9 Crop Management

Richard R. Johnson
Deere & Company Technical Center
Moline, Illinois

The major challenge in soybean [*Glycine max* (L.) Merr.] management is to integrate all production variables to meet the unique characteristics of an individual farm. This integration involves more than managing genotypes and environments. Constraints from inputs such as capital, time, and labor can greatly influence the management system adopted. Sometimes availabilities of needed inputs such as irrigation water, drainage rights, or local markets also place restrictions on optimum cropping systems for a given farm. In short, several factors can affect crop management decisions and no one management system can be considered to be the optimum.

The objective of this chapter is to discuss crop management research that has been reported since the review of Pendleton and Hartwig (1973). Emphasis will be on general concepts. Another recent comprehensive reference concerning soybean management has been prepared by Scott and Aldrich (1983).

9-1 SEED SELECTION

9-1.1 Wide vs. Specific Adaptability

Improved cultivars have made substantial contributions to past increases in soybean yield (Luedders, 1977; Boerma, 1979; Wilcox et al., 1979; Boyer et al., 1980). To capitalize on genetic improvements in yield, newly released cultivars must continually be evaluated in different production environments. Breeders have traditionally emphasized development of cultivars that perform well over a wide range of climatic and edaphic conditions (Schutz and Bernard, 1967). The current importance of wide adaptability is recognized by a survey of 15 states accounting for about 88% of the 1983 U.S. soybean production (Crop Reporting Board, 1983b). In this survey, 'Williams' was the leading cultivar for the 8th consecutive year and accounted for 12.3% of the 1983 harvested area.

Soybeans: Improvement, Production, and Uses, 2nd ed.—Agronomy Monograph no. 16.

To produce widely adapted cultivars, plant breeders have emphasized traits such as major pest resistance, lodging resistance, nonshattering pods, and high average yields. As soybean cultivars have gained in importance and have been increasingly exposed to a broader range of cropping conditions, there has been a tendency to release cultivars for special growing situations. For example, short-statured cultivars have been released for high-yielding environments in the northern USA (Cooper, 1981); 'Amcor' has been identified as a Maturity Group II cultivar adapted to low yield environments (Walker and Cooper, 1982); and 'Narow' is a Maturity Group V cultivar especially adapted for planting in narrow rows at conventional spring planting dates (Caviness et al., 1983). Although these specialty cultivars can perform quite well in prescribed environments, they may be adversely affected by other major production variables. The cultivar Narow is not only less suited for late planting, but is also highly susceptible to injury from the herbicide metribuzin [4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4*H*)-one] (Caviness et al., 1983). When selecting cultivars, it is thus important to identify strengths and weaknesses. Compared to more stable yielding cultivars, those developed for special environments can provide exciting opportunities but can also expose a grower to greater risk if environmental conditions develop that are not consistent with the specialty cultivar's requirements.

9–1.2 Maturity Classification

Planting cultivars of differing maturity can assist in spreading risk and can also spread harvest time. Stage of plant development is influenced by temperature and photoperiod (Major et al., 1975). For this reason, soybean cultivars have been placed in 13 maturity groups ranging from 000 (earliest) to X (latest). Designation of early, mid-, and full-season cultivars is used to describe relative maturity on a local basis, but for full-season production these designations seldom span more than three maturity groups at a given location. For full-season production at a given location, it is usually possible to identify cultivars that will yield well yet differ in maturity by as much as 20 to 30 days. There has been some tendency, especially in areas with shorter growing seasons, for mid- and full-season cultivars to yield more than early season cultivars.

9–1.3 Determinate and Indeterminate Growth Types

Soybean cultivars differ in growth habit as well as maturity. Bernard (1972) reports that determinate cultivars have predominated in Japan, Korea, and the southern USA, whereas indeterminate soybean cultivars have been grown in northeast China and the northern USA. Indeterminate cultivars continue main stem elongation several weeks after beginning flowering, while determinate plants terminate main stem elongation at, or soon after, the onset of flowering. Semideterminates are an intermediate stem type that terminate stem growth fairly abruptly after a flowering period almost as long as that of indeterminate types. Shading or lodging can cause a semideterminate stem to appear indeterminate, and insect or other injury to an indeterminate stem tip may simulate determinateness.

Several determinate and semideterminate cultivars adapted to the northern USA have recently been released. Within a maturity group, these determinate and semideterminate cultivars are generally shorter, more lodging resistant and have lower basal pod heights than indeterminate cultivars (Hartung et al., 1981; Cooper, 1981; Beaver and Johnson, 1981a). Cooper (1981) reported that these short-statured determinates are adapted to high yield environments, but are not adapted to environments with early season stress. Beaver and Johnson (1981a) found that determinate and semideterminate cultivars yielded as well as indeterminate cultivars in a wide range of productivity levels, but determinate cultivars had a less predictable yield response to varying levels of productivity. At least three factors may account for the less stable performance of short-statured determinate cultivars. First, Fehr et al. (1981) reported that 100% defoliation of determinate cultivars causes greater yield loss at all reproductive stages than that which occurs with indeterminate cultivars. Secondly, Septoria brown spot (caused by *Septoria glycines* Hemmi) has been shown to make faster vertical progress and cause greater yield loss in a short determinate than in an indeterminate cultivar (Pataky and Lim, 1981). Thirdly, because there is a high correlation between plant height and lowest pod height, environments with early season stress can cause sufficient height reduction in short-statured cultivars to increase the potential for harvest losses (Beaver and Johnson, 1981a; Hartung et al., 1981).

Since semideterminate cultivars are generally intermediate in height between determinate and indeterminate cultivars, semideterminates may possess more yield stability potential than determinates when grown in northern environments. Green et al. (1977) and Wilcox (1980) have compared semideterminate and indeterminate breeding lines in narrow and wide rows. Narrow rows increased yields of both plant types in about equal proportions and both research groups concluded that either plant type could be successfully used in a midwestern U.S. breeding program. Availability of future semideterminate cultivars in the northern USA may thus depend upon which plant type plant breeders choose to place their emphasis.

9–1.4 Number of Cultivars and/or Blends

Ryder and Beuerlein (1979), Boquet et al. (1982) and Beatty et al. (1982) have emphasized that several different cultivars are often capable of producing high and nearly equal yields when planted at optimum dates under a range of cultural conditions. Walker and Fehr (1978) concluded that stable production could best be achieved by growing several rather than one cultivar.

Since the mid-1970s, mixtures of two or more pure line cultivars have been sold as blends. One objective in producting a blend is to combine pure lines so that the blend yield is greater than the weighted mean yield of the component cultivars in a pure stand (Fehr and Rodriguez, 1974). This might be accomplished by combining pure lines that complement each other, i.e., a lodging resistant but pest susceptible cultivar might be combined with a lodging susceptible but pest resistant cultivar. In practice, there is little evidence that a blend will yield more than the weighted mean yield of its components (Walker and Fehr, 1978; Fehr and Cianzio, 1980). At least two factors limit the use of blends. First, replanting harvested seed from a blend is not recommended because the genetic makeup of the blend may change. Secondly, blends containing cultivars differing in maturity do not allow for a spread in harvest time. For these reasons, blends have not been used as widely as pure line cultivars. A producer with small land area might find a blend to be a desirable way to spread risk and achieve more stable yields.

9–1.5 Seed Germination and Size

The warm germination test measures viability under relatively ideal conditions and has historically been a standard measure of seed quality. Yet, a loss in seed viability is often preceded by a loss in vigor. One or more of the vigor tests have been useful in identifying seed that will have stand establishment advantages under less than ideal field conditions (TeKrony and Egli, 1977; Johnson and Wax, 1978; Tao, 1978; Kulik and Yaklich, 1982). In the absence of stand differences, there has seldom been a yield advantage in using high vigor seed (Johnson and Wax, 1978; Egli and TeKrony, 1979). Nevertheless, the uncertain nature of weather and soil conditions provide adequate justification for planting seed of high germination and vigor. Seed of high quality seldom costs much more than that of lower quality. In a recent survey, TeKrony (1982) reported that the accelerated aging test, cold test, and tetrazolium tests are the vigor tests most often used by seed-testing laboratories. The survey also showed that since 1976 there had been a substantial increase in the number of vigor tests conducted. Standard warm germination tests of at least 80% are often considered a minimum for acceptable field use. Using vigor tests in conjunction with warm germination tests will help measure acceptable quality. A more thorough discussion of seed quality can be found in chapter 8 of this book.

In general, seed size has not had much effect on crop yields. Where differences have been reported, the advantages have usually been in favor of larger rather than smaller sizes (Fontes and Ohlrogge, 1972; Smith and Camper, 1975). Size uniformity rather than absolute size may be the most important factor affecting yield since this leads to plant uniformity (Fontes and Ohlrogge, 1972).

9–2 TILLAGE

Recent changes in tillage practices have greatly influenced crop management. An extensive review of tillage is presented in chapter 10 in this book. The following will briefly cover tillage from the standpoint of management.

Before 1960, clean tillage was used because it assisted in economic control of weed, insect, and disease pests. After World War II, advancing technology in the chemical industry began to furnish pesticides that provided alternate methods of pest control. Chemical pesticides along with improved seeding equipment have allowed production agriculture to adopt what is now becoming known as conservation tillage. Conservation tillage systems are designed to provide a rough, residue-covered soil surface that is resistant to wind and water erosion. No-tillage represents the extreme in conservation tillage since seed is planted in a previously undisturbed soil, and the only tillage used is that necessary to place seed in the soil. Less extreme forms of conservation tillage are usually referred to as reduced tillage since the entire field is often tilled, but in such a way that crop residue is still present on the soil surface at planting time. In a review of soil erosion control with conservation tillage, Laflen et al. (1981) have emphasized that it is generally the percentage residue cover rather than the particular tillage system per se that reduces erosion.

In addition to soil conservation, a number of other reasons are advanced to promote conservation tillage. These include a conservation of labor, moisture, energy, and money. Compared to clean tillage, the reduced number of tillage operations in conservation tillage systems generally do conserve soil, labor, and moisture. However, cost and energy reductions associated with reduced machinery operations are sometimes offset by an increased need for pesticides and fertilizers (Siemens and Oschwald, 1978; Lockeretz, 1983; Jolly et al., 1983). Soybean yields obtained with different tillage systems have differed (Siemens and Oschwald, 1978; Bauder et al., 1979; Nave et al., 1980; Colvin and Erbach, 1982; Touchton and Johnson, 1982; Gebhardt and Minor, 1983). In general, drought-prone and well-drained soils yield more with conservation tillage because of increased moisture conservation. However, fine-textured and poorly drained soils often yield less with conservation than with clean tillage—largely due to wetter and cooler soils that delay planting and reduce early season crop growth. Rotating corn (*Zea mays* L.) and soybean has helped eliminate yield reductions experienced in continuous corn when conservation tillage has been used (Triplett and Van Doren, 1977; Erbach, 1982; Mulvaney, 1984).

Use of conservation tillage in soybean production has steadily grown. No-Till Farmer (1983) has surveyed state agronomists of the Soil Conservation Service (SCS) each year since 1972. In 1972, about 2, 12, and 86% of the soybean area was reported to be in the no-, reduced, and clean tillage categories, respectively. By 1982, about 7, 38, and 55% of the soybean area was in these same categories. Of the 1982 soybean area that was no-till planted, nearly 80% was double-cropped soybean. A 1982 Office of Technology Assessment (OTA) report suggests that USDA estimates of conservation tillage use are somewhat lower than those of No-Till Farmer but follow the same general trend. The OTA report projects that 75% of U.S. cropland will eventually be in some form of conservation tillage, but cites other estimates ranging from 50 to 84% adoption. Pest control, particularly weeds, was the major factor given as limiting the rate of adoption of conservation tillage.

An important concept of conservation tillage is the mulch of residue left on the soil surface. Table 9–1 is from a review by Colvin et al. (1981) and shows the amount of residue remaining on the surface after a single tillage pass in different cropping situations. The previous crop, time of tillage, and sequence of tillage events affect residue remaining. Speed, tillage depth, and ground engaging attachments used also affect amount of residue left by a single pass of a particular tillage machine, and account for the ranges given for each implement in Table 9–1. When prior tillage has been conducted, some implements can return buried residue to the surface—thus accounting for values above 100% in Table 9–1. At least one company currently markets over 30 different sweeps, shovels, or spikes for use on chisel plows (Johnson, 1982). Sweeps tend to incorporate small amounts of residue while spikes and twisted shovels tend to incorporate intermediate and large amounts of residue, respectively. Some of the ranges for residue left on the surface in Table 9–1 appear to be conservative and will likely change as tillage machines are modified. For instance, moldboard plows are currently available that can be manually

Table 9–1. Percent pretillage residue cover remaining after a single tillage pass (Colvin et al., 1981).

Tillage implement	Fall without previous tillage		Spring without previous tillage		Spring following previous tillage	
	Avg	Range	Avg	Range	Avg	Range
	% pretillage surface cover after corn					
Moldboard plow	4	0–10	7	5–10	—	—
Disk	84	—	50	42–73	80	46–100
Chisel	56	40–85	56	44–68	—	—
Field cult.	—	—	—	—	84	—
Till plant (sweep)	—	—	62	59–66	—	—
Plant (double-disk opener)	—	—	90	82–100	80	—
	% pretillage surface cover after soybean					
Moldboard plow	2	—	3	—	—	—
Disk	—	—	—	—	58	56–60
NH_3 knife on 762-mm centers	—	—	39	27–54	44	43–45
Chisel	14	—	28	25–31	115	106–130
Till plant (sweep)	—	—	—	—	74	73–76
Plant (double-disk opener)	—	—	81	70–94	100	76–113

or hydraulically adjusted to vary width of cut from 36 to 61 cm per bottom. When operated at narrow widths, these plows can leave up to 25% residue cover in corn stubble, but will incorporate most residue if adjusted to the widest cut (Johnson, 1982). Thus, in conservation tillage, the manner in which a machine is equipped and operated can be as important as selection of the particular implement.

Compared to corn, soybean produces less residue which is subject to more rapid decomposition. Soil erosion following soybean is greater than following corn (Siemens and Oschwald, 1978; Laflen and Moldenhauer, 1979). Thus, where soybean is grown in rotation, tillage systems used after the soybean crop may be more important for erosion control than those used to prepare for the soybean crop. As shown in Table 9–1, a given tillage tool often incorporates a higher percentage of soybean than corn residue. Following the soybean crop, delaying all tillage until spring provides the most effective erosion control. In the corn-soybean rotation, anhydrous ammonia is often applied as the N fertilizer for corn. Anhydrous knife applicators may leave less surface residue cover than some other tillage tools and should be considered as a tillage tool when managing residue (Table 9–1).

Some soybean herbicides must be soil incorporated and others tend to give more consistent weed control if incorporated. Thompson et al. (1981) have provided an extensive review of the incorporation capabilities of several different types of tillage tools. As in residue management, successful herbicide incorporation is often as dependent on how the machine is equipped and operated as on the general type of implement used.

In most areas of the USA, soybean yields have not been increased by deep tillage. However, certain soils in the southeastern USA compact easily. On these soils, root penetration ceases at a bulk density of about 1.75 g cm^{-3} which is often found in the compacted layer, and soybean crops have typically responded to subsoiling that is deep enough to break the hard pan (Musen, 1977; Smith et al., 1978; Martin et al., 1979). In the south central Midwest, there are about 5 million ha of claypan soils that are poorly drained and often experience periods of excessive rainfall and drought within the same growing season. These soils are not improved by deep tillage, but soybean yields have increased with a combination of irrigation and improved surface or internal drainage (Walker et al., 1982). Drainage alone or irrigation alone had only slight effects on soybean yield but did improve corn yields.

Hanthorn and Duffy (1983) surveyed the 1980 cropping season costs and returns of clean, reduced, and no-tillage soybean producers in midwestern, midsouthern, and southeastern USA. Herbicide use and cost differed by region, but additional herbicide applications were generally substituted for any reductions in tillage and mechanical cultivation. Insecticide use and costs were not significantly different among tillage strategies. The number of mechanical cultivations did not differ between reduced and clean tillage systems but ranged from 1.12 to 1.79 cultivations per season among the three regions. No-tillage soybean averaged 0, 0.19, and 0.47 cultivations in the Southeast, Midsouth, and Midwest, respectively. Midwestern producers received the highest returns, but in this region no-tillage soybean generated significantly lower returns than clean tillage soybean—largely due to lower yields. Returns in the Midsouth and Southeast did not differ with tillage system. The authors concluded that no one tillage strategy shows a clear economic advantage over others.

In summary, the relatively uniform set of tillage practices of the past have evolved into more complex management systems. Optimum tillage practices have become site specific much like fertilizer and pesticide recommendations. Tillage systems will need to differ not only from one region to another, but from field to field, and in some cases, practices within a field will change from 1 yr to the next. The concept of rotating tillage systems on a given field has several merits. More thorough tillage may be necessary after a high residue-producing crop such as corn, than after a low-residue, erosion-prone crop such as soybean. Occasional use of clean tillage can sometimes reduce problems encountered in reduced or no-tillage systems. For example, deeper moldboard plowing can greatly reduce problems from shallow germinating annual weeds or carryover herbicides. Using more thorough tillage in years when relatively immobile nutrients (i.e., lime, P, or K) are applied can help reduce nutrient availability problems. One of the challenges researchers will face in coming years is the integration of other crop management practices with the changing tillage systems. It seems obvious that reduced and no-tillage systems will require better management on the part of the grower than is required under clean tillage systems.

9–3 FERTILITY

Soybean fertility is covered in detail in chapter 12 in this book. This section will present only a brief review of recent management research.

9–3.1 Nitrogen

Soybean is a legume and when well nodulated is capable of fixing its own N. Harper (1974) found that both symbiotic N_2 fixation and nitrate (NO_3^-) utilization appear essential for maximum yield. However, he found that excessive NO_3^- appears detrimental to maximum yield because symbiotic fixation is completely inhibited. Apparently, most soils can meet NO_3^- needs of the plant because soil applications of N show no yield advantage regardless of source of N or time, method, or rate of application (Rogers et al., 1971; Chesney, 1973; Welch et al., 1973; Pal and Saxena, 1976; Deibert et al., 1979; Nelson and Weaver, 1980; Porter et al., 1981). An exception to this rule has occurred on soils that are somewhat poorly drained, low in organic matter and strongly acid below the plow layer (Bhangoo and Albritton, 1976). These soils have sometimes responded to N rates in the range of 50 to 110 kg ha^{-1}.

In Iowa, Garcia and Hanway (1976) combined N with P, K, and S to form a relatively low salt NPKS solution. Significant yield increases were obtained from two to four NPKS foliar sprayings between developmental stages R5 to R7. Results of similar studies since the Iowa work have been discouraging, and the practice has not generally been recommended (Welch et al., 1979; Keogh et al., 1979; Poole et al., 1983). Labeled N was applied in NPKS treatments by Vasilas et al. (1980). From 44 to 67% of the total N applied was recovered in the plants, and a high proportion of the recovered N was found in the seed. Yield was increased in 1 out of 2 yrs. In summary, several attempts have been made to increase soybean yields with N fertilizer, but positive results have been elusive and economic returns rarely occur.

9–3.2 Lime, Phosphorous, and Potassium

Liming acid soils to a pH of 6.0 to 6.5 is an important prerequisite for profitable soybean production. Limestone differs greatly in neutralizing value and fineness of grind. These factors along with the soil depth that is being neutralized are important considerations in determining lime application rates. No-tillage and forms of reduced tillage that provide little soil mixing will often have different lime requirements than systems using deeper, more thorough tillage. Alkaline soils with a pH > 7.5 can also cause problems in soybean production, but it is seldom economical to attempt to reduce pH. Availability of Fe, Mn, Cu, B, Zn, and P all decrease in alkaline soils. Micronutrient applications may be required to correct deficiencies. Soil-applied triazine herbicides are also more prone to cause soybean injury on alkaline soils (Ladlie et al., 1976). This injury can occur from triazine carryover from a previous crop or from direct application to the soybean crop. In short, growers must often manage around a high pH problem rather than correcting the high pH itself. For example, management of alkaline soils may involve factors such as greater use of micronutrients, more careful selection of herbicides and cultivars, and greater use of banding or starter fertilizers.

High soybean yields require adequate levels of P and K, and rates of application should be based on soil tests and local recommendations. Where soil test levels are high, method of P and K application is of little importance. On soils testing low in P and K, however, application method is more important. In Iowa, deMooy et al. (1973) concluded that soybean is less responsive to P and K fertilizer than is corn and that soybean yields showed little difference between the effect of direct and residual fertilizer. When using fall plow down, they suggested that in a corn-soybean rotation application to corn in the cropping sequence will be more effective than to soybean. Both P and K are relatively immobile nutrients and under conditions of conservation tillage there may be merit in the application of these elements at that point in the cropping sequence where more thorough tillage is used. Starter or band applications have tended to be helpful on cool or low testing soils. In Minnesota, Ham et al. (1973) reported the largest yield response from combinations of starter and broadcast fertilizer. Placing fertilizer directly with the seed can cause injury and is generally not recommended.

9–3.3 Micronutrients

Molybdenum is an essential element for N metabolism and its use on soybean has recently been reviewed by Boswell (1980). Positive yield responses to supplemental Mo application have been reported in the Far East (Japan, China, Taiwan), Europe, and at least 12 states in the USA. In the USA, positive responses have more frequently occurred east of the Mississippi River where rainfall is moderate to heavy and soils tend to be acid. Boswell (1980) further notes that critical tissue levels of Mo have not been well established although most leaf tissue contents have been <0.20 mg kg^{-1} where yield has been increased by added Mo. Rates must be higher for soil applications than for seed or foliar spray treatment. Responses have been obtained with seed treated Mo at rates as low as 17 g ha^{-1}, while soil application rates may need to be >800 g ha^{-1}. Liming to maintain soil pH above 6.2 may effectively correct or prevent Mo deficiencies.

Manganese deficiency is common on alkaline, sandy soils during cool, wet spring weather. In Wisconsin, Randall et al. (1975) reported that row application was somewhat more effective than broadcast application. Combined row and foliar application resulted in higher yields than either row or foliar treatments alone. Georgia research has confirmed the inefficient utilization of broadcast Mn (Wilson et al., 1981). In Florida, Robertson et al. (1973) obtained yield increases from both Mn and Cu fertilization. Copper has also increased yields on some soils in Indiana (Oplinger and Ohlrogge, 1974). In North Carolina, Barnes and Cox (1973) compared copper sulfate with chelated and/or complexed Cu materials, and found all sources were equally effective at increasing double-crop soybean yields when broadcast and incorporated into the soil before wheat (*Triticum aestivum* L.) planting.

Iron chlorosis is a common problem on calcareous soils. Iowa researchers have developed a visual score ranging from 1, no yellowing, to 5, severe yellowing. Froehlich and Fehr (1981) reported that average yield loss increased by 20% for each unit increase in chlorosis score. Thus, Fe chelate sprays (Randall, 1977) or cultivars resistant to Fe chlorosis (Neibur and Fehr, 1981) should be used to prevent chlorosis expression.

In Georgia, Touchton and Boswell (1975) reported yield increases from applications of 0.28 to 1.2 kg ha^{-1} of B, but observed yield decreases from 2.24 kg ha^{-1}. Similar results were obtained from broadcast soil applications and from foliar sprays during early bloom.

In summary, micronutrient deficiencies are the exception rather than the rule. However, if soil or plant tissue tests indicate a deficiency, applications should be considered.

9–4 PLANTING PRACTICES

9–4.1 Planting Date

In warm climates, cool soil temperatures seldom control planting time, but in cooler areas, temperature can play an important role. The optimum temperature for hypocotyl elongation is about 30°C which also corresponds to the optimum temperature for germination (Hatfield and Egli, 1974). However, soybean germination and growth typically begins at temperatures of 8 to 10°C. In Missouri, Major et al. (1975a) planted soybean at dates ranging from late April to early July and found that the number of days to emergence decreased from about 18 at early dates to 5 days at later dates. For emergence, the number of growing degree days above 10°C remained constant at about 100 indicating that temperature was the primary variable influencing days to emergence. If plants are frosted after emergence, Hume and Jackson (1981) found that plants damaged at the cotyledon stage generally survive better than those frosted at later stages. In most cases, a plant would regrow with 50% of its tissue damaged, but with 70% tissue damage, only an occasional plant regrew.

Soybean tolerance to relatively wide ranges in planting dates has no doubt helped the widespread acceptance of this crop. Nevertheless, soybean does have an optimum planting date that can differ by both region and cultivar. Several recent studies in the northern USA have included factorial combinations of planting dates, row widths, and cultivars (Ryder and Beuerlein, 1979; Beaver and Johnson, 1981b; Helsel et al., 1981). In each of these studies, planting date was the variable having the greatest impact on yield. Highest yields were generally obtained with early to mid-May planting dates, and yields began to drop off quite rapidly with planting dates beyond late May.

In some areas of the southern USA, soil moisture conditions for planting are most favorable during April before temperatures get too high. Yet, planting during the short photoperiods of early to mid-April often results in shorter plants and lower yields than planting between late April and early June (Caviness and Thomas, 1979; Parker et al., 1981; Boquet et al., 1982; Thurlow and Pitts, 1983; Griffen et al., 1983). Planting after early June generally causes reduced yields as plants again become shorter. On shallow soils with a limited water-holding capacity, non-irrigated soybean typically shows erratic planting date responses that are largely dependent on the timing of summer rains.

Several of the above studies reported that cultivars differed in response to planting date. If adapted cultivars are planted during early to mid-May, many of the cultivar interactions with planting date are minimized. Cultivar choice for earlier or later plantings are less clear cut, but most sudies have shown an advantage for using mid- to full-season cultivars for extremely late planting dates such as those associated with double-cropping.

Plants are generally taller when planted between mid-May and early June and decrease in height with either very early or late plantings. In Arkansas, Caviness and Thomas (1979) observed decreased lodging on the shorter plants resulting from very early or late plantings. In Illinois, Beaver and Johnson (1981b) observed that short determinate cultivars exhibited a general increase in lodging when planted later while indeterminate cultivars decreased in lodging as planting dates were delayed past early June.

9–4.2 Plant Density and Row Width

In nonstress environments, light interception by the crop canopy can limit crop yields. Equidistant plant spacings represent the ideal. At plant densities resulting in maximum yields, equidistant spacings would occur at 15- to 25-cm row widths and would result in maximum seasonal light interception. Several studies in the northern USA have shown a yield advantage for planting in rows narrower than 75 to 100 cm (Green et al., 1977; Ryder and Beuerlein, 1979; Costa et al., 1980; Wilcox, 1980; Cooper, 1981). When several row widths have been used within an experiment, intermediate row widths of about 50 cm have provided much of the yield advantage gained in going to row widths of 25 cm or less (Helsel et al., 1981; Beaver and Johnson, 1981b).

Some row width studies in the southern USA continue to show little yield advantage for row widths <90 to 100 cm (Doss and Thurlow, 1974; Heatherly, 1981). However, several southern studies have shown an advantage of planting in row widths of 45 to 50 cm compared with 90 to 100 cm (Akhanda et al., 1976; Parker et al., 1981; Beatty et al., 1982; Boquet et al, 1982; Thurlow and Pitts, 1983). Many of these southern studies showing a narrow row advantage have included May as well as later planting dates indicating that full-season seedings also have the potential to gain from narrow rows.

In general, planting date and cultivar selection have not caused large interactions with row-width response, but there has been some tendency for later planting dates and early flowering cultivars to be somewhat more responsive to narrower row widths.

Under irrigated conditions, Reicosky et al. (1982) concluded that early in the season, 25-cm rows had slightly higher evapotranspiration than 100-cm rows, whereas later in the season, row spacing had no effect on evapotranspiration. During 2 yrs of lower seasonal water supplies in western Iowa, Taylor (1980) observed no differences in yield among row widths. In a 3rd yr when water supply was high, narrow rows yielded more than 100-cm rows. Under severe drought conditions in North Dakota, Alessi and Power (1982) found that enhanced early season water use by soybean in narrow rows leaves less water available for pod-fill resulting in reduced yields. Using these and other findings, they concluded that narrow rows may be beneficial when water is not restricting; may have no effect on yield when moderate stress is encountered; and may reduce yields under extreme full-season water stress situations.

Several systems exist to control weeds in narrow-row seedings grown without cultivation and in wider rows grown with cultivation (Wax et al., 1977). These systems generally involve combinations of herbicides and may involve both soil-applied and postemergence compounds. Soybean plants in the early vegetative stages are quite tolerant to physical injury, and use of ground equipment for early season postemergence applications has not reduced the yield potential of narrow-row seedings. In Illinois, Nave et al. (1980) used full-scale equipment and larger plots to grow soybean crops under clean and reduced tillage in row widths of 18, 38, 51, and 76 cm. They found that weed control and stand establishment were more difficult to achieve with narrow rows and reduced tillage. Preemergence herbicides used in reduced tillage treatments were associated with severe weed problems in 3 of 4 yrs. Where these problems existed, cultivation was generally more effective for controlling weeds in 51- and 76-cm rows than was application of postemergence herbicides in 18- and 38-cm rows. The 18-cm rows averaged 4 to 6% higher yields than other row widths. This study illustrates that the 7 to 20% yield advantage often reported in small plot, narrow-row research in the northern USA is not always as easily achieved in full-scale production situations.

Indiana and Iowa researchers have compared erosion rates from soybean planted with clean tillage in solid seeded, 51-, and 76-cm row widths. Row width had only a minor effect on soil erosion, but tended toward less erosion in narrow rows (Mannering and Johnson, 1969; Colvin and Laflen, 1981). In Tennessee, Shelton et al. (1983) found that crop rotation and tillage system had more influence on erosion from soybean fields than did soybean row width.

Soybean seed size differs greatly and planting rates should be based on the number of seeds per unit area rather than weight per unit area. Whether planted in rows or in equidistant spacings, soybean plants can produce similar yields across a wide range of seeding rates (Wilcox, 1974; Lueschen and Hicks, 1977; Hoggard et al., 1978; Costa et al., 1980). As seeding rates increase, plant height, height of the lowest pod, and lodging all tend to increase. When using high-quality seed, seeding rates of 350 000 to 500 000 seeds ha^{-1} are generally sufficient to maximize yield, reduce potential harvest losses due to low basal pod height, and insure adequate stands in unfavorable seedbeds. The lower seeding rates are better suited to wider rows and lodging susceptible cultivars, while the higher rates are more suited to narrow rows and lodging resistant cultivars.

Soybean plants can tolerate some variation in spacing within a row. Stivers and Swearingin (1980) induced skips in 76-cm rows before the V-3 growth stage. Several short skips reduced yield less than one long skip of the same total length. With alternate skips in each row, yield reductions varied from 1.1% with 0.30-m skips to 15.3% with 1.22-m skips when skips constitute 50% of the entire row. This study was conducted under weed-free conditions. Eliminating small skips may be more important for helping control early season weed growth than for yield per se.

The main reasons for using narrower rows and higher plant densities are to intercept sunlight sooner in the season and to provide early season competition with weeds. The fact that soybean plants often have similar yields under a range of plant populations and narrower row widths implies that complete light interception early in the season is often not necessary to maximize yield. As discussed in secion 9–6.1, plant growth responses before reproductive development often have only minor effects on yield, but optimum growing conditions are crucial during pod fill. Johnson et al. (1982) have used this concept and planting pattern research discussed above to draw the following summary points on planting patterns.

1. The objective of choosing a planting pattern should be to have full canopy closure by the time all plants are flowering.
2. In the USA, optimum row widths are narrower as planting progresses northward.
3. Late-planted and double-cropped soybean are often more responsive to narrower rows than are soybean planted at conventional spring planting dates.
4. Within a region, soybean cultivars that benefit most from narrow rows are those that flower earlier or do not "spread out" into row centers.
5. Within a region, fields that are consistently under stress from weeds, drought, fertility, disease, or insects will be less likely to respond to narrow rows.
6. Planting in 15- to 25-cm row widths approaches the ideal pattern of equidistant spacing and should result in maximum yields if stand is adequate and pests are controlled.
7. If postemergence pest control and improved stand establishment are needed, producers can realize the majority of the narrow-row advantage by using row widths of 40 to 50 cm and leaving out rows to provide clearance for tractor wheels.

Considering the above summary points, it is of interest to review row widths in the 10 leading soybean-producing states in the USA (Table 9–2). These states account for about three-fourths of the harvested U.S. soybean plants and data in Table 9–2 are from annual surveys of 90 to 140 fields in each state. During the past 5 yrs, average row widths have steadily narrowed in each state due to increased use of solid seeded and intermediate row widths. It would appear that average row widths in several states are still too wide for optimum yields. The availability of improved herbicides and improved narrow-row planting equipment should encourage continued adoption of narrow rows.

9–4.3 Inoculation

Adequate populations of *Rhizobium japonicum* must be present to produce a well-nodulated soybean crop that will not require N fertiliz-

Table 9–2. Soybean row widths for 1979 to 1983 in the leading 10 soybean producing states in the USA. Adapted from data of the Crop Reporting Board (1981, 1983b).

State	Hectares harvested (1979–1983 Avg)	Year	25 cm or less	26 to 72 cm	73 cm and greater	Avg width
	millions			% of fields		cm
Illinois	3.8	1979	5	7	88	81
		1980	5	10	85	78
		1981	18	10	72	71
		1982	18	8	74	71
		1983	17	13	70	68
Iowa	3.3	1979	1	5	94	87
		1980	3	6	91	84
		1981	3	9	88	82
		1982	3	7	91	83
		1983	4	11	84	80
Missouri	2.2	1979	5	5	90	83
		1980	13	7	81	76
		1981	18	7	75	73
		1982	22	10	68	70
		1983	27	13	60	66
Minnesota	1.9	1979	8	10	82	80
		1980	12	10	78	75
		1981	10	10	80	75
		1982	17	18	65	68
		1983	13	15	71	69
Arkansas	1.8	1979	13	1	86	92
		1980	21	4	75	88
		1981	12	12	76	86
		1982	12	14	75	86
		1983	13	15	73	85
Indiana	1.8	1979	3	7	90	83
		1980	9	12	79	77
		1981	12	6	82	76
		1982	14	14	72	74
		1983	18	9	73	71
Ohio	1.5	1979	28	16	56	60
		1980	32	13	55	59
		1981	37	18	45	54
		1982	35	15	50	56
		1983	38	9	53	55
Mississippi	1.5	1979	10	7	83	90
		1980	25	7	69	86
		1981	21	10	68	86
		1982	24	11	65	84
		1983	14	16	70	80
Louisiana	1.3	1979	24	3	73	94
		1980	27	3	70	91
		1981	33	4	62	90
		1982	36	10	55	85
		1983	26	9	65	88
Tennessee	0.9	1979	10	15	74	84
		1980	16	15	69	81
		1981	18	22	60	76
		1982	26	20	54	72
		1983	22	20	58	73
Ten state total	20.0					
U.S. total	27.2					

ation. In rhizobia-free tropical soils, Smith et al. (1981) determined that inoculum levels above 1×10^5 rhizobia per centimeter of row were necessary to establish effective nodulation. On rhizobia-free soils in North Carolina, Mahler and Wollum (1981) found that four different serogroups produced adequate nodulation, but some serogroups resulted in higher grain yields than others. In Wisconsin, Brill (1981) has also identified superior N_2-fixing strains when used in fields where legumes had never been grown. However, the superior strains were unable to compete with indigenous strains when introduced into fields with a history of soybean production.

To increase the probability of establishing nodules from the more efficient rhizobia strains, granular soil inoculants have been developed to be applied in the seed furrow using insecticide attachments on planters. These soil inoculants have the capability of supplying many times more rhizobia per seed than is attained with seed treatment inoculums. When applied to soils where soybean are grown with some regularity, however, both the seed and soil inoculants have failed to increase yields in Arkansas (Thompson and Pongsakul, 1976), Illinois (Johnson and Boone, 1976), Indiana (Nelson et al., 1978), and Louisiana (Dunigan et al., 1980).

Surveys conducted during 1979 in Arkansas and South Carolina found that 54 and 70%, respectively, of the farmers were inoculating soybean (Wolf and Nester, 1980). In Arkansas, those using inoculants treated 45% of their planted area; 96% used planter-box inoculants, 2% used pre-inoculated seed, and 2% used a granular-type inoculant. About one-fourth of the inoculants used in both surveys also contained Mo. Apparently, many producers use inoculants as a carrier of Mo or as a cheap insurance to insure adequate nodulation.

The quality of planter box inoculants being sold to farmers in South Carolina and Georgia was surveyed by Skipper et al. (1980). Viable rhizobial counts ranged from 6.9×10^9 to $< 1.0 \times 10^3$ per gram of inoculant. The low viable rhizobial counts were associated with poor nodulation under greenhouse conditions. Nonpeat-base products and combination products containing Mo and/or fungicides were inferior to peat-base inoculants. In Alabama, Hiltbold et al. (1980) also surveyed commercial inoculants available for sale and found a wide range of efficacy among the products. When used on fields with low indigenous supplies of rhizobia, yield increased with products providing more than 10^3 rhizobia per seed. Smith et al. (1983) studied the effects of shipping conditions on quality maintenance of granular soil inoculants shipped around the world. They found that prolonged shipping times, higher temperatures, and reduced moisture all decreased the final population of rhizobia; but final inoculant moisture content exerted the largest influence.

In summary, there is little need to inoculate succeeding crops if a well-nodulated soybean crop has been grown. Where used, fresh inoculants in sealed containers should be maintained under cool conditions until used in the field. Rhizobia strains differ in their capability to contribute to high yields, and one of the challenges of N research is to determine how to manage these differences under field conditions.

9–4.4 Fungicidal Seed Treatments

Seed treatments provide one means to control seed-borne and soil-borne diseases. The ability of soybean to compensate for wide differences in stand, the availability of high-quality seed, and the spotty nature of seed and soil-borne diseases all reduce the need for fungicide seed treatments. A survey by MacFarlane (1980) reported that of the 1981-planted soybean seed, about 47% was to be treated with a fungicide treatment—11% by a commercial seed treatment firm, local elevator, or farmer using a mechanical seed-treating device, and 36% by planter box treatments in the field. Most university plant pathology departments surveyed recommended seed treatment when seed germination was < 80% and/or when cool, wet soil conditions were anticipated. Wall et al. (1983) have criticized such recommendations as being too vague for grower use. They found captan [*cis-N* ((trichloromethyl) thio)-4 cyclohexene-1, 2-dicarboximide] and carboxin-thiram (5,6-dihydro-2-methyl-*N*-phenyl-1, 4 oxathiin-3-carboxamide; tetramethylthiuram disulfide) seed treatments to be equally effective in increasing emergence of seedlots with more than 15% *Phomopsis* spp. No seed treatment, however, consistently improved field emergence of seeds with reduced quality caused by mechanical damage, age, or size. They also found no obvious differences in fungicide performance in relation to planting dates or soil types.

Rushing (1982) has emphasized that fungicide seed treatments must be matched to the potential problem. He lists *Pythium* spp., *Phytophthora* spp., and *Rhizoctonia* spp. as the three major soil-borne diseases which can reduce soybean yields. Captan and thiram provide nonsystemic activity against *Pythium* spp. with virtually no control against other pathogens listed. Carboxin-thiram controls all but *Phytophthora* spp. Use of highly tolerant cultivars have been effective in controlling *Phytophthora* spp. under mild and moderate disease pressure, but does not always offer control during seed germination and seedling stages of development (Schmitthenner and Kroetz, 1982). Metalaxyl [*N*-(2,6-dimethylphenyl)-*N*-(methoxyacetyl)-alanine methyl ester] is a systemic seed fungicide that will control *Phytophthora* and *Pythium* but because of its narrow spectrum of control will require inclusion of protectants such as captan, thiram, or carboxin-thiram to provide broad spectrum control.

In summary, when high-quality seed is used, adequate stands are generally achieved without the need for fungicide seed treatments. However, under stress conditions seed fungicides can aid stand establishment if the proper chemicals are used for the anticipated pathogen.

9–4.5 Planting Equipment

Properly designed planting equipment should provide population control, accurate seed spacing in the row, seed depth control, and adequate seed-soil contact (Agness and Luth, 1975). Factors such as operating speed, seedbed condition, and machine cost can all influence how well a given planting device meets these requirements. Since the early 1970s, at least three significant changes have occurred in soybean planting equipment. First, a full range in row width capabilities has become commercially available. Throckmorton (1980) reviewed machines available for narrow, intermediate, and wide row planting. He noted that cost restrictions have largely restricted narrow (15 to 25-cm widths) plantings to various types of drills. Intermediate row widths (30–70 cm) can be seeded with either drills or row crop planters, and if skips are left for tractor tires, cultivators are also available for use. Row widths $>$ 70 cm are almost always seeded with row crop planters. Several different metering devices are used on soybean planters including feed cups, air drums, fluted rollers, horizontal plates, and air-disk meters. Nave and Paulsen (1979) tested these five meters and concluded that all provided about equal seed-spacing accuracy while causing only minimal seed damage.

A second significant change on planters has been improved depth gauging. During the early 1970s, most row crop planters gauged depth from the press wheel while drills used spring-loaded depth control rods (Baumheckel, 1976). Depth bands were available on both drills and row crop planters, but bands had to be changed to alter depth. In 1975, a row crop planter was introduced that gauged depth with a double-disk opener at the point of seed release. This concept provided excellent uniformity in depth control (Agness and Luth, 1975), and similar concepts have since been adopted on a number of other commercial row crop planters as well as at least one commercial grain drill.

A third change in soybean planting equipment has been the introduction of machines capable of planting in reduced and no-till seedbeds. Colvin and Erbach (1982) reported that any one of several different drills could be used to successfully plant in narrow row widths under reduced tillage conditions. Nave et al. (1977) have stressed that when a drill does not have coulters, it is helpful to use a tillage tool between the tractor and drill to remove wheel tracks. Use of depth bands and seed-firming wheels was also reported to be of value in obtaining target stands with drills.

No-till seedbeds often have an abundant quantity of surface residue and are firmer than prepared seedbeds. No-till double-crop seedbeds are generally the most adverse because the small grain crop has often depleted the surface soil moisture and the residue is fresh. Machines differ in their capacity to plant in the wide range of no-till seedbeds. In general, row crop planters designed to plant in row widths wider than 30 cm have the capability of no-till planting in a wider range of seedbeds than grain drills designed to plant in row widths of 15 to 25 cm. Most planters capable of operating under no-till conditions use some type of coulter to open the soil for the seeding device. Each coulter requires a great deal of weight, up to several hundred kilograms, to guarantee penetration in dry, firm seedbeds. Heavy-duty drills with close row spacings are available but

require more planting units and weight—both requirements that increase machine cost. A second option to open a seed furrow is to use powered tillage blades, a factor that also increases machine cost. Thus heavy-duty drills capable of no-till planting under adverse conditions are expensive per unit of width.

A number of lighter-duty drills are also available with coulters. These machines have limited ability to no-till plant, but are effective in fields where some full-width tillage has been conducted. In looser soils or fields where irrigation can be used to moisten the topsoil, these machines can effectively serve as no-till planters. Several row crop planters capable of no-till planting in row widths of 36 to 50 cm have recently been introduced. Compared to no-till drills these machines offer the advantage of more successful operation in adverse seedbeds at a lower cost per unit width.

Selection of proper coulter type is important for no-till planting. Smooth coulters require the least down pressure for penetration, but prepare an extremely narrow furrow that must be followed by an aggressive furrow opener. Rippled coulters have a straight sharp edge, but ripples located beyond the coulter edge do some limited soil loosening. Fluted coulters have a curved edge that loosens soil in a band 2- to 5-cm wide. Smooth or rippled coulters generally work better in surface residue and cover a wider range of soil conditions than do fluted coulters. Compared to fluted coulters, smooth or ripple coulters:

1. Require less weight to penetrate hard, dry soil.
2. Incorporate less crop residue into the seed zone.
3. Operate at higher speeds and in wetter soils without removing soil from the weed zone.

The wider seed zone prepared by fluted coulters helps decrease misalignment problems with the seed opener and can be especially advantageous when planting contoured rows.

9–4.6 Seeding Depth

Cultivars differ in their emergence capability but a seeding depth of 2.5 to 4 cm is optimum for most cultivars and soils. Shallower depths may be justified on crust-prone soils, and deeper planting may be justified on loose sands. Some cultivars have an inhibition of hypocotyl elongation at 25 °C, but all are unaffected by higher or lower temperatures (Burris and Knittle, 1975). High-quality seed and rotary hoeing are of little help in aiding emergence if extensive hypocotyl swelling occurs under these conditions. If sensitive cultivars are planted in soils near 25 °C, planting depth should be $<$ 2.5 cm.

Some planting guides recommend that soybean should not be planted in dry soil. However, if the seed zone is uniformly dry and if the planting date is moving past the optimum, it seems that a shallow planting in dry soil can often be justified. High-quality seed should remain viable for 10 to 14 days. If sufficient time has passed for the soil to dry, there are many regions that would have a high probability of rainfall within an additional 10 to 14 days. The penalty for late planting, especially with a prolonged wet period after an initial rain, may exceed the risk of rain not coming soon enough for emergence. A planting depth that places all seed in either dry or moist soil in the upper 4 cm of soil should be selected. This will avoid varied emergence times within a field and associated maturity differences at harvest time.

9–5 CROPPING SYSTEMS

9–5.1 Rotations

It is a common practice to rotate soybean with crops such as corn, wheat, or cotton (*Gossypium hirsutum* L.). There are a number of reasons to support growing soybean crops in rotation rather than in a continuous soybean sequence. These reasons include: (i) higher yields, (ii) a decreased need for N fertilizer on subsequent crops, (iii) breaking up of pest cycles, and (iv) spreading labor and machine requirements over a larger portion of the growing season.

In a previous review, Pendleton and Hartwig (1973) noted that soybean has been grown continuously in some areas without serious yield losses. Yet, most recent research has shown a yield advantage for rotation. In a 10-yr central Illinois study, Slife (1976) found that soybean yields averaged 14% higher when grown in a corn-corn-soybean or corn-soybean-wheat sequence as compared to a continuous soybean sequence. In Minnesota, Hicks and Peterson (1981) found that soybean yields in a corn-soybean rotation were 11% higher than in a continuous soybean cycle. In a 4-yr northern Illinois study, yields in a corn-soybean rotation were 21% higher than continuous soybean when grown under clean tillage and were 26% higher under reduced tillage (Mulvaney, 1984). In all three of the above studies, corn in rotation with soybeans yielded more than continuous corn. In Ohio, Jeffers et al. (1970) compared continuous cropping with 2- and 3-yr rotations of soybean, corn, and sugarbeet (*Beta vulgaris* L.). Compared to continuous cropping, soybean crops grown in alternate years yielded 3% more, while soybean grown every 3rd yr yielded 6% more. Sugarbeet and corn both responded more to rotation than did soybean. In Arkansas, Hinkle (1970) compared continuous soybean crops with various rotations involving cotton and soybean double-cropped after wheat. Soybean crops grown in rotation averaged 14% higher yields than continuous soybean and were more responsive to rotation than was cotton. In summary, these studies show that rotation soybean generally yield more than continuous soybean and several other crops also benefit from rotations that include soybean.

Soybean crops can cut fertilizer costs by reducing the need for N by subsequent crops (Higgs et al., 1976). The amount of N credit from soybean will depend on the cropping sequence and region of the country. Beuerman et al. (1982) emphasize that soybean plants cause a net removal of N from the soil, but Illinois recommendations call for an N reduction of 40 kg ha^{-1} for corn and 10 kg ha^{-1} for wheat when grown after soybean.

Rotations can be highly effective in breaking pest cycles. When herbicides were used, Slife (1976) observed fewer weed seeds after 10 yrs where soybean crops had been in the rotation than where continuous corn had been grown. Rotating herbicides within a continuous corn sequence caused a similar reduction in weed seeds. If soybean crops are rotated with corn, there is seldom a need to apply a corn rootworm (*Diabrotica* spp.) insecticide unless extensive infestations of volunteer corn were present in the soybean crop. In Arkansas, Hinkle (1970) reported that continuous soybean crops are subject to yield reductions from charcoal rot (*Sclerotium bataticola*), but rotations will reduce problems with this pest.

The soybean cyst nematode (*Heterodera glycines*) is often controlled by resistant cultivars, but more than one race is now present in some areas. Crop rotations can be effectively used to help prevent the excessive buildup of new races. In Arkansas, Price et al. (1976) have recommended a 3-yr rotation to help limit the spread of new races. In the 1st yr a nonsusceptible crop such as cotton, corn, or sorghum is grown. In the 2nd yr, a cultivar resistant to the prevalent race is grown. The 3rd yr, a cultivar susceptible to all races is grown.

Crop rotations can also effectively spread labor and machinery requirements. In the northern USA where the corn-soybean rotation is common, soybean planting can often be delayed until corn planting is complete without any subsequent reduction in yield potential. Yet, in this rotation early season soybean cultivars are often ready for harvest before corn. In areas with a longer growing season, double-cropping rotations use more of the total growing season in addition to spreading labor requirements.

9–5.2 Double-cropping

In double-cropping, soybean crops are planted after the harvest of a previous crop. The most common case in the USA is planting after a small grain such as wheat, but soybean plants are also double-cropped after vegetable crops, corn, and the initial harvest of a forage crop. During 1980 to 1983, 9 to 16% of the U.S. soybean area was double-crop planted (Crop Reporting Board, 1983a). Of the 1982 double-cropped soybean crops, No-Till Farmer (1983) reports that 39, 39, and 22% were planted with clean, reduced, and no-tillage, respectively. Since double-cropping after wheat is the most common case, this system will be emphasized in this discussion.

Planting and maintaining a vigorous weed-free wheat crop will maximize total yields and minimize weed problems in the soybean crop. Early wheat cultivars have been developed especially for double-cropping and can assist in timely soybean planting (Collins and Jones, 1975). Although timing of fertilizer application is not critical for soybean, most states recommend that P and K for both crops be applied at or before small grain planting (Herbek, 1982). If lime is needed, it is best applied in the fall to allow more time for neutralizing activity to occur. If drying and storage facilities are available, harvesting high moisture wheat may gain several days in the planting of soybean, a process that is more important in shorter-season areas.

Management of small grain straw differs greatly. Most agree that where a market exists, it is generally profitable to harvest and remove the straw. Otherwise, it should be chopped and uniformly spread behind the combine. In some areas of the southern USA, straw burning is common. Advantages of burning straw are destroying weeds and surface weed seeds, reducing potential for seedling disease, easier cultivation, and minimizing phytotoxic effects of wheat residue. These advantages must be weighed against the disadvantages of greater air pollution and possible long-term effects such as reduced soil organic matter and increased compaction (Collins, 1982). In Mississippi, Sanford (1982) obtained the highest and most consistent yields when soybean were no-till seeded into burned stubble, but these yields did not differ from systems where straw was burned followed by conventional tillage or where straw was shredded followed by no-till planting. Lowest yields were obtained when straw was incorporated into the soil or soybean was no-till planted into standing straw. In Arkansas, Collins (1982) has noted that wheat straw contains phytotoxins that can slow soybean growth and potentially reduce yields. The growth-retardant capacity dissipates after about 3 weeks of decomposition.

Having an adequate moisture supply for rapid soybean germination and emergence is crucial to successful double-cropping success. In many areas, maintaining wheat residue is important for moisture conservation and soil erosion control. Under no-tillage conditions in Virginia, Hovermale et al. (1979) concluded that a 20-cm wheat stubble resulted in optimum yields, but additional straw mulch showed no benefit.

Baldwin (1982) has reviewed weed control for double-cropping. Weed control programs should be based on past weed history, tillage program, and careful scouting after emergence. Often a program of preplant or preemergence (soil applied) and postemergence herbicides is necessary. Due to absorption by straw or ash, the activity of most soil-applied herbicides will be lower when applied following small grains. Therefore, the highest labeled rate for a specific soil texture and organic matter should usually be used. In a no-tillage system, all existing vegetation should be controlled before soybean emerges. No-tillage planting should not be considered if an emerged weed problem is so severe that complete control with burn-down herbicide is uncertain.

Compared to earlier planting dates, the later planting dates associated with soybean double-cropping cause large enough genotype $\times$ planting date interactions to justify evaluating double-crop soybean cultivars under the double-crop environments (Akhanda et al., 1976; Carter and Boerma, 1979). Traits which increase vegetative growth are desirable in double-cropped cultivars and may account for the reason that mid- to full-season cultivars often perform better than earlier season cultivars. Later planting dates also enhance the need for narrower rows and may justify slightly higher seeding rates. As with full-season production, double-cropped soybean has generally not responded to N fertilizer (Herbek, 1982).

Some areas in the southern USA have attempted double-cropping soybean after soybean. Cultivars are available which when planted shortly before the spring equinox, will mature near the summer solstice and permit a second crop (Boote, 1981). Timely planting, use of irrigation, and narrow rows are among the intensive management practices required for these systems (Woodruff, 1980; Boerma and Ashley, 1982). The higher risk nature of this system has caused Woodruff (1980) to conclude that this system may have more merit if crops other than soybean are considered for the second crop.

9–5.3 Intercropping

In the midwestern USA, researchers have used relay intercropping in an attempt to extend multiple cropping further northward or to obtain higher yields than obtained with double-cropping (Jeffers and Triplett, 1978; Chan et al., 1980; McBroom et al., 1981). In this system, soybean crops are planted into the growing small grains, so both crops occupy the same area until small grain harvest. Soybean crops finish out the season—much like a relay team in a track event. The risks in this system are greater than with double-cropping. Generally, the small grain rows are widened to accommodate soybean seeding equipment. Thus, small grain yields are often reduced in accordance with how much the rows are widened and how much the small grain plants are injured during soybean planting. Early season moisture is critical since the small grain crop is actively growing and can easily remove moisture from the soybean seedling root zone.

Soybean crops in relay systems sometimes grow tall enough to interfere with small grain harvest. Thus, soybean planting date should be selected with regard to growth stage of the small grain crop rather than calendar date. In central Illinois, soybean crops interplanted during late boot or early heading stages of small grain growth produced greater soybean yields than soybean planted during early jointing or early grain fill (Johnson and Brown, 1979). Choice of soybean cultivar was found to be important by Jeffers and Triplett (1978) and Johnson and Brown (1979). A period of vegetative growth after small grain harvest is essential to allow plants to fill in the canopy and support a reasonable seed load. Fuller-season indeterminate cultivars can have an advantage in this regard. On the other hand, McBroom et al. (1981) found no major differences in intercrop yields among a broad range of soybean cultivars.

As in any successful cropping system, early season weeds must be controlled in relay intercrop systems. Some preemergence soybean herbicides can be safely applied to small grains, or postemergence chemicals compatible with both crops can be used. In summary, relay intercropping requires a high level of management and adequate early season moisture. Further research will be required to determine if the system can be profitable in mechanized agriculture.

Another intercropping system that has received some attention is the planting of corn and soybean in alternate strips. In Minnesota, 1, 3, 6, and 12 rows each of corn and soybean have been planted in alternate strips using 76-cm row widths (Crookston and Hill, 1979). Although corn yields were impoved in some combinations, accompanying soybean yields were always reduced to the extent that none of the combinations made better use of the land area than did sole cropping.

9-6 POSTEMERGENCE CROP MANAGEMENT

9-6.1 Critical Stages

Establishing an adequate uniform stand is critical for high yields. Once this has been accomplished, a major management objective is to minimize crop stress throughout the remainder of the growing season. Final crop yield will be a product of the seasonal dry matter production and the partitioning of this dry matter into grain production. By minimizing stress the crop will be given the optimum opportunity to intercept sunlight and to convert this solar energy into dry matter. The proportion of the dry matter partitioned into grain yield will largely depend on the cultivar and planting date that were used.

Not all growth stages are as important as others in influencing final yield. In general, the early portion of pod filling (reproductive stages R4 and R5) is the period most responsive to an optimum growth environment while the vegetative period and later portions of pod filling are the least responsive. Optimum growth environment is of intermediate importance during flowering and early pod formation (reproductive stages R1-R3). The sensitive nature of early pod filling to stress has been shown by experiments that have induced defoliation (Caviness and Thomas, 1980), water stress (Sionit and Krammer, 1977), lodging (Woods and Swearingin, 1977), and shade (Schou et al., 1978). In all of these studies, stress during early pod fill reduced yield more than stress at any other growth stage. Other approaches have enhanced the dry matter supply by increasing photosynthesis beyond normal. Hardman and Brun (1971) found that CO_2 enrichment during vegetative and flowering stages did not increase yield whereas similar treatment during pod fill increased yield. Schou et al. (1978) found that light enrichment treatments increased yield most during late flowering to early pod fill.

Stresses during vegetative growth that do not affect stand will generally have only minimal effects on yield when compared to stresses

occurring at pod-filling and pod-formation stages. Stresses during vegetative growth that will not soon be outgrown should be corrected early to assure optimum conditions by reproductive development. For example, several postemergence herbicides will control their target weeds only if applied early in the season. Or, if nodulation fails and N deficiency develops early, fertilizer N should be applied. Other early season stresses may be temporary and are often outgrown without affecting yield. Such stresses may include minor crop injury due to herbicides or insect feeding as well as short-term drought.

Other chapters will discuss in detail postemergence crop management for irrigation (chapter 10 in this book), weed control (chapter 11 in this book), diseases (chapters 17 and 18 in this book), and insects (chapter 20 in this book). The general management concept that should be emphasized is that the most critical time to minimize stress is during early pod fill. The remainder of this section will review research with growth regulators.

9-6.2 Chemical Growth Regulators

Growth regulators continue to receive considerable attention, but compounds causing economic soybean yield increases are not currently available. Response to TIBA (2,3,5-triiodobenzoic acid) has been variable (Clapp, 1973; Stutte and Rudolph, 1971). Tanner and Ahmed (1974) reported that TIBA increased seed yield under good growth conditions but did not affect yield when conditions were poor for growth. Johnson and Anderson (1974) reported yield increases by applying low rates of 2,4-D (2,4-dichlorophenoxyacetic acid) 1 to 2 weeks before TIBA application at beginning bloom. However, they concluded that the feasibility of using 2,4-D with TIBA to increase yield is limited since optimum rates vary with environment and cultivar.

Morphactin-containing compounds can delay senescence and have been studied for their growth regulating properties with soybean. Clapp (1975) applied methyl-2-chloro-9 hydroxylfluroene-(9)-carboxylate at flower initiation and increased seed yield during 1 of 2 yrs. Dybing and Lay (1981) also used various morphactins to delay senescence but obtained either no change or a reduction in yield. Dybing and Lay (1982) found that a morphactin could increase soybean oil concentration but also resulted in a decrease in protein concentration.

Several additional growth regulating compounds from the chemical industry have been evaluated for effects on crop yield and have exhibited varying responses (Stutte and Rudolph, 1971; Blomquist et al., 1973; Stutte et al., 1975; Oplinger et al., 1978; Fuehring and Finkner 1978). To date, none of these compounds have achieved commercial use on soybean plants. The sometimes critical nature of application rate and timing as well as the difficulty of screening for yield will provide ample challenges as efforts continue in the future to identify growth regulators that may have potential to increase yield.

9-7 HARVESTING

9-7.1 Late-Season Frost Injury

Physiological maturity occurs when the grain reaches its maximum dry matter accumulation. In Kentucky, TeKrony et al. (1981) found that physiological maturity occurred when one normal pod on the main stem had reached its mature pod color (stage R7). In Minnesota, Gbikpi and Crookston (1981) reported that loss of green color in all pods is the best indicator of physiological maturity and occurs slightly later than appearance of one normal pod at mature pod color. Seed moisture content at physiological maturity will usually be in the range of 40 to 60%.

Frost after physiological maturity generally does not damage plants if pods remain intact. However, some regions have a limited number of frost-free days, and frost before physiological maturity can lead to crop damage. Premature death from frost can leave a cross section of the seed green. To grade U.S. no. 1 or 2, the percentage of green bean (*Phaseolus vulgaris* L.) cannot exceed 1 and 2%, respectively. In addition, early frost can reduce seed yield. Saliba et al. (1982) exposed plants to freezing temperatures at various growth stages after stage R4 (full pod). Freezing injury was first observed at temperatures ranging from -2.8 to -3.9°C and was positively associated with the concentrations of epiphytic ice nucleation active bacteria that were present on plant leaves. The latest growth stage at which freezing caused significant yield reductions differed with cultivar and varied from R6.0 to R7.2. Frost-injured plants reached maturity earlier, but had seed moisture equivalent to nonfrosted plants. Protein concentration was not affected by frost, but seed oil concentration was reduced if frost occurred before R6 (full seed). Judd et al. (1982) found that temperatures required to cause reductions in seed germination and vigor decreased as seed maturation progressed. Seed in yellow pods (55% moisture) showed reductions in germination and vigor following an 8-h exposure at -7°C whereas germination of seed in brown pods at 35% moisture was reduced only by exposure to -12°C.

9-7.2 Chemical Dessication

Chemical dessication prior to physiological maturity can reduce soybean yield (Whigham and Stoller, 1979). If applied after physiological maturity, dessicants can speed the rate of field drying without affecting yield. In Ohio, Byg and Walker (1974) found that a dessicant could advance harvest 2 to 5 days with early cultivars and 1 day or less with later-maturing cultivars. Thus, use of dessicants to advance harvest time can seldom be justified unless excessive green weeds are present.

9-7.3 Harvesting Equipment

As recently as the early 1970s, soybean-harvesting losses were generally more than 8% of crop yield and the majority of the losses occurred

at the combine header (Nave et al., 1973; Ayres, 1973). At this time, floating cutter bar headers which reduced harvest losses over a rigid platform by 25 to 30% were available and were beginning to be used. Nevertheless, it was apparent that significant reductions in harvest losses could be attained with further header improvements.

During the mid-1970s, several header improvements were provided that have led to the capability of reducing harvest losses by about 50%. Bichel and Hengen (1978) have reviewed these improvements and research contributing to their development. Several companies now offer flexible cutterbar headers that feature full-width skid shoes, improved cutterbar flexibility and long-floating dividers that assist in dividing the crop at the header edge. The flexible platforms can be locked straight for harvesting small grain, and have the advantage of being suited to any row width. In 1976, a flexible cutterbar platform was introduced that had guard and sickle spacings half the normal 7.6 cm, thus doubling the number of cutting edges. This feature lowers shatter losses and allows faster travel speeds. In 1975, a low-profile, row-crop header with individual row units that float independently to follow uneven ground was introduced. Corrugated meshed belts grip plants before they are cut by a rotary knife. Compared to flexible platforms, row-crop headers have the advantages of higher travel speeds, elimination of reel shatter and lower harvest losses, but are currently restricted to row widths of 76 cm or greater. Automatic height control is available for all header types. Nave et al. (1980) has reported that harvesting losses can be reduced to $< 4\%$ by the use of these improved combine headers.

Another development in harvesting has been the introduction of rotary combines. These machines have one or more rotors that replace the conventional cylinder and straw walkers for threshing and grain separation. In Illinois, Newbery et al. (1980) compared conventional-cylinder, single-rotor, and double-rotor machines at three seed moisture contents. Each threshing mechanism was operated at four peripheral velocities. Total threshing and separation losses were under 0.6% for all three machines. For all three mechanisms, percentages of split seeds increased as peripheral threshing speed was increased, but the increase was less with rotary threshing. When operated in the manufacturers' recommended cylinder or rotor-speed range, the percentage of splits was well below the allowable 10% limit for U.S. no. 1 soybean. Soybean susceptibility to breakage and seed-coat crack percentage did not differ as a result of the type of threshing mechanism or the cylinder or rotor speed.

Once harvest maturity is reached, it is not unusual for seed moisture to vary by several percentage points within a few hours. Drier grain is more susceptible to splitting. Newbery et al. (1980) have emphasized that a reduction in percentage of splits as a result of decreased cylinder or rotor speed may be offset by an increase in threshing and separating losses, especially for rotary threshing mechanisms. Grain loss monitors and on-the-go cylinder or rotor speed adjustments are features on modern combines that can help reduce grain loss and damage—especially at lower seed moistures.

With the increased interest in conservation tillage and soil erosion control, another important aspect of the combine is straw redistribution behind the machine. Straw choppers are more effective at this process than straw spreaders, and choppers with extended vanes are capable of spreading the straw over a full-header width.

9–7.4 Storage and Drying

Storage and drying needs have been outlined by Pepper et al. (1982). Soybean plants having 10% moisture or less remain in generally good condition up to 4 yrs. Market-grade soybean with about 12% moisture retain their grade for nearly 3 yrs, although germination and other qualities of the seed gradually decline over that period. Seed with 13% moisture can be safely stored from harvest to late spring but if moisture is 14%, the safe period is limited to the winter months. Usually, soybean above 15% moisture should not be stored without drying.

A few days in the harvest season may be gained if harvest begins at 18 to 20% moisture and the grain is later dried or aerated to a moisture level safe for storage. Humidity of drying air should be kept above 40% to avoid seed-coat cracking. Soybean for seed should not be dried at temperatures above 43°C. To avoid splits and other damage, maximum temperatures above 54 to 60°C are seldom recommended. To reduce respiration and the activity of mold or insects, grain should be cooled if the temperature of the grain mass is 6°C above outside air temperature, but grain temperature should not be reduced below 2 to 5°C.

9–8 CROP MANAGEMENT OUTSIDE THE USA

This chapter has emphasized management research from North America. Yet, the concepts discussed are applicable to other areas of the world. For example, extensive planting date and planting pattern studies have recently been conducted in two areas of Australia (Constable, 1977; Lawn et al. 1977). The results were quite similar to those obtained in the southern USA at similar latitudes.

A unique program that developed during the 1970s was the International Soybean program (INSOY). This program of the University of Illinois at Urbana-Champaign and the University of Puerto Rico, Mayaqüez Campus, cooperates with international and national organizations to expand the use of soybean. Since the inception of the INSOY cultivar testing program in 1973, more than 250 cultivars have been tested in over 100 countries by some 500 cooperators. Each year, INSOY publishes results of cultivar trials in its publication series. The INSOY Newsletter (INSOY, 1982) summarized a number of generalizations that can be drawn from tests to date:

1. In the tropics, yields tend to be larger from later-maturing than from earlier-maturing cultivars.
2. Yields are somewhat lower in tropical and subtropical than in temperate regions.
3. Plants are affected more by changes in altitude than by changes in latitude.
4. Shattering and lodging are seldom serious problems.
5. Size of harvested seed is not related to yield.
6. Yields from a newly introduced crop are usually good.
7. Poor nodulation is a major problem in popularizing soybean cultivation in the tropics.
8. Chemical composition of seed is comparable in all environmental zones.
9. Seed quality is a universal problem, but small seeded cultivars have better seed quality than large seeded cultivars.
10. Protein and oil concentration of a cultivar remains stable in different sites and environments.

9–9 SUMMARY

Since the early 1970s, several developments have greatly influenced soybean management. Plant breeders continue to release improved higher-yielding cultivars for all maturity zones. These cultivars must continually be evaluated under different cropping systems to determine the best cultivars for use in each cropping system. Development of improved herbicides as well as improved tillage and planting equipment, have allowed increased adoption of conservation tillage. These same developments have also allowed the increased use of narrower row widths. As further improvements occur in chemical pesticides and farm equipment, there will no doubt be an even greater adoption of these two important production practices.

Strong evidence has developed supporting the need to rotate soybean with other crops. Double-crop production of soybean has grown to become a significant crop rotation in itself. Several innovations in combine headers have resulted in reduced harvest losses. Nitrogen fertilization and growth regulators are two areas of management research that have received considerable attention, yet remain elusive in terms of providing any additional new tools to increase yields.

As soybean plantings have increased and as the management tools available for production have become more complex, a greater need has developed for educational efforts that carry these management alternatives to the producer. Future gains in soybean productivity will become even more dependent on imaginative, interdisciplinary research.

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10 Tillage and Irrigation

D. M. Van Doren, Jr.
Ohio State University and the
Ohio Agricultural Research
and Development Center
Wooster, Ohio

D. C. Reicosky
USDA-ARS-NCR
North Central Soil Conservation
Research Laboratory
Morris, Minnesota

Tillage and irrigation have been treated in this chapter as separate topics, even though both deal with management of soil water and effects of water on soybean growth. Literature cited to support various discussions will be illustrative rather than exhaustive, with the majority published after 1970. In the process of condensing the many disparate studies into a manageable size, some tangetial information has been omitted, with a regrettable loss of overall content.

10-1 TILLAGE

In order to illustrate the effects of tillage over a wide range of practices, five tillage treatments will be specified. There are infinite variations of these five as well as other general systems not listed herein, but these systems produce a wide range of soil environments for soybean growth for comparative purposes. Wherever possible all five will be documented during subsequent discussions, but since no single study encompasses all five systems, there is some incompleteness in the discussion.

1. Moldboard plow overall to 20-cm depth (fall or spring) followed by 10-cm overall secondary tillage with disc, harrow, etc. preplant and possibly postemergence cultivation.
2. Chisel plow overall to 20-cm depth (fall or spring) possibly followed by the same secondary tillage as with moldboard plowing.

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