Sorghum

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# Sorghum

## GENERAL DESCRIPTION

**Sorghum** (*Sorghum bicolor* [L.] Moench) is a crop indigenous to Africa, where it appears to have been domesticated in Ethiopia about 5 000 years ago. It is now widely cultivated in dry areas of Africa, Asia, the Americas, Europe and Australia between latitudes of up to 50 °N in North America and Russia and 40 °S in Argentine. Sweet sorghum is a variant closely related to grain sorghum; it differs mainly in that its stalks are taller and juicier with higher sugar content than the grain sorghum type. Sorghum is the fifth most important cereal in the world after wheat, rice, maize and barley. In Africa it comes second after maize in terms of production. Sorghum is well adapted to tropical climates with several traits making it a drought-tolerant crop that survives under adverse climatic conditions, and thus is often relegated to poor soils and low-input management. It is extensively grown under rainfed conditions for grain and forage production. High production may be achieved when sufficient water and nutrients are applied especially at critical stages of crop growth.

World sorghum production during 2009 was about 59 million tonne of grain from 40 million ha with an average productivity of 1.4 tonne/ha (FAO, 2011), with the United States, India, Mexico, Nigeria, Sudan, Ethiopia, Australia, and Brazil as major producing countries, in that order (FAO, 2011) (Figure 1).

Sorghum is mainly cultivated in dry areas, often on shallow to medium deep, lighter to medium textured soils, and also on medium to deep soils of high water retention capacity as a post-rainy season crop (Figure 2).

In India, rainy season (*kharif*) sorghum is sown between the second week of June and the first week of July, with rains of the southwest monsoon. However, sorghums are prone to fungal attacks leading to grain *mould* if late season rains occur during grain maturity. Post-rainy season (*rabi*) sorghum is sown generally from the last week of September to second week of October, and is generally exposed to low winter temperatures at sowing resulting in low germination and poor stand establishment. Late sown *rabi* season crops are exposed to terminal drought when grown on black soils (Vertisols) with stored soil moisture and are prone to disease such as charcoal rot. Sorghum planting season in the United States starts from the second week of May to first week of August in Kansas and South Dakota, and from the last week of March until the first week of August on the Great Plains. In the subtropical and temperate regions of Argentina,

**FIGURE 1** Typical developmental stages of sorghum (FAO 2011).

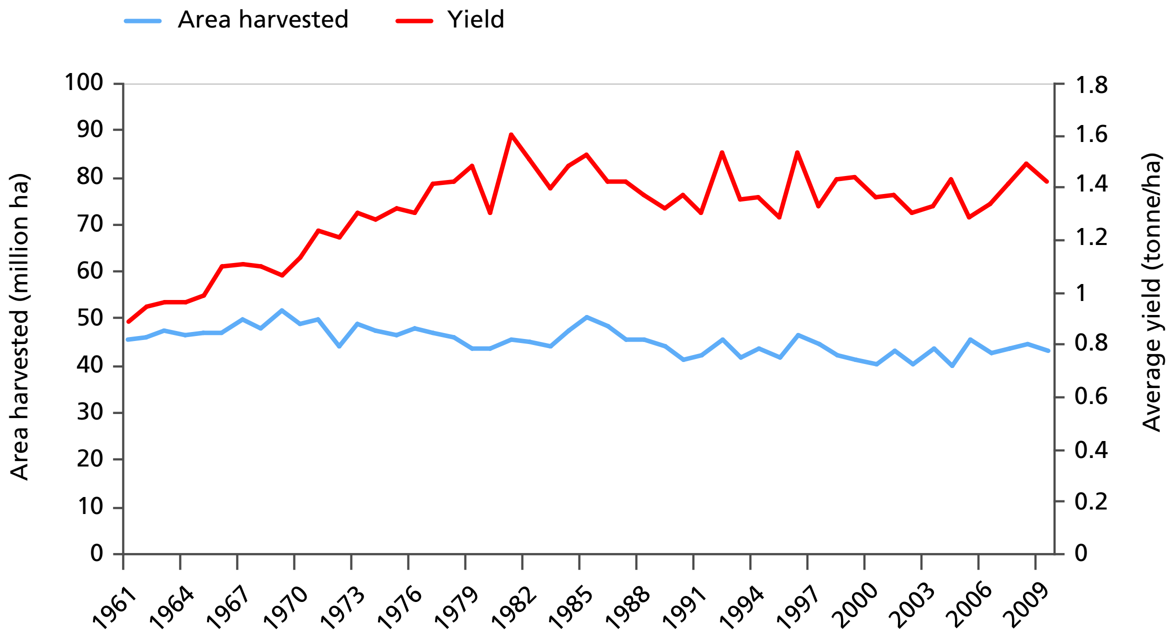
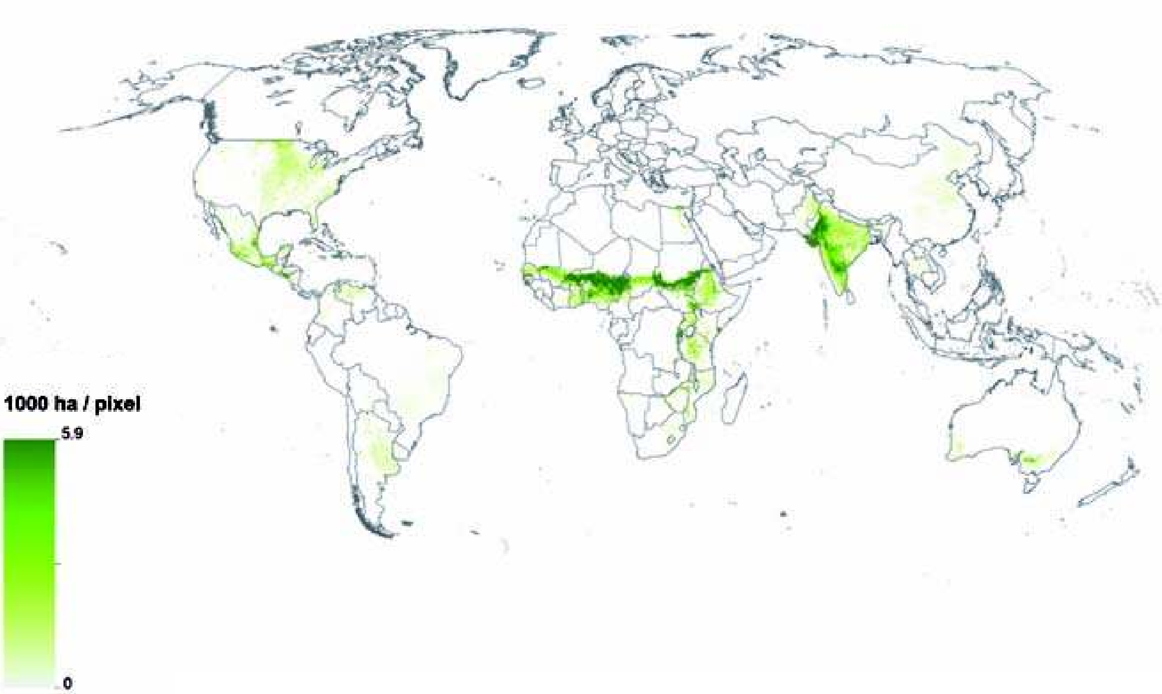



**FIGURE 2** Sorghum harvested area (GAEZ, 2011).




Reference year 2000

sowing usually starts in late September and continues to October; although late sowing may take place between the end of November to the beginning of January. In Sudan and Burkina Faso, sorghum planting starts in late May and continues up to early July, but late plantings take place from late July until early August in areas of erratic rainfall in West Africa. Sorghum is normally planted from mid-October to mid-December in Southern Africa. Season length of early maturing sorghum cultivars, which include most hybrids, is 110 days or even less, whereas long season sorghum may last as long as 5 to 7 months.

In rainfed situations, plant populations may range from 50 000 to 150 000 plant/ha, with low densities in the low rainfall areas. Under irrigation or non-limiting moisture, 120 000 to 200 000 plant/ha are generally recommended. Overly high plant populations increase plant competition, increase the chances of charcoal rot, and may increase water use. The advantage of more heads per unit land area is counterbalanced by reduced head size, leading to very little increase in grain yield. On low fertility soils with low input management in some African countries, 50 000 plant/ha have been found to be optimal. As for sweet sorghum, 110 000 to 120 000 plant/ha have been found to be optimal for the rainy season in India.

Sorghum grown mixed with assorted pulse crops for domestic consumption is a traditional practice of poor dryland farmers in India and Africa. Sorghum intercropped with pigeonpea at 2:1 row ratio is a prevalent cropping system on Vertisols in India. Paired rows of sorghum intercropped with paired rows of groundnut at a 4:2 row ratio in India, and sorghum intercropping with cowpea at 2:2 row ratios in Africa, are also popular with farmers on Alfisols with short growing seasons. Post-rainy season sorghum, after rainy season fallow, is most common on Vertisols in India and Ethiopia. In China and the United States sorghum is frequently grown with irrigation after the first season soybean, or after winter wheat as a double crop.

## GROWTH AND DEVELOPMENT

As a $C_4$ crop, sorghum does not tolerate cool temperature regimes. For seed germination, the minimum temperature is about 8 °C, and optimum temperature, 21–35 °C (*Peacock, 1982*). Under field conditions, a minimum soil temperature in the range of 15–18 °C is required for 80 percent emergence in 10-12 days. Normally in the field emergence takes 5–10 days. Panicle initiation takes place after approximately one-third of the growth cycle, after the last leaf has initiated and about one-third of total leaf area has developed. Rapid leaf development and stem elongation follow panicle initiation. Rapid growth of the panicle starts after all but the last two or three leaves emerge. By the time the flag leaf is visible, all but the final 3 to 4 leaves are fully expanded and light interception is approaching its maximum; a few lower leaves may begin to senesce if nitrogen is not plentiful or the crop is planted very densely.

The rate of leaf appearance in sorghum is closely related to thermal time. When temperature is not limiting, it takes about 2 days for each new leaf to emerge. For a cultivar with 18 leaves, in India a typical phenology and growth stages of 0 to 9 (as defined by Vanderlip and Reeves, 1972) are as follows: emergence (0); 3-leaf stage (6 days after emergence, 6 DAE/6); 5-leaf stage (16 DAE/10); panicle initiation (32 DAE/16, approximately 9 leaf stage); flag leaf appearance (50 DAE/18, tip of final leaf visible in the whorl); boot stage (head enlarges in flag leaf sheath, 60 DAE/10 ); 50 percent flowering (68 DAE/8, half of the plants complete pollination, from the tip downwards); soft dough stage (80 DAE/12 squeezing kernel between fingers results in little or no milk); hard dough stage (96 DAE/16 when seed cannot be compressed between fingers); and physiological maturity (106 DAE/10 black layer (spot) appearance on the hilum at the base of the seed).

Sorghum leaves are upright when young but blades tend to bend downwards with maturity. Sorghum leaves develop on either side of the stem, exactly opposite to one another. As for all crops, rate of dry matter production is strongly affected by radiation intercepted, which depends on leaf area, especially between emergence and panicle initiation. Number of leaves per plant varies widely, from 7 to 24 depending on cultivar and climatic conditions. Sorghum is a short-day plant and panicle initiation is hastened by short days and longer nights. Since panicle initiates only after all leaves have initiated, if panicle initiation and blooming is earlier, the plant would have fewer leaves. Panicle initiation can be strongly affected by temperature regimes in addition to photoperiod. There are rather complicated interactions between photoperiod and temperature regimes, as well as a dependence on the cultivar's maturity group (Morgan *et al.*, 1987). Generally within the temperature range favourable for growth, leaf number tends to decrease as temperature decreases in growth Stage I, especially when the decrease is in night temperature (Quinby *et al.*, 1973).

As for all crops, leaf area index (LAI) depends on plant density, leaf number per plant, and the stage of growth. Maximum light interception, hence full canopy cover, is reached at LAI of 4 to 5. The aim of grain sorghum is to achieve full canopy cover but avoid excessive LAI since excessive vegetative growth tends to reduce the harvest index. Fodder sorghums exceed LAI of 7 with populations of more than 150 000 plants/ha and high input management in the tropics. In short duration sorghum with reduced leaf number, maximum leaf area (and canopy cover) is achieved at 50 days or earlier after emergence under favourable temperatures. However, planting density must be substantially higher than that for long season cultivars to achieve full canopy cover because of fewer leaves per plant. Sorghum seeds are considerably smaller than those of maize, hence the initial leaf area (initial canopy size per seedling, $cc_o$) of sorghum seedling is smaller compared to that of maize. Sorghum develops less leaf area than maize under similar input, environment and plant density because of its smaller leaf sizes.

Sorghum head is a panicle, with spikelets in pairs. The inflorescence (panicle) is either compact or open, developed on the main stem (peduncle) with primary or secondary branches on which the florets are borne. The peduncle length varies from 75 to 500 mm in different cultivars. The floral structure is suited for self-pollination; however, approximately 6 percent cross-pollination occurs naturally with wind. Hybrid sorghum seed is produced utilizing cytoplasmic male sterility line as the female parent. Sorghum flowers begin to open and pollinate soon after the panicle has completely emerged from the boot. Pollen shedding begins at the top of the panicle and progresses downward for 6 to 9 days. Pollination happens soon after sunrise in the colder part of the day. At maturity, about 600 to 3 000 seeds have developed on the panicle, all enclosed in glumes varying in colour from black, red, brown to tan. The seed number per panicle, a key component setting yield, is determined mostly during the periods of panicle initiation and flowering.

Under seasonal average daily temperatures greater than 20 °C, early grain cultivars take 90 to 110 days and medium-duration cultivars, 110 to 140 days to mature. When mean daily temperature is below 20 °C, there is an extension of about 10 to 20 days in the growing season for each 0.5 °C decrease in temperature, depending on cultivar. At an average temperature of

15 °C, grain sorghum takes 250 to 300 days to mature. It follows that in cool climates, sorghum is grown mostly as a forage crop.

As for all cereals, the root system has two components, the seminal root system and a secondary root system that develops from nodes below and just above the soil surface. Nodal roots start appearing at the third and fourth leaf stage and branches both laterally and downwards. Roots initiated at nodes close to and above the soil (so called prop roots) develop and penetrate into the soil only when the surface soil is moist. The fully developed root system is approximately 1 m wide laterally and down to about 2 m into the soil, and can reach 3 m in very open subsoils. The maximum depth is generally approached at the time of flowering, but the roots continue to extend during the reproductive phase, at least under dryland conditions. When the soil profile is moist, most of the water is taken up from the top one-fifth of the root zone. As the soil water depletes and the upper part of the profile dries out, the uptake zone moves progressively downward. This uptake pattern repeats after each irrigation or heavy rain. Normally, when sorghum is full grown, nearly all of the water extracted is from the top 1 to 2 m of soil.

## WATER USE AND PRODUCTIVITY

Rainfall of 500–800 mm well distributed over the cropping season is normally adequate for cultivars maturing in 3–4 months. Sorghum tolerates water logging and can also be grown in areas of high rainfall. The consumptive use (ET) of 110 to 130-day sorghum crops range between 450 and 750 mm, depending on evaporative demand. Seasonal water use is higher for late maturing genotypes because of longer growing periods. For rainy season sorghum in India, consumptive water productivity for biomass ($WP_{B/ET}$) ranges from 2.3 to 6.0 kg/m$^3$, and consumptive water productivity for grain yield ($WP_{Y/ET}$) ranges from 1.0 to 1.5 kg/m$^3$, in different environments. For post-rainy season sorghum in India, $WP_{Y/ET}$ ranges from 0.23 to 2.2 kg/m$^3$, with a mean of 1.2 kg/m$^3$ from several studies across many soil types and cultivars. An analysis of many years of data in Texas, the United States, yielded a mean $WP_{Y/ET}$ of 1.5 kg/m$^3$ (Krieg and Lascano, 1990). One study at the same location varying planting density and geometry found $WP_{B/ET}$ of dryland sorghum to be in the range of 3.0 to 3.6 kg/m$^3$, but $WP_{Y/ET}$ to be more variable, in the range of 0.8 to 1.3 (Steiner, 1986). Harvest index was different for different densities, accounting for the wider range of $WP_{Y/ET}$. In Nebraska, the United States, another study found $WP_{Y/ET}$ to be 1.2, 1.8, and 1.9 kg/m$^3$ for three different cultivars (Garrity *et al.*, 1982).

## RESPONSES TO STRESSES

Sorghum is considered to be drought resistant, especially in comparison to maize. A part of the perceived resistance may be because sorghum cultivars grown in water-limited areas are the short-season type, thus their water requirement is less than that of maize, a crop generally with a longer life cycle. That said, there are real differences in drought-resistance traits. Sorghum with its tillering habit is much less determinant than maize, and therefore is more 'plastic' in reproductive development. If short water stress during the panicle initiation stage reduces the potential grain number of the main stem panicle, panicles on the tillers that are initiated later, after the stress is over, can produce more grain and make up for much of the loss. If water stress is severe enough at flowering to cause head blast (death of a portion or whole head) tillers may emerge from nodes high on the stem to form branch heads to produce grain and compensate for at least part of the loss, provided that harvest can be delayed (Hsiao *et al.*, 1976). Such compensations are not possible with modern maize cultivars having very limited tillering capacity. The flip side is that if water is ample during the vegetative period, many sorghum cultivars would tiller excessively, with a high portion of the tillers being barren, leading to high biomass produced but with a low harvest index.

Sorghum accumulates solutes and osmotically adjusts in response to developing water stress, apparently more so than maize (Fereres *et al.*, 1978). This would allow sorghum to maintain stomatal opening and carry on photosynthesis longer as the soil water depletes, and possibly also aid in delaying canopy senescence induced by water stress. In addition to stomatal closure, sorghum leaves roll noticeably under water stress, reducing the effective transpiration surface. The rolling is attributed to turgor changes in the rows of motor cells along the midrib and veins on the upper surface of the leaf. Motor cells are also present in maize leaves, but maize leaves roll only minimally under water stress. Leaf growth by expansion is highly sensitive to water stress in both sorghum and maize.

In terminal drought-prone areas such as the Mediterranean region and Australia, lodging of dryland sorghum as the crop matures is often a problem. Breeders have developed cultivars that maintain a green canopy longer at maturity, the so called 'stay-green' trait. Such cultivars apparently have better lodging resistance, presumably because less of the stalk material is remobilized and translocated to the grain at maturity. In terms of *AquaCrop* parameters, the canopy decline coefficient (CDC) would have to be adjusted to a lower value, and probably also the stress coefficient ($K_S$) for senescence, adjusted by making it less sensitive to water stress, for the stay-green cultivars.

Sorghum is moderately tolerant to salinity. As EC increased from 11 to 18 dS/m, grain yield was reduced from 50 percent to 100 percent. Much of the temperate effects on sorghum have already been discussed under Growth and Development. Leaf extension closely parallels air temperature to approximately 34 °C. Pollination and fruit setting may fail when night temperatures fall below 12-15 °C at flowering, and pollens produced below 10 °C and above 40 °C are most likely non-viable. Sorghum grain contains around 1.5 percent nitrogen and 0.25 percent phosphorus. For a high yield of 8 tonne, the grain alone removes 120 kg of N and 20 kg of P. To achieve this yield, fertilization must account also for the N and P in the stover residue and the efficiency of applied nutrients and native soil supply. For water-limited situations, fertilization rates would be adjusted downward. In areas prone to terminal drought, care must be taken to avoid too much N supply early in the season because the resultant fast early growth would exhaust water stored in the soil and accentuate the terminal drought damage.

## IRRIGATION PRACTICE

In dry areas with low and/or erratic rainfall the crop responds well to supplemental irrigation. However, considerable differences exist among cultivars in their response to irrigation. The timing of irrigation should aim to avoid water deficits during the critical growth stages of the crop, the period that starts at panicle initiation and ends at early grain filling. Water stress during panicle initiation would reduce panicle size and potential grain number; severe stress at flowering would inhibit pollination; and stress at early grain filling would cause abortion of youngest developing grains and reduce weight per grain. Grain size is also reduced if stress occurs late during grain filling and causes early canopy senescence, with the consequence of premature ending of $CO_2$ assimilation. In terms of total available water (TAW) in the root zone, about two-thirds can be depleted before irrigation without significant effect on transpiration. Up to 75 percent may be depleted during the ripening phase. When water supply is limited, irrigation around booting/flowering, after moderate stress during the vegetative phase, and increasing stress during the ripening period is a deficit irrigation strategy that minimizes yield loss. For fodder sorghum, a late light irrigation maintains stalk quality at harvest. The number of irrigations normally varies between one and four, depending on climatic conditions, and soil texture. Methods of irrigation include furrow irrigation, often in alternate rows, and other surface methods (border, basin or corrugation).

## YIELD

Average yield of sorghum varies widely from the high productivity country averages of 4.7 tonne/ ha in the the United States and Argentina, and 4.3 tonne/ha in China to productivity levels of 0.6 tonne/ha in Sudan, and 1.0-1.5 tonne/ha in India, Burkina Faso or Ethiopia. Modern high-yielding cultivars are bred with heads held high above the foliage for machine harvest. On small farms in developing countries, harvesting is mostly done by hand cutting the panicles placing them in sacks and taking them to the threshing floor for further drying to a moisture content of 12–13 percent. Sorghum grain can only be threshed when seed moisture is 20-25 percent or less, even though the seed is physiologically mature at higher moisture levels (around 30-35 percent). Some hybrids have a loose, open type of panicle, which hastens field drying. In India and for fodder production, sweet sorghum is harvested generally at milk-ripe stage and when sucrose content is in the range of 17 to 18 percent. Sweet sorghum yields between 35 to 45 tonne per hectare of fresh biomass and grain yields are in the range of 1-1.5 tonne/ha (Rao *et al.*, 2008). Productivity of post-rainy season sown (October-November) sweet sorghums are less than rainy-season sorghums in India (by 30-35 percent) because of short day length and low night temperature.

Average yield under irrigation is 5 to 7 tonne/ha while yield potential exceeds 12 tonne/ha, substantially less than a comparable maize crop. Average sorghum grain yields on farmers' fields in Africa are as low as 0.5–0.9 tonne/ha because sorghum is often grown in marginal areas under traditional low input practices based on landraces. Forage yields from open-pollinated and hybrid cultivars can reach 25 tonne/ha of dry matter.

Harvest index of sorghum is more variable than that of maize, mainly because of variable tillering in sorghum. Generally, reported HI of sorghum are more frequently low, between 0.3 to 0.4 (e.g. Muchow, 1989; Steiner, 1986). Higher HI (>0.5), however, have been observed and are apparently the result of vegetative (tiller) growth being inhibited by water deficit, which differ among cultivars (Hsiao *et al.*, 1976). High HI can also be deduced from the data of Garrity *et al.* 1982, Prihar and Stewart, 1991.

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