IRRIGATION OF OILSEED CROPS

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ABSTRACT

Development, water use and yield formation of oilseed crops are inter-related. Greatest yields are expected with a well-established canopy, a plant population sufficient to support a large number of seeds set per acre and favorable weather conditions for an extended seed fill period. Oilseed water requirements closely follow canopy formation and evaporative conditions. Supplemental irrigation scheduled by the water balance method results in higher yields than with irrigation scheduled by growth stage. A straight-line relationship between yield and water use indicates the yield threshold (maximum water use with no expected yield) and yield response to increased water use. When precipitation, available soil water and limited irrigation fail to meet crop water requirements, yield reductions depend on the degree of plant water stress at critical stages of growth. Full-season soybean with full irrigation offers greatest productivity potential. A smaller yield threshold and extensive rooting system for sunflower provides advantages for limited irrigation or double-crop conditions. Winter canola can provide good productivity during fall and spring growing seasons when heat stress can be minimized.

INTRODUCTION

Oilseed crops (i.e. soybean, sunflower, canola) provide management options for irrigators seeking to reduce irrigation requirements, diversification and/or to reduce input costs. In 2003, soybeans were planted on 25% of irrigated cropland in Nebraska and on 12% of irrigated acres in Kansas (NASS). Sunflower is emerging as an irrigated crop in W. Kansas with a substantial increase in double-cropped sunflowers reported in 2005. Canola, irrigated in the San Luis Valley of Colorado, is an emerging feedstock for biodiesel production.

Irrigated soybean yields range from 55 to over 70 bu/A in variety trials conducted throughout the central Great Plains (2003 – 2005); greatest yields occurred in north-central Kansas and the east-central Platte valley of Nebraska. Varieties with top yields exceeded trial averages by 10%. Irrigated sunflower yields ranged from 2200 to 2900 lb/A in similar trials located in the central High Plains with greatest yields in NW Kansas. Top-yielding hybrids exceeded trial averages by

20% or more. Irrigated winter canola yields of 2600 lb/A have been recently reported for w. Nebraska.

Several irrigation guidelines are available for oilseed crops (Baltensperger et al., 2004; Bauder, 2006; Kranz et al., 2005; Rife and Salgado, 1999; Rogers, 1997; Rogers et al., 2005). This report is intended to integrate these guidelines with recent and regional field studies. Emphasis is given to crop development, water use and yield responses for irrigated oilseed crops.

DEVELOPMENT, WATER USE, YIELD FORMATION

Oilseed development, water use and yield formation are inter-related. Water, nutrients, sunshine and soil conditions must be sufficient, with minimal stress from pests and heat for crop growth to meet potential productivity. Water requirements and yield formation factors frequently correspond with development stages. Crop-specific considerations will follow a general discussion of oilseed development, water use and components of yield.

Development

Uniform seedling emergence is favored by soil-seed contact in a firm moist seedbed at a sufficient soil temperature. Expansive growth of seedling leaves require assimilates, derived from photosynthesis and nutrient uptake, as well as sufficient plant-available water for turgor-driven growth. Development of new leaves corresponds with plant temperature as well as time. Thus, leaf appearance is related to degree-days (^{o}F-d). For example, new leaves of a standard sunflower hybrid appear in 67 ^{o}F-d intervals. Leaf appearance and growth comprise the major processes of canopy formation.

Rapid canopy closure is desirable, because the crop canopy shades the soil and reduces evaporative water losses. Leaf expansion is typically exponential during early to mid-vegetative growth when supported by sufficient water, nutrients and non-stress conditions. Crop water requirements increase with canopy formation (Figure 1) because transpiration increases in proportion to leaf area. Light penetration into lower layers of the crop canopy is desirable. Photosynthesis can be limited by the amount of light reaching shaded leaves. Canopy formation nears completion with flowering for some determinant crop types such as sunflower. However, canopy formation continues with flowering for indeterminant crops such as canola and most soybean varieties of maturity group IV and earlier.

Reproductive development marks the end of the juvenile phase and begins with differentiation of floral buds. Potential seed number (a yield formation factor) can be set at this point, for determinant crops. Development and growth of floral organs proceeds systematically through stages including pollen shed, seed set and seed fill. Again, sufficiency of water, nutrients and light will support these yield formation processes. The onset of reproductive development frequently varies with thermal time, but may be affected by day-length as well. Reproductive stages of soybean, sunflower and canola are presented in Tables 1, 2 and 3.

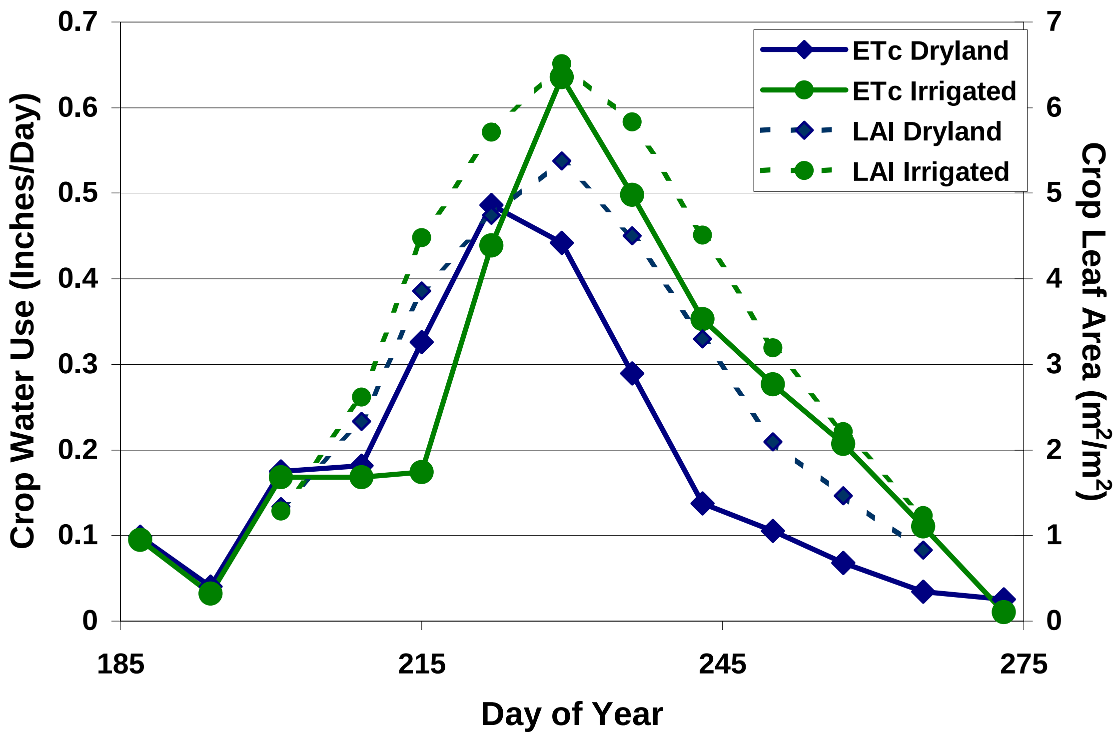

Figure 1. Sunflower water use and canopy formation (leaf area) for dryland and irrigated crop (adapted from Aiken and Stockton, 2003).

Table 1. Description of soybean reproductive stages (from Ritchie et al., 1994).

Stage	Title	Description
R1	Beginning flowering	Open flower at any node on main stem. Indeterminate plants start at bottom and flower upward. Determinate plants start at top four nodes and flower downward.
R2	Full bloom	Open flowers on one of the two uppermost nodes on main stem.
R3	Beginning pod	Pod 3/16 inch long at one of the four uppermost nodes on main stem.
R4	Full pod	Pod 3/4 inch long at one of the four uppermost nodes on main stem.
R5	Beginning seed	Seed 1/8 inch long in one of the four uppermost nodes on main stem.
R6	Full seed	Pod containing a green seed that fills pod cavity on one of the four uppermost nodes.
R7	Begin maturity	One normal pod on main stem has reached mature pod color.
R8	Full maturity	95% of pods have reached mature pod color. Approximate 5 to 10 days ahead of harvest.

Table 2. Description of sunflower reproductive stages (from Schneiter and Miller, 1981.)

Stage	Description
R-1	The terminal bud forms a miniature floral head rather than a cluster of leaves. When viewed from directly above, the immature bracts form a many-pointed starlike appearance.
R-2	The immature bud elongates 1/4 to 3/4 inch above the nearest leaf attached to the stem. Disregard leaves attached directly to the back of the bud.
R-3	The immature bud elongates more than 3/4 inch above the nearest leaf.
R-4	The inflorescence begins to open. When viewed from directly above immature ray flowers are visible.
R-5	This stage is the beginning of flowering. The stage can be divided into substages dependent upon the percent of the head area (disk flowers) that has completed or is in flowering. [i.e., R-5.3 (30%), R-5.8 (80%), etc.]
R-6	Flowering is complete and the ray flowers are wilting.
R-7	The back of the head has started to turn a pale yellow color.
R-8	The back of the head is yellow but the bracts remain green.
R-9	The bracts become yellow and brown. This stage is regarded as physiological maturity.

Table 3. BBCH decimal description of canola growth stages (from Canola Council of Canada www.canola-council.org).

Stage	Description
0	Germination: sprouting development
1	Leaf development
3	Stem elongation
5	Inflorescence (flower cluster) emergence
6	Flowering
7	Development of seed
8	Ripening

Stand establishment, canopy formation and reproductive development are significant components of the yield formation process. The crops' capacity to fill seed and achieve yield potential can depend on the active leaf area and number of seeds set per acre. Greatest yields are expected with well-established canopy, a plant population sufficient to support a large number of seeds set per acre and favorable weather conditions for an extended seed fill period.

Water use

Oilseed water requirements closely follow canopy formation and evaporative conditions. When scheduling irrigation relative to evaporative conditions, crop coefficients can be used to calculate daily crop water use (e.g., KanSched, Rogers et al., 2002). Typical crop coefficients, daily water use and development stages for soybean and sunflower are presented in Figure 2. Lower seasonal water requirements for canola can be expected for the spring growing season, which is shorter and with less evaporative demand than the summer growing season of soybean and sunflower. When soil water reserves are insufficient, actual crop water use is less than evaporative demand (Figure 3) and yield reductions are likely.

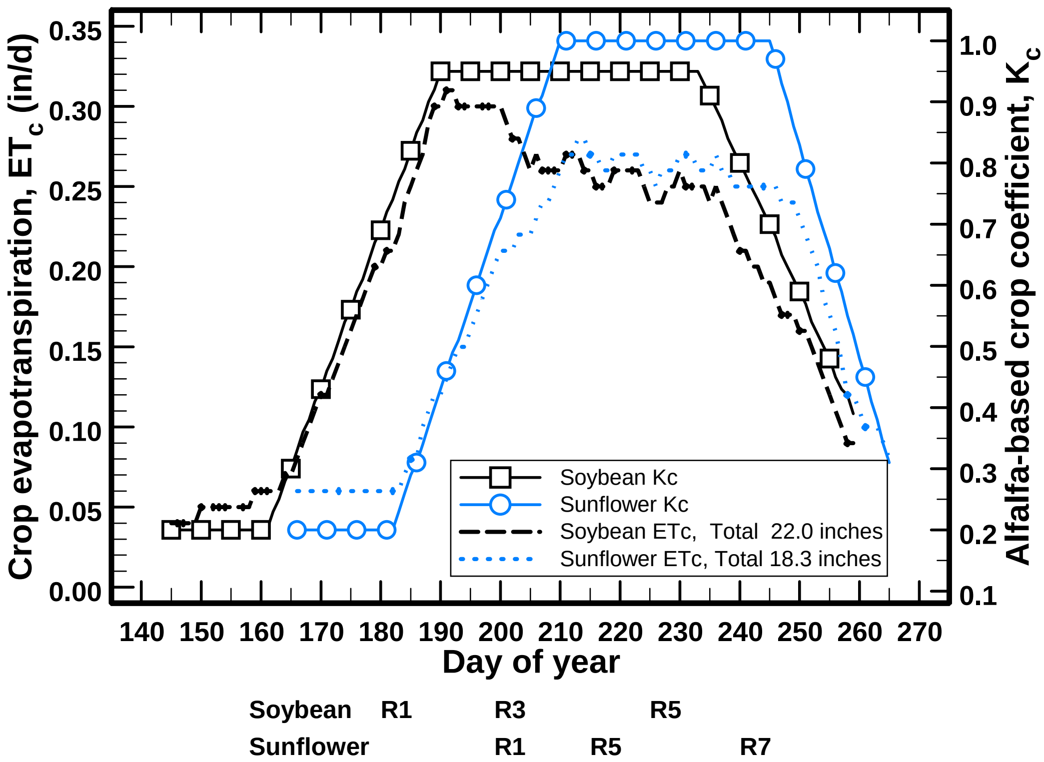

Figure 2. Crop coefficient (Kc) and daily crop evapotranspiration (ETc) for soybean and sunflower, calculated from 34 years (1972-2005) of weather recorded at Colby, KS. Reproductive development stages for soybean and sunflower are noted below the graph for reference.

Irrigation is generally required to meet crop water requirements in the central Great Plains. Two methods of scheduling irrigation are by water budget or by growth stage. Water budgets seek to maintain available soil water above a minimum value (e.g., 65% of available water holding capacity). Growth stage irrigation seeks to provide sufficient water to meet crop water requirements during specific critical stages. Studies in west-central Nebraska (Klocke et al., 1989; Elmore et al., 1988) and north-central Kansas (Gordon, 1996) indicate greater soybean yields with water budgets than with growth stage irrigation scheduling. Similar studies are in progress for sunflower.

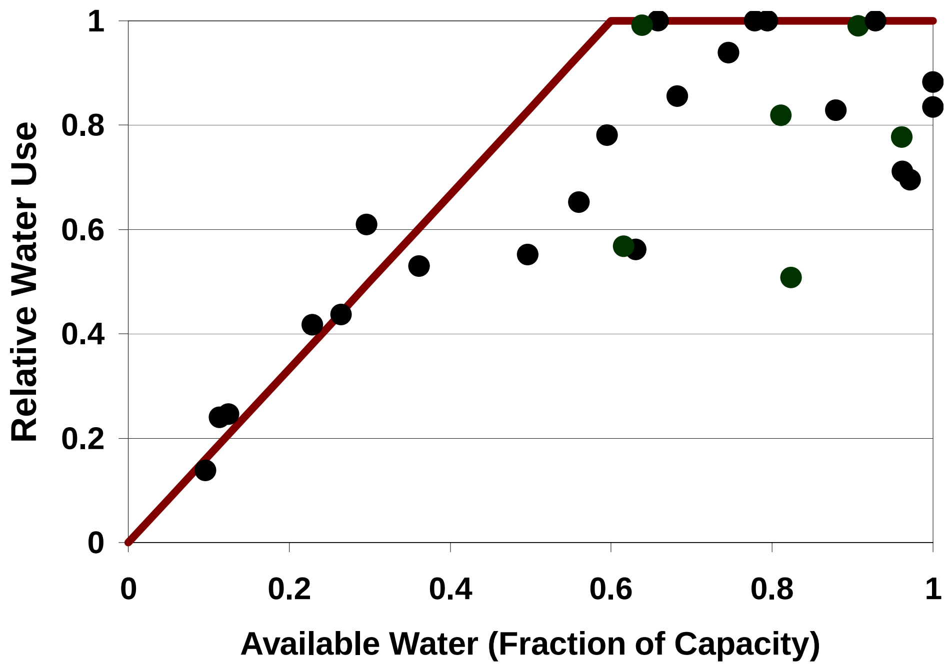

Figure 3. Water uptake by sunflower roots (relative to maximum observed uptake) is reduced when the available soil water in the wettest soil layer is less than 60% of available water capacity. The line approximates an envelope containing observations of water uptake in relation to available soil water. Water uptake from all soil layers is equivalent to crop evapotranspiration (Aiken and Stockton, 2003).

For limited irrigation systems, water available to the oilseed crop is likely to be insufficient during canopy formation and/or reproductive development stages. For example, Figure 4 shows that sunflower canopy formation at flowering (R5) can be limited by available soil water during earlier reproductive growth (R3). Limited irrigation, while not providing full water requirement of the crop, can improve seed yield. For example, a one-inch irrigation applied to soybean in SE Kansas at R4 (full pod), R5 (beginning seed) or R6 (full seed) increased seed yield by 241 lb/A. The R4 application increased the number of seeds per plant while the R5 and R6 applications increased seed weight (Sweeney et al., 2003).

Yield responses

When supply of water limits crop water use, seed yields are frequently limited as well. A straight line can represent the relationship between seed yield and seasonal crop water use (Figure 5). For example, soybean yield at Colby, KS increased 3.7 bu/A with each additional inch of water use (precipitation, irrigation plus change in stored soil water). The yield threshold (the amount of water use at which the first increment of yield is expected) occurred with 7.3 inches of crop water use. Similar results were reported for west-central Nebraska (Klocke et al., 1989; Payero et al., 2005). For sunflower, the yield threshold was 4.2 inches and the yield response was 166 pounds per inch of crop water use (Figure 6).

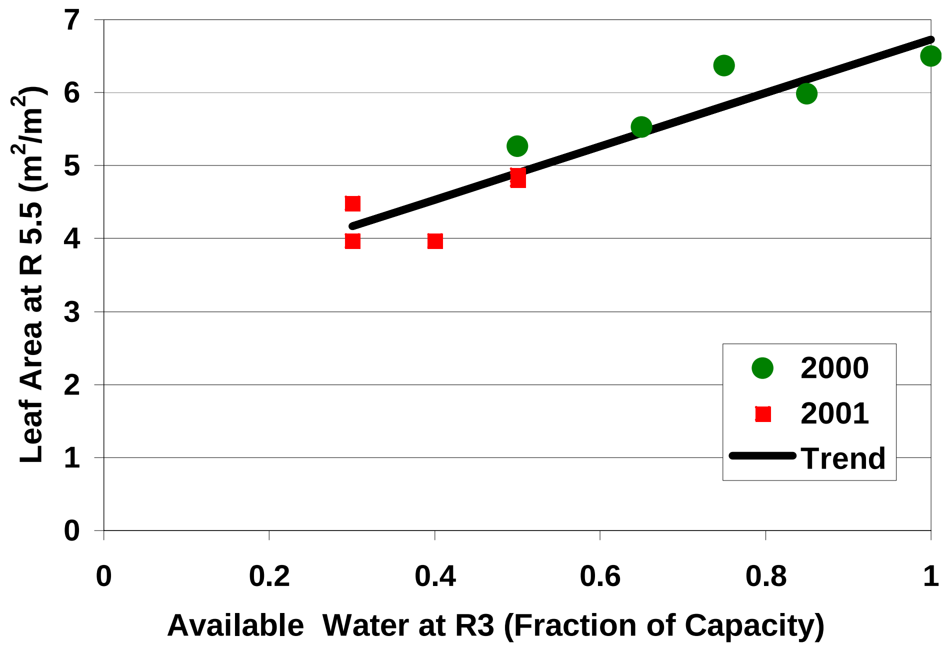

Figure 4. Sunflower leaf area at flowering (R5) in relation to available soil water at mid-bud (R3) growth stage (Aiken and Stockton, 2003).

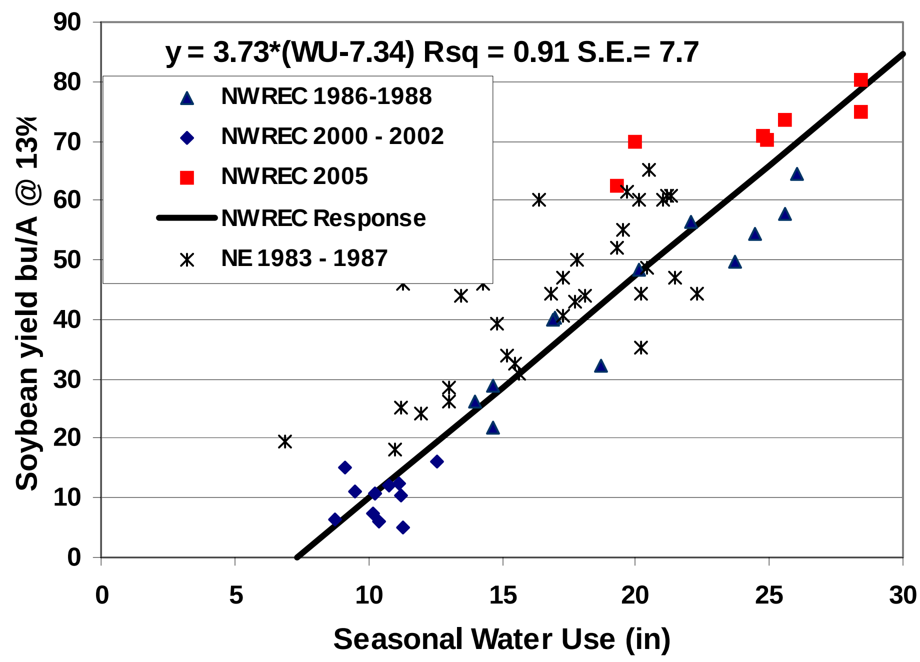

Figure 5. Soybean yield response to seasonal water use at Colby, KS and central Nebraska sites (adapted from Aiken and Gordon, 2003; Lamm, 1989).

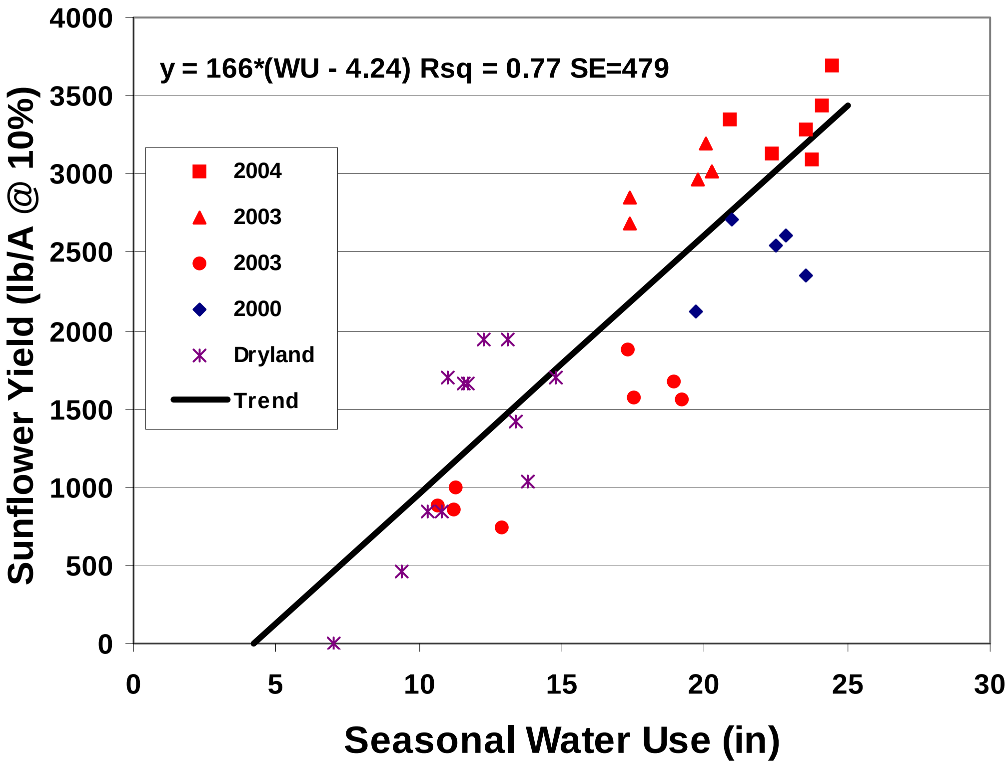

Figure 6. Sunflower yield response to seasonal water use at Colby, KS (adapted from Aiken and Stockton, 2003; Lamm, pers. comm).

Under limited irrigation, water can be allocated to minimize the impact of water deficits on yield formation. For example, soybean yield can be most sensitive to water deficits during flowering and full pod reproductive stages (Table 4). The yield response to limited irrigation can be greatest if water is applied to alleviate deficits during stages which are most critical for yield formation. Critical stages, with maximum crop water use rates, are R3 to R6 for soybean and R1 to R7 for sunflower. Water stress during these critical stages is expected to reduce yield potential. However, Table 4 and Figure 4 indicate that sunflower is also susceptible to soil water deficits during vegetative growth. Additionally, a recent study at Akron, CO showed that delaying limited irrigation until the R4 stage increased oil content of sunflower, though yields were less than that of full irrigation. Irrigators with limited capacity will benefit from good judgement and additional water use and growth stage information.

Double cropping

Soybean or sunflower can be double-cropped after wheat harvest where growing season temperatures and the length of growing season are sufficient. Yield potential will be reduced due to the reduced growing period and effects of the yield threshold. The smaller yield threshold of sunflower may indicate a comparative advantage for double-cropping. Cooler weather can extend the duration of grain fill period but may alter the composition of fatty acids in oil (cooler temperatures can slow the conversion of linoleic fatty acids to oleic forms in oilseeds).

Table 4. Susceptibility of soybean and sunflower to soil water deficits (Adapted from Lamm and Stone, 2005).

	Soybean		Sunflower	
Growth Stage	Time period (days)	Susceptibilty Factor	Time period (days)	Susceptibilty Factor
Vegetative	38	6.9	53	43.0
Flowering	33	45.9	17	33.0
Seed Formation	44	47.2	23	23.0
Ripening	-	-	7	1.0

CROP-SPECIFIC CONSIDERATIONS

Soybean

A full-season, well-watered soybean crop offers relatively greatest productivity potential for non-calcareous soils with acid to neutral pH. The nitrogen-fixing crop can require minimal N fertilizer, provided soil is properly inoculated. Iron chlorosis can limit productivity on calcareous soils with pH exceeding 7.5 (Penas and Wiese, 1990); foliar diseases can also limit productivity. "Early determinate varieties are recommended for production systems involving narrow rows, high seeding rates, early plantings, good fertility, and a yield potential in excess of 50 bushels per acre" (Schapaugh, 1997). Photoperiod effects on flower initiation highlight the importance of selecting varieties from maturity groups appropriate for planting period and desired days to maturity.

Sunflower

Sunflower is commonly planted in early June, in the central Great Plains, to avoid stem weevil and sunflower moth pests. The deep-rooted crop can extract more soil water than other crops. Combined with the smaller yield threshold, sunflower can give relatively greater yields when water supplies are limited. The heat-tolerant crop also tolerates calcareous soil and high pH conditions. Decreasing daylength (when less than 15 h) near the R1 stage can reduce the duration of reproductive stages, due to photoperiod effects, when grown at latitudes less than 40^{o}.

Canola

Winter canola is established in early fall and harvested mid-summer, similar to winter wheat. The yield advantage of winter varieties over spring varieties is similar to that of winter wheat, approximately 30%. The small-seeded cool-season crop may be difficult to establish, as well as sensitive to heat stress during yield formation stages.

Physiological perspectives

Oilseed crops tend to produce less yield than feed grain crops (i.e., corn and grain sorghum). Less productivity results from differences in photosynthesis and in seed composition. The C3 physiology of oilseed crops is inherently less effective than the C4 physiology of feed grain crops. The C3 carbon-fixing enzyme Rubisco, is approximately 2/3 effective when exposed to atmospheric oxygen concentrations. Plants with C4 physiology also use Rubisco, but it functions in bundle sheath cells where oxygen concentrations are very small, and the enzyme functions at near complete effectiveness, resulting in increased crop productivity.

The second difference between oilseed and feed grain crops involves oil and protein content. The amount of starch which can be produced from a unit of carbohydrate (sugars produced from photosynthesis) is 0.88. The remaining fraction, 0.12, is consumed in the conversion process. More carbohydrate is used up in the formation of oil (0.67) and protein (0.65). As a consequence, the fraction of carbohydrate converted to oil is 0.33; to protein is 0.35. Smaller seed yields of oilseed crops is a consequence of greater oil and protein (in the case of soybean) content, for which a greater fraction of the photosynthetically-fixed carbohydrates are consumed.

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