Soybean

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GENERAL DESCRIPTION

Cultivated soybean (*Glycine max* (L.) Merr.) is a major oilseed and protein rich annual legume crop grown on about 99 million ha and producing 223 million tonne of grain worldwide (*FAO, 2011*). The crop originated in China and is closely related to *Glycine soja*, its wild progenitor. Soybean represents nearly 50 percent of the total area cropped with seeds providing approximately 56 percent of the total edible oilseeds and 30 percent of vegetable oil production worldwide. Over the last 50 years, world production has increased eight times as a result of the substantial increase in average yields and the expansion in cultivated area (Figure 1).

Soybean is grown from the equator to latitudes 55° N or S and as high as 2 000 m. However, main soybean production is concentrated between 25° and 45° N regions, and generally grown below 1 000 m altitude (Singh *et al.*, 2009) (Figure 2). The five top producers of soybean, the United States, Brazil, Argentina, China and India, in that order, account for more than 93 percent of global production. Soybean cultivation is also increasingly popular in Paraguay, Canada, Bolivia, Ukraine, Uruguay, Indonesia, Russian Federation and Nigeria.

Today most commercially grown soybeans are the yellow-seeded field cultivars used for animal feed, oil production (for food and industrial uses), and as a protein-rich food. Other cultivars are available for special use: forage and hay (with an abundance of stems and leaves) and as a vegetable (large-seeded, various coloured varieties).

Soybean fits well into crop rotations and intercropping systems. Most prominent cropping sequences are soybean-maize and soybean-wheat in the United States, Brazil and Argentina. Soybean-chickpea, soybean-mustard, soybean-wheat sequences and soybean intercropping with pigeonpea or cotton are common in India and China. In Indonesia double or even triple cropping is practised with rice(-rice)-soybean, where soybean is grown on the residual moisture in rice fields in the dry season. In Vietnam soybean is grown as a late summer crop for fodder after the rice harvest. Work by International Crop Research Institute for the Semi-arid Tropics (ICRISAT) in India had shown that yield increases with soybean-chickpea and soybean/pigeonpea sequential and intercrop systems was possibly because more nitrogen is made available when one legume crop follows another. If soybeans have not been grown in a particular location for

FIGURE 1 World soybean harvested area and average yield over the period 1961-2009 (FAO, 2011).

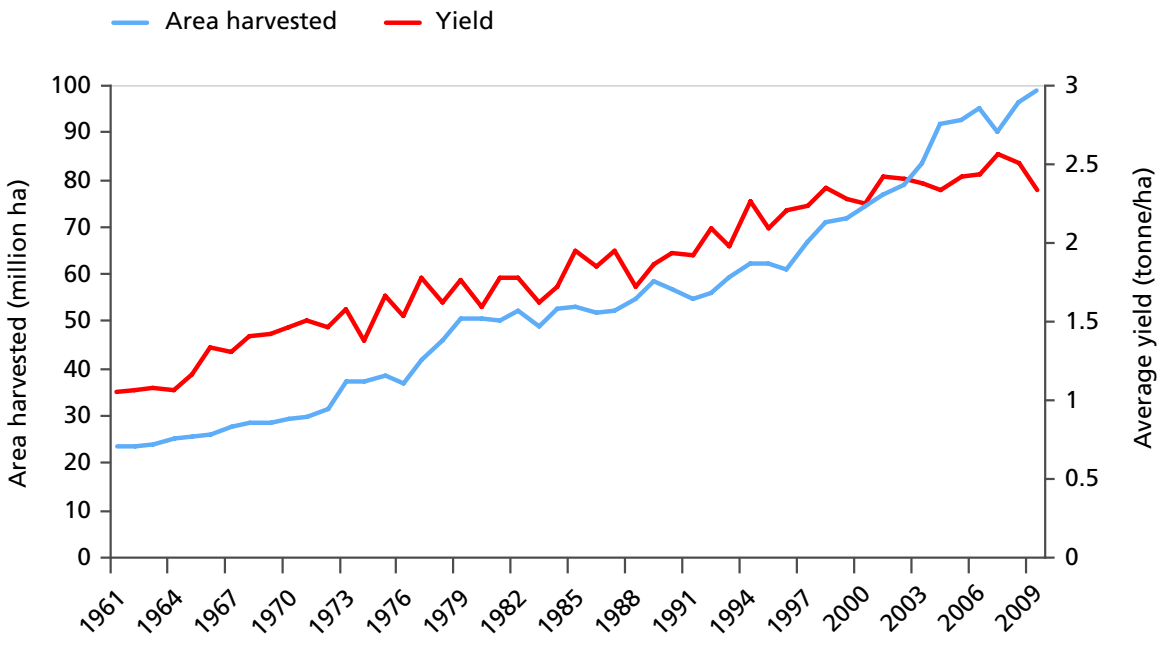
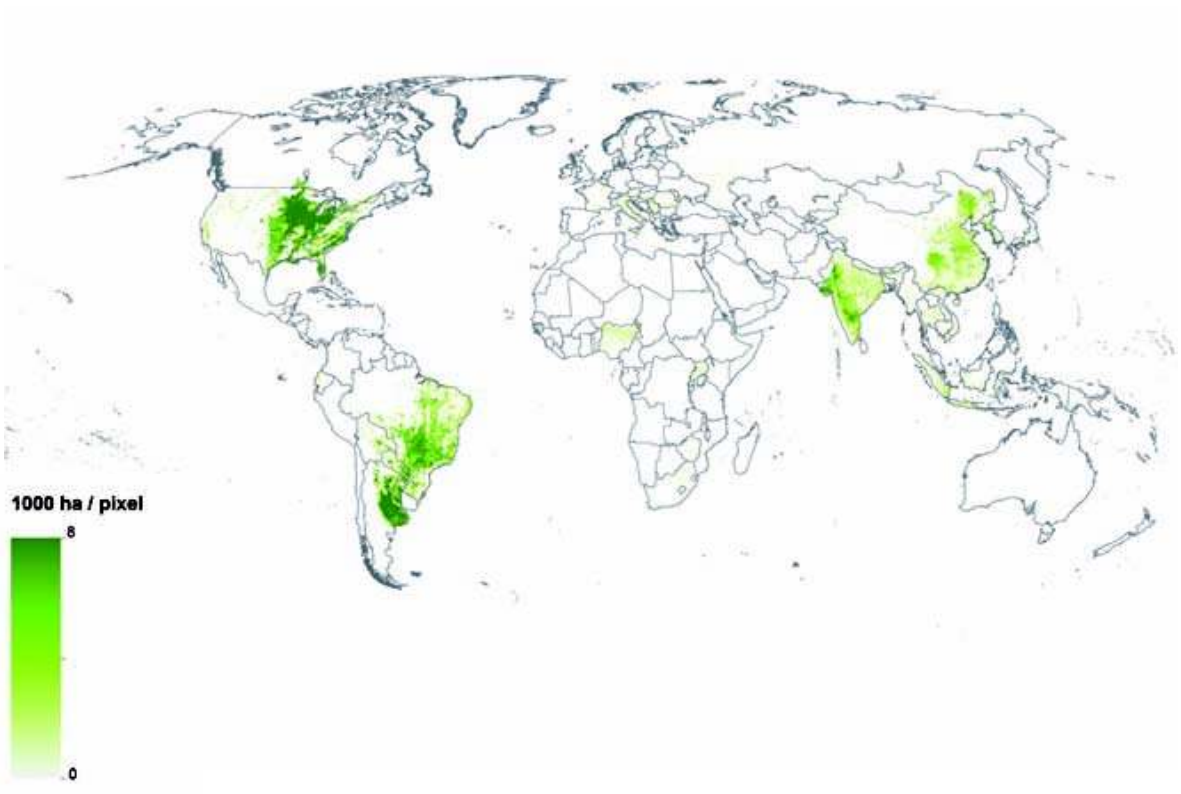


FIGURE 2 Soybean harvested area (GAEZ, 2011).



Reference year 2000

three or more years, it is best to inoculate the seed with an effective strain of nitrogen-fixing bacteria (*Rhizobium*).

GROWTH AND DEVELOPMENT

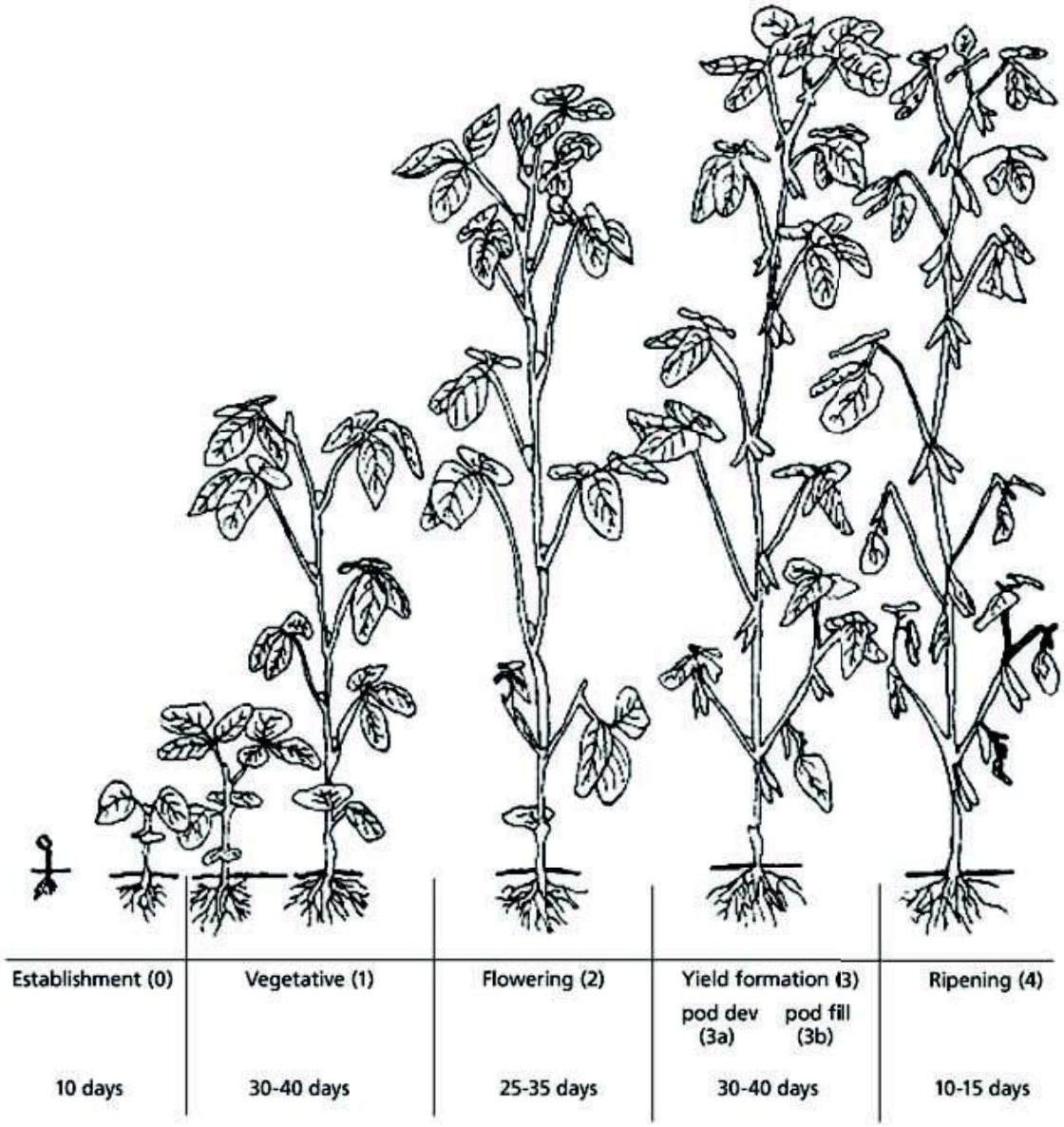
Soybean cultivars vary from being highly determinate to indeterminate. Indeterminate plants are those that continue to produce leaves, new flowers and pods for several weeks after the start of flowering. They typically grow taller, to 1 m, and are more common at higher latitudes with short growing seasons. Growth is stopped by cold temperature near the season's end. Determinate plants complete their growth in height and then produce the flowers at about the same time. They are usually one-half to two-thirds (0.45 to 0.6 m) as tall as indeterminate cultivars. There is however no correlation between plant height and seed yield (Figure 3).

Soybean is grown mainly under rainfed conditions in late spring or summer, when there is rain. In India and China, soybean is mostly sown in May/June to early July but may be grown in spring and sown between February and March in the southern regions. In the United States, Brazil, and Argentina sowing season starts in May and ends by mid-July as the summer crop or is planted after winter wheat. Late plantings generally have smaller canopies and produce less than early plantings. In areas of high rainfall, raised seedbeds in the form of broad-bed and furrow or ridge and furrow land forms are well suited to draining out excess water from Vertisols and to providing good aeration of the root zone. Planting density ranges from 150 000 to 500 000 plant/ha, depending on seed cost and environmental factors. In India, optimum plant population of 330 000 plant/ha is recommended, and it can be achieved with a seed rate of 80-100 kg/ha based on seed size. In the United States, common row spacing is 0.50 m, while in Brazil, Argentina, China and India, rows are often narrower (0.33 m). Sowing depth of 2.5 to 4.0 cm is optimum for good germination. Optimum average air temperature for rapid germination is approximately 30 °C.

Soybean is very adaptable to different cropping systems, as there is wide variation in the length of the life cycle, between 70 and 140 days depending on the cultivar and season. Because of variation in season length with latitude and the need to fit into a particular time span in crop rotations, life cycle length was important enough to prompt the designation of soybean cultivars by maturity groups in North America. The designation uses Roman numerals up to X, with the duration to maturity increasing as the numeral increases. The breeding of lines with even shorter life cycles later caused the extension of the low end of the maturity groups, from I to 0, 00, and 000. Soybean flowering is determined by photoperiod and thermal regime. Cultivars in late maturity groups, grown in lower latitudes, initiate flowers at shorter day length (e.g. 10 hours), whereas cultivars in early maturity groups, grown in higher latitudes, initiate flowers at longer day length (e.g. 13 hours). It is important to grow locally-adapted cultivars at a given latitude. For example, if a cultivar suitable for a higher latitude is grown at a lower latitude, it would flower and mature too early and yield less.

Short duration cultivars, ranging from 95 to 115 days, are popular in India, the USA, China (Heilongjiang province and Huai river valley), while even shorter life cycles are used in Korea. Medium duration cultivars of 120 to 140 days are grown in China (Northeast and Loess plateau). Brazil and Argentina prefer the longer season cultivars, which produce up to 20

FIGURE 3 Typical developmental stages of soybean.



percent higher yield than the early maturing. Most cultivars suitable for the rainy season are medium maturing, between 95 and 115 days. For cultivars of this maturity range, indicative duration of the different growth phases is as follows:

- sowing to emergence: 6 days;
- sowing to maximum canopy: 50-55 days (depends on plant density);
- sowing to onset of canopy senescence: 80 days, and time from onset to completion of canopy senescence: 25 days;
- sowing to physiological maturity: 105 days; and
- sowing to flowering: 36-45 days, and flowering duration: 14-20 days.

Determinant cultivars reach maximum canopy cover and height at early reproductive stages (between R1 and R3 of soybean growth stages), while the canopy of the indeterminate type

can continue to grow after this. Maximum canopy cover varies between 65 and 95 percent depending mostly on row spacing and plant density. Soybean flowers are white or purple, very small and borne in short clusters. Only about 25 to 60 percent of the flowers actually produce pods, which become prominent one to two weeks after the flowers appear. Pod setting lasts two to several weeks, longer for the indeterminate cultivars. When conditions are not limiting, a pod produces three to four seeds and they fill in about one month.

As for all crops, soybean preferentially grow roots relative to shoot at germination to shortly after emergence. Maximum depth of rooting for soybean is about 1.3 to 1.8 m deep and can reach up to 2.40 m, depending on water status, soil type and temperature, and life cycle length of the cultivar (Kanemasu, 1981). Most roots are located in the upper 0.3 m of soil, but prolonged dry periods cause roots to proliferate more in the deeper soil layers. As is the case for other crops, water stress increases the root to shoot ratio, and tends to increase total root length. Soybean genotypes vary in their growth and development of root systems.

WATER USE & PRODUCTIVITY

Depending on climate, soils, crop cultivar, and management practices, evapotranspiration (ET) of soybean varies between 300 mm and 800 mm. In India, soybean ET was reported to be around 450 mm. Seasonal water use of 330 mm to 760 mm has been reported in the United States, and similar values in Australia. *FAO Irrigation and Drainage Paper* No. 56 presented values between 450 and 825 mm. Peak daily water use of soybean is about 8-9 mm/day, which normally occurs as maximum canopy cover is reached (near full bloom to beginning of pod filling).

Biomass water productivity ($WP_{B/ET}$) of soybean, i.e. slope of the linear relationship between biomass and cumulated ET, has been found to vary from 1.2 to 1.6 kg/m^3 in studies carried out in different parts of the world. Higher $WP_{B/ET}$ values were observed in the United States/ Canada studies while lower values were found in India. The difference may be due to limitation of nitrogen and other mineral nutrients in the latter. For oilseed crops such as sunflower and soybean, $WP_{B/ET}$ decreases after anthesis because the protein and oil in the seed require more energy and photosynthetic assimilates to make than cell walls or starch. Soybean showed significant increase in seed yield with elevated atmospheric CO_2, by up to 35 percent.

RESPONSE TO STRESSES

Water, temperature, nutrient stresses affect the growth and development of soybean. Vegetative (leaf and stem) growth is very sensitive to water deficits. Water stress that occurs at the beginning of podsetting to full seed-filling has a greater negative impact on yield than when it occurs at other stages. The seed-filling period is very critical to yield. If environmental conditions are adverse (drought, hail, or disease), seed-fill will be restricted and yields will be cut severely (Doorenboos and Kassam, 1986).

Soybean is very sensitive to frost at seed emergence and pod filling, but losses due to frost in grain yields for indeterminate cultivars are less compared to other cultivars because of the extended flowering period.

A number of studies indicate that soybean yields are not substantially affected until the root zone soil has been depleted below 60 percent of total available water (TAW), provided canopy development has not been hampered by prolonged mild water deficits during the vegetative phase. Water stress during grain filling reduces seed size considerably, and water stress after flowering and during pod filling is most critical (Doss and Thurlow, 1974). In addition to the usual inhibitory effects on leaf expansion, transpiration and photosynthesis, water deficits also inhibits nitrogen fixation in soybean.

Excess moisture severely affects germination and early growth of soybean. However soybean tolerates flooding or waterlogging up to 7 days, but yield can be reduced by more than 40 percent if prolonged flooding occurs at floral initiation or beginning of the seed filling stage. In addition to being detrimental to root activities, flooding reduces nodulation. Soybean exposed to flooding for more than 8 days produce adventitious roots on the stem with aerenchyma tissue which facilitates oxygen diffusion to the submerged apical root portion (Mayaki *et al.*, 1976).

Soybean can be grown in a wide range of soils, except those that are very sandy, with optimum growth in alluvial soils high in organic matter. Usually, the fertilizer phosphorus and potassium requirements are 35 to 70 kg/ha P_2O_5, and 36 to 84 kg/ha K_2O. Soybean is often assumed to be capable of fixing atmospheric nitrogen to meet its requirement for high yield; although benefit from a starter dose of 10 to 20 kg/ha N is recognized. However, this assumption may not hold under conditions of high yield potential but with a soil low in organic and mineral nitrogen. A soybean crop at maturity contains on average 70 kg of N, 30 kg of P_2O_5, and 60 kg of K_2O per tonne of grain produced. So a yield of 3 tonne/ha would require at least 210 kg/ha of N by symbiotic fixation and uptake from the soil. A number of studies have shown that even under favourable conditions, symbiotic fixation usually supplies not much more than half of the N, with the rest coming from the soil. Nitrogen fixation is reduced under water stress; irrigation and rainfall distribution greatly affect N accumulation and N supplies from those fixed.

Soybean cultivation is successful in climates with warm summers, and optimum growing conditions at mean temperatures of 20 °C to 30 °C. Days to flowering of soybean were shortest at 30 °C, and an increase in days to flowering at 25 °C, 35 °C and 20 °C has been observed. At 20 °C self pollination without opening of the flowers has been reported for various cultivars, so has abortion of flower and newly set fruit at 35 °C. High canopy temperature (approaching 40 °C) reduces CO_2 assimilation rate, and low stem temperature slows translocation, which stops in soybean at 2 °C to 3 °C.

Soybean is generally sensitive to salinity, but cultivars differ substantially in their salt tolerance. Some moderately tolerant cultivars exclude chloride from their leaves. High phosphate supply in the growth medium increases sodium uptake and reduces salt tolerance of some cultivars.

IRRIGATION PRACTICE

Soybean is commonly grown under rainfed conditions; for example, only 8 percent of the total area in the United States is irrigated. Efficiency of applied water is highest when irrigation is applied during the reproductive stage (around R3 stage) relative to applications before

flowering. Irrigation during pod filling also prevents or stops accelerated canopy senescence caused by water stress, ensuring good green canopy cover to continue photosynthesis and maximize translocation of assimilates and minerals from leaves to seeds. As with other crops, the irrigation requirement of soybean varies, depending on rainfall, climate, water storage capacity of the soil and rooting depth. The number of applications varies from a minimum of 2 to a maximum of 8 irrigations in the season to ensure that the crop is not exposed to substantial stress once pod setting has begun. Irrigation scheduling, based on 60 percent depletion of TAW, consumes less water without severely affecting crop yields if soil water content is adequate at sowing. In many cases a single irrigation at late bloom is most beneficial compared to any other growth stage.

Surface irrigation by flooding, ridge and furrow, basin, and border application methods are commonly practised. Sprinkler irrigation by center-pivot, side-roll, traveling-gun, tow-line, and solid-set, is also practised in some countries. When soil water is deficient, irrigation increases plant height, leaf area, leaf number and length of primary root, as well as the dry weight of stems, leaves, reproductive organs and roots (Rhine *et al.*, 2009).

YIELD

Soybean yield averages around 2.0 to 2.5 tonne seed/ha (at 13-14 percent seed moisture content) for major producing countries but in developing countries, a large yield gap exists between farmers' yields and achievable soybean yield. Average soybean yields in the United States approach 3 tonne/ha, and in Brazil, 2.7 tonne/ha (Bhatia *et al.*, 2008; Singh *et al.*, 2009). In Europe, Italy has the highest average yield, at 3.5 tonne/ha. The yield is 1.6 tonne/ha in China while it is only 1 tonne/ha in India. The yield potential of cultivars of variable duration (65-130 days) in India ranges between 1.2 to over 4 tonne/ha with low to high input crop management (Singh *et al*. 2009). In the United States, top yields of over 5 tonne are not unusual in some areas. This difference in yield is probably related to differences in management practices and to the different nutrient status of the soil, including nitrogen, with a tendency of the crop to be exposed to nutritional stress in low-yielding farming systems. Soybean is primarily utilized as the source of protein and oil. The seeds contain 40-42 percent protein and 17.5 percent to 20 percent oil, with polyunsaturated fatty acids such As oleic and linoleic acids dominating. Soybeans grown in different locations can vary substantially in protein, amino acids and lipid concentrations, as indicated by a study comparing the chemical compositions of beans grown in China with those grown in the United States and Brazil (Grieshop and Fahey, 2001). It appears that environmental conditions under which soybeans are grown can significantly impact chemical composition and nutritional quality.

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