A summary of the effects of growth stage scheduled irrigation in soybean

For the Protein Research Foundation

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August 2013

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1. INTRODUCTION

Soybean (*Glycine max*) is a very important crop in the animal feed industry where soybean oil cake (90%) and full fat soy (10%) are the main soybean commodities (PRF, 2013a). The oil is usually used as household cooking oil or for industrial uses. There is, however, a huge potential to use this oil for the production of bio-diesel.

According to the PRF (2013a), the oilcake need in 2012/2013 is estimated at 1.9 million ton, with the local production set at 918 180 t. This implies that about a million ton of oilcake needs to be imported to fulfil in the requirement. Of this million ton, about 75% will be made up by soybean oilcake. This all implies that there is still a huge scope for more soybeans to be produced in South Africa, but the fact is that space is limited. The alternative is to produce more of the soybean under irrigation to increase yield per unit area. According to Smit (1998), yields under irrigated conditions (3 to 5 t ha^{-1}) can be up to twice as high as under dryland conditions (1 to 2 t ha^{-1}).

From other crops we, however, know that there is specific critical growth stages during which the plants will not tolerate drought stress. For maize it is 20 day before till 20 days after pollen shed, while for cotton it is during the effective flowering stage. So for most crops where seed is harvested, the period just before until a bit after flowering is the most critical growth period, requiring good irrigation management.

In South Africa only about 12% of soybean is produced under irrigation, which represented about 55 000 ha in the 2012 season (PRF, 2013b). Although soybean has always played an important role, little information is available on irrigation of soybeans. Smit (nd); Birch *et al.* (1990); and Pannar (2006) are the only authors who have written about it in extension pamphlets.

The aim of this literature review is not to state how much water is needed, but to identify the most sensitive growth stages for soybean in terms of drought and also to evaluate when the best time is to start and stop irrigation.

2. LITERATURE REVIEW

2.1 INTERNATIONAL INFORMATION

2.1.1 When to start and stop irrigation in soybean

Irrigation should not commence too early – thus during vegetative growth the plants can be stressed a bit otherwise a shallow root system and tall plants that fall over easily will develop (Specht, 2002). He also stated that soybean yield do not respond to irrigation during vegetative and early flowering stages, and that irrigation during these growth stages could lead to the plant being more susceptible to diseases. Irrigation in the early stages can be postponed if there was water stored in the soil profile before plant. He claims that in 15 years research, heavy irrigation (bringing the soil back to no less than 75% of field capacity on a weekly basis) at pod elongation has always resulted in a positive yield response. After this the irrigation can be reduced to 50% of field capacity on a weekly basis, but should not stop until all the beans have fully enlarged. Hodges and Heatherly (1983) also advise that soybean should be irrigated until seeds have reached their full size before irrigation should be stopped. Constable and Hearn (1980) found that plant available water should be kept above 60% during pod fill but could be depleted below 60% during the vegetative growth stage.

Eck *et al.* (1987) subjected soybeans to water stress during different reproductive stages. This resulted in a 9-13% reduction in seed yield when stress initiated during R1/R2 were extended to R3. When this stress was extended further to R4.5, the yield reduced by 46%, while if the stress only started at R3 to R4.5, the yield reduction was only 19%. When stress started at R5 but was relieved at R6 the yield decrease was between 15 and 46% over two seasons, while stressing it from R5 throughout R6 (5 weeks total) increased the yield decrease to between 45 and 88% for the two seasons. When the stress was only applied throughout R6 (3 weeks total) the yield decrease was between 21 and 65% for the two seasons. The main difference between the seasons was that the first received a higher rainfall than the second season. This answers the question as to when to stop irrigating. If producers stop too early, it can have a substantial effect on the final yield. This is supported by Specht (2002) which stated that if irrigation is stopped too early, it hastens maturity and results in lower yields as the individual seeds cannot reach their maximum potential (size).

2.1.2 Irrigating soybean according to growth stage

Klocke *et al.* (1989) did a trial with indeterminate soybean cultivars in Nebraska. They advocate that soybean should be irrigated according to growth stages. In doing so, one need to give attention to the soil water holding capacity, climatic factors and the irrigation system itself. They recommend that in the warmer and dryer production areas, irrigation to meet evaporative demand should be applied from the beginning of the season (thus vegetative growth stage), while in moist areas, it can be delayed until the flowering stage. But even in the latter case the soil should have a good water holding capacity and be filled to field capacity before planting. This is similar to what Specht (2002) has suggested. Their research, however, indicated that rainfall supplemented with irrigation from flowering in most cases resulted in better yields than waiting till pod fill. In these cases, irrigation at flowering often resulted in similar yields than where full irrigation from start to end of season was applied.

In a trial with a determinate and indeterminate cultivar, both responded the best in terms of yield when irrigation was applied during both flowering and pod growth or only during pod fill stage (Schulze, 1986). Where the plants only received water during the flowering stage and nothing during vegetative nor pod fill, the yield was reduced. With more water applied, yield, number of pods per plant, LA and LAI increased, while maturity was delayed. The literature cited by Schulze (1986), in general agree that irrigation improved yields while irrigation during flowering and/or pod fill is important for good yields. Kanemasu (1981) reported a reduction in yield due to irrigation during vegetative and flowering stages. Griffin *et al.* (1981) reported that irrigation during pod fill only, resulted in lower yields while irrigation during flowering and pod fill increased yields.

Kadhem *et al.* (1985a; 1985b) evaluated 16 soybean cultivars (determinate and indeterminate) in terms of sensitivity to drought at seven growth stages ranging from vegetative growth through to seed fill stage. The control only receiving rainfall, while a fully irrigated treatment was also included. From this study it was concluded that soybean yields in general reacted best to irrigation applied between growth stages R3.5 to R4.5, thus during the mid to late pod elongation stages.

Korte *et al*. (1983a; 1983b) also used different soybean cultivars and irrigated them during R1 to R2 flowering (F), R3 to R4 pod elongation (P), or R5 to R6 seed enlargement (S). Plants irrigated during any of the reproductive stages resulted in less flower and pod abortion, while irrigation later in the ontogeny resulted in fewer ovules being aborted. However, more flowers and pods did not significantly increase the seed yield, while fewer aborted ovules did. Irrigation during F, resulted in lowest yield due to lower 100 seed mass, while the 100 seed mass of P and S plants were not affected or increased respectively, leading to higher seed yields, but with S plants showing the highest seed yield increase.

Sweeney and Granade (2002) reported an increased in yield with applying irrigation during R1 to R2 (beginning to full bloom), at R4 (full pod), or at R6 (full seed). They stated that while R1/R2 or R4 irrigations had a positive effect on number of seeds, irrigation at R6 in addition increased individual seed mass.

Sweeney *et al.* (2003) and Specht *et al.* (1989) compared an irrigated versus none irrigated soybean crop as well as irrigating it during certain growth stages (R4, R5 or R6). The irrigated crops on average yielded 20% (Sweeney *et al.*, 2003) to 50% (Specht *et al*., 1989) more than the none irrigated crop.

Shaw and Laing (1966); Shipley and Regier (1970); Dusek *et al*. (1971); Doss *et al*. (1974); Sionit and Kramer (1977); Constable and Hearn (1980); Korte *et al*. (1983a, 1983b); and Stegman *et al.* (1990) all stated that soybean seed yield is least sensitive to water deficits during the vegetative stage, more sensitive during flowering and pod set, and most sensitive during pod fill. Krote *et al*. (1983); Westgate and Peterson (1993); and Liu *et al*. (2003) all reported more pod abortion if the plants are stressed during flowering and early pod growth, leading to lower yields.

Demirtas *et al.* (2010) withhold water during six growth stages (during vegetative growth V_5 (fifth trifoliate), flowering (R_2), podding (R_4), seed fill (R_6), full bloom + podding ($R_2 + R_4$), and podding + seed fill ($R_2 + R_6$)), with a fully irrigated and a dryland treatment included as controls. Their data (averaged over two years) indicated a decrease in yield from 3.79 t ha^{-1} for the well irrigated control to 2.81 t ha^{-1} for the treatment stressed during pod growth and seed fill ($R_2 + R_6$) (Table 1). As expected, water use efficiency (WUE) under dryland conditions (T_8) was the best for all the treatments while it decreased with between 0.14 and 0.11 kg m^{-3} when the plants did not receive water during R_6 (T_5), $R_2 + R_4$ (T_6) and $R_2 + R_6$ (T_7). Irrigation water use efficiency was also severely negatively affected by withholding irrigation during R_6 (T_5) and $R_2 + R_6$ (T_7) (Table 1).

Table 1. Effect of drought treatments on irrigation, crop evapotranspiration (ET_c) seed yield, water use efficiency (WUE), and irrigation water use efficiency (IWUE) of soybean in 2005 and 2006. (Adapted from Demirtas *et al.*, 2010)

Treatment[a]	Irrigation (mm)		ET_c (mm)		Yield (t ha^{-1})		WUE (kg m^{-3})		IWUE (kg m^{-3})	
	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
T_{1} (Full irrigation)	428	453	684	771	4.00	3.57	0.58	0.46	0.37	0.34
T_{2} (V5)	323	310	616	638	3.66	3.46	0.59	0.54	0.38	0.45
T_{3} (R2)	348	358	654	759	3.64	3.41	0.56	0.45	0.36	0.37
T_{4} (R4)	322	297	642	711	3.51	3.27	0.55	0.46	0.34	0.40
T_{5} (R6)	242	217	578	646	2.91	2.67	0.50	0.41	0.20	0.28
T_{6} (R2 + R4)	291	349	632	689	3.35	2.93	0.53	0.43	0.32	0.25
T_{7} (R2 + R6)	211	269	571	603	3.01	2.60	0.53	0.43	0.28	0.20
T_{8} (Dryland)	0	0	381	346	2.42	2.07	0.64	0.60	-	-

Treatments with growth stages next to the treatment number indicates the stage during which the plants did not receive irrigation.
V5: 5 nodes on the main stem beginning with the unifoliate node; R2: Full bloom; R4: Pod 2 cm long; R6: pod containing full-size green beans

As the soybean plant ages from R1 (beginning bloom) through R5 (seed enlargement), its ability to compensate for stressful conditions decreases and there is an increased reduction in the potential yield (Foroud *et al.*, 1993). Water deficit during flowering (R2 stage) has little effect on seed yield whereas a deficit during pod elongation (R3 stage) and seed enlargement (R5 stage) are significant. Shaw and Laing, 1966; Doss *et al.*, 1974; Woods and Swearingen, 1977; Sionet and Kramer, 1977; Ashley and Ethridge, 1978; Korte *et al.*, 1983a; 1983b; Huck *et al.*, 1983; Foroud *et al.*, 1993 all reported similar results than Demirtas *et al.* 2006. Water deficit at either the R2 or R3 stages significantly reduced yields (Brown *et al.*, 1985).

Dogan *et al.* (2007) applied full irrigation during the vegetative stages where after the soybean plants were either not stress (control) or stressed at various reproductive stages (R1-R2; R3; R4; R5 and R6). The result of the stress was a reduction in yield for all the stressed treatments, with the highest reduction reported for stress at R6.

Sutherland and Danileson (1980) showed that water stress during flowering followed by full irrigations increases yield. Water stress imposed on soybeans throughout the growing stages reduces vegetative growth and affects flowering and yield (Boyer *et al.*, 1980; Hodges and Heatherly, 1983).

Water stress during reproductive development often decreases the seed size in soybean (Sionet and Kramer, 1977; Momen *et al.*, 1979; Kadhem *et al*., 1985a; 1985b). Meckel *et al.* (1984) ascribe this to a shortening in the length of the seed filling period, rather than reduced seed growth rate.

Most of the observations made in this section can be explained by the results from Malek *et al*. (2012). They investigated absolute growth rate (AGR), LA and LAI of field grown soybean and reported that for all the genotypes tested, the growth rate was slowest during the vegetative phase leading to a smaller portion of total dry mass produced before flower initiation, and the bulk thereafter. Due to the plants reaching maximum LA and LAI during the pod fill stage, AGR was at its maximum. Taking this into account, it could explain why yield reacted more positively to irrigation during the reproductive than vegetative growth stages. They observed that irrigation at R4 increased the number of seeds, while irrigation at the other two stages increased the seed mass.

De Costa and Shanmugathasan (2002) measured numerous growth related characteristics of the soybean plant in relation to its response to withholding of irrigation during certain growth stages. By withholding water during V1 – R1, R1 – R4 and R4 –R8, the following was reported. LAI, radiation interception and biomass increased with more growth stages being irrigated, but the singular growth stage showing the highest positive reaction to this was the vegetative growth stage. Radiation use efficiency was most positively affected by irrigation during flowering and pod fill stages, while for pod number, and harvest index it was at the flowering stage. Mean pod growth rate during pod filling exceeded corresponding overall crop growth rate of all treatments indicating translocation of reserves.

2.2 SOUTH AFRICAN INFORMATION

Birch *et al.* (1990) compiled a pamphlet on irrigation of Soybeans in Natal. According to this, about 60% of the soybean crop produced in KwaZulu Natal is under irrigation, mainly in the Bergville, Winterton and Colenso areas and that without irrigation the yields were 1.5 t ha^{-1}, while with irrigation between 2.5 and 3.5 t ha^{-1} were harvested. In the higher rainfall areas of KwaZulu Natal, irrigation, however, seldom contribute to higher yields. Irrigation of soybean is thus only advised if it is economically viable. It is stated that between 450 and 750 mm well distributed rainfall can lead to high yielding soybean crops. In Figure 1, the seasonal water demands of soybeans are presented. According to this figure, water demand peaks at early flowering through early seed development, making these stages very sensitive to water stress. Birch *et al.* (1990) then states that the least critical stages in terms of water stress is during vegetative growth and then again after the seeds have reached their maximum size, while the most sensitive stages are during pod elongation and seed development. Failing to reducing water stress during these stages could lead to a 30-50% loss in yield, which cannot be overcome by irrigation at later stages. They recommend that during early vegetative and near maturity, the soil water depletion can be as high as 70% of plant available water, while it should be decreased to 30% during pod elongation and seed development. For the rest of the season the soil moisture content can be maintained close to 50% of plant available water. Lastly, they also state that about 75% of the total water requirements of a soybean crop should be available during 60 to 140 days after planting, depending on the growing season length of the cultivar.

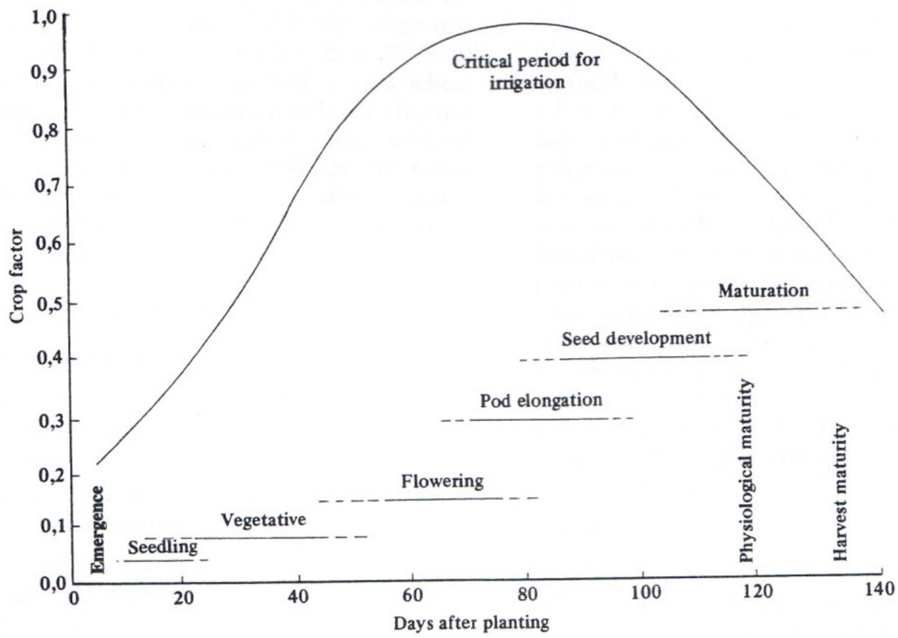

Figure 1. Seasonal water demands of soybeans (Birch *et al*., 1990).

Pannar, South Africa, also has a production guide specific for soybean production (Pannar, 2006). They advise soybean producers to ensure that enough water is available at plant for fast germination and also to irrigate to prevent soil crusting in soils where that can be a problem. The most critical growth stage in terms of water management is during pod filling.

It is also during this stage that a lot of P and K are taken up for seed growth and a water deficiency could thus lead to severe deficiencies in these elements. Should water stress occur during the late grain fill stage, Pannar estimate a yield loss of as much as 30%, emphasizing what was said earlier, namely not to stop irrigating too soon.

SUMMARY

From local and international literature it is clear that irrigation can have a huge positive effect on soybean yields. This positive effect can, however, be diminished if the plants are stressed during the flowering, but especially the pod and seed growth stages. Irrigation during vegetative growth only seems feasible if the soil profile is depleted of plant available water at plant or if very low rainfall is experienced during this stage. In both these cases it is not advised to irrigate to field capacity, but to keep the soil water content between 50 – 70% of plant available water (PAW). During flowering it can be kept at 50 – 60% depletion of PAW, while at pod and seed growth, depletion should not be allowed to go below 25 – 30% of PAW.

The consensus of when to start and when to stop irrigation is as follows: Start irrigating during vegetative growth only if the plants are facing severe water stress. Most of the time first irrigation is advised at the beginning of flowering, but some authors have also pushed the first irrigation till the start of pod formation without significant yield reductions. Again, exactly when to start will depend on the plant available water in the soil and the evapotranspiration demand due to the climate and the plant. About 99% of authors recommended irrigation during the pod and/or seed growth stages. The date to stop irrigation would thus be after the seeds have reached the maximum size, but before it begins to mature. At maturity, no significant translocation of photosynthetates will take place as the leaves are dying down and the whole plant is shutting down. Irrigation at this stage might even be harmful to yield as it might delay harvesting due to too wet soil, resulting in increased seed losses.

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