15) equal to the number of inter-nodes under good management systems. These leaves on sweet sorghum stalks reduce juice quality, sugar, and ethanol obtainable from the crop, and reduce the payload of the crop. It is highly desirable to develop a commercial leaf stripper that can save cost of detrashing in sweet sorghum. However, a simple, compact, reliable, and safe device using rubber fingers to remove the leaves from rows of standing stalks was developed, tested and evaluated (Monroe et al. 1983) but still a more reliable harvesting machinery need to be developed, which will also reduce the cost of harvesting.

Fig. 13. Stalk of CSH 22 SS, with leaves and without leaves (detrashed).

XI. Pest management

The important pests which cause significant damage to sweet sorghum are described below.

1. Sorghum shoot fly, *Atherigona soccata*

- Shoot fly females lay cigar shaped eggs singly on the lower surface of the leaves at the 1 to 7 leaf stage.
- The larva cuts the growing point, resulting in wilting and drying of the central leaf known as ‘dead heart’ (Fig. 14).
- The damaged plants produce side tillers, which may also be attacked (Fig. 15).
- During the rainy season, shoot fly damage is greater in crops planted 15-20 days later than the first monsoon rains or when the rainfall is erratic and farmers resort to staggered plantings.
- Shoot fly infestations are normally high in the postrainy season, when the crop planted in September-October.

2. Stem borers, *Chilo partellus* and *Sesamia inferens*

- The first indication of stem borer infestation is the appearance of small elongated windows or round holes on the young leaves (Fig. 16) due to feeding by the young larvae. These damage symptoms on the leaves appear on crop that is 15 to 25 days old.
- The third-instar larvae migrate to the base of the plant, bore into the shoot and damage the growing point resulting in the production of a dead heart in 25 to 45 days-old crop (Fig. 18). Normally, two leaves dry up as a result of stem borer damage, while only one leaf dries up due to shoot fly damage.
- Stem borer larvae also feed inside the stem and cause extensive tunneling (Fig. 16), which is not apparent unless the stems are split open.
- Heavy damage in the stems and peduncle result in peduncle breakage or partial seed set.
- Extended period of drought and poor plant growth result in greater damage by the stem borer.
- Spotted stem borer (Chilo partellus) is important in the rainy season crop, while pink stem borer (Sesamia inferens) (Fig. 17) is predominant in the postrainy season crop.

A. Integrated pest management practices

Instructions to farmers on integrated pest management practices include:

Fig. 14. Dead heart of sorghum caused by shoot fly.

Fig. 15. Tillers produced due to shoot fly in sorghum.

Fig. 16. Shot-holes caused by stem borer, in sorghum leaves.

*Fig. 17. Pink stem borer (*Sesamia inferens*) and Chilo damage in sorghum.*

- Adopt synchronous and timely/early sowings of cultivars with similar maturity over large areas to reduce the damage by shoot fly, midge and head bugs.
- Apply balanced fertilizers having adequate N and P to promote better plant growth that results in reduced damage by shoot fly and stem borers.
- Use high seed rates and delay thinning (to maintain optimum plant stand) to minimize shoot fly damage.
- Rotate sorghum with cotton, groundnut or sunflower to reduce the damage by shoot fly, midge and head bugs.
- Intercropping sorghum with pigeonpea, cowpea or lablab also reduces the damage by stem borers.
- Collecting and burning of stubbles and chaffy earheads, and feeding the stalks to cattle before the onset of monsoon rains reduces the carryover of stem borers and midge.
- Plant sorghum varieties with less susceptibility to insect are relatively less damaged by shoot fly and stem borers.
- Treat seeds with carbofuran (5% a i), thiamethoxam (9.0 ml kg^{-1} seed), or imidacloprid (0.165 mg kg^{-1} seed) to improve plant stand, seedling vigor, and reduce the damage by shoot fly and to some extent stem borer, and maize aphid.
- When the shoot fly damage reaches 5 to 10% of the plants with dead hearts (Plate 1), the crop may be sprayed with cypermethrin 10 EC (750 ml ha^{-1}) or endosulfan 35 EC (350 g ai ha^{-1}). Alternatively, carbofuran granules (5 to 7 granules/plant) may be applied in the leaf whorls (Fig. 16).
- For stem borers, dusts or granules can be applied in the whorl leaves of damaged plants or the entire field can be sprayed with endosulfan, fenvalerate or cypermethrin.
- Neem seed kernel extract (5 kg ha^{-1}) or Bacillus thuringiensis (Bt) formulations can be sprayed for the control of stem borers, armyworms and head caterpillars.
- For sorghum midge, the crop may be sprayed at the 50% flowering stage (1 midge/panicle) with endosulfan or cypermethrin. Early and uniform planting of the crop in a geographical area minimizes shoot fly, midge and head bug damage.
- For earhead bugs (1 to 2 bugs per panicle) and head caterpillars (2-3 larvae per panicle), the crop may be sprayed at the completion of flowering and at the milk stage with endosulfan or cypermethrin.

- Use of insect tolerant varieties such as ICSV 700 and ICSV 93046 minimizes losses due to shoot fly and stem borer.
- Use of intercrops such as pigeonpea and mung bean minimizes the risk of crop failure and reduces insect damage.
- Use of carbofuran or imidachloprid seed treatment (@ 10 g/kg of seed) in case of delayed sowing or application of carbofuran granules in the soil (1.0 kg ai ha^{-1}) at the time of sowing to controls shoot fly. After seedling emergence, 15-20 carbofuran granules are placed in the leaf whorls to control shoot fly, stem borer, aphids and shoot bug or imidachlopric or acephate are sprayed to control the aphids and shoot bug.
- Carbaryl (0.5-1.0 kg a I ha^{-1}) or fenvalerate (75-100 g ai ha^{-1}) or endosulfan (700 g ai ha^{-1}) are sprayed at 50% flowering to control sorghum midge (when we see > 1 midge fly per panicle) and at completion of flowering (1 bug per 2 panicles) for head bugs. At the milk stage, endosulfan or fenvalerate is sprayed if there are 5 to 10 nymphs per panicle.

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