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# Impact of Superabsorbent Polymer on Yield and Growth Analysis of Soybean (*Glycine max* L.) Under Drought Stress Condition

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**Abstract:** The aim of present study is evaluation of the effect of four rates of superabsorbent polymer (0, 75, 150 and 225 kg ha$^{-1}$) and three irrigation intervals (6, 8 and 10 days) on growth and yield of soybean (cult. $L_{11}$) under field conditions. The results of this study showed that there was a significant effect among irrigation intervals on seed yield, Total Dry Matter (TDM), Leaf Area Index (LAI), Crop Growth Rate (CGR), plant height and Harvest Index (HI). Moreover, The highest increase in seed yield, Total Dry Matter (TDM), Leaf Area Index (LAI), Crop Growth Rate (CGR) and Harvest Index (HI) were achieved at 225 kg ha$^{-1}$ polymer compared with the control (without polymer). These results indicate that application of superabsorbent polymer at 225 kg ha$^{-1}$ appeared to increase all the above growth and yield attributes.

**Key words:** Soybean, superabsorbent polymer, irrigation intervals

## INTRODUCTION

World population is increasing at an alarming rate and is expected to reach about six billion by the end of year 2050. On the other hand food productivity is decreasing due to the effect of various abioticstresses; therefore minimizing these losses is a major area of concern for all nations to cope with the increasing food requirements. Drought stress is one of the major limiting factors that affect crop growth and productivity. Also in several key production environmentals (soil and groundwater) is becoming depleted through compaction, erosion, salinization, net nutrient export and diminishing water supply Global climate change is now generally considered to be underway (Hillel and Rosenzweig, 2002) and is expected to result in a long-term trend towards higher temperatures, greater evapotranspiration and an increased incidence of drought in specific regions. Hydrophilic polymers may have great potential in restoration and reclamation projects where opportunity for post planting irrigation is limited and thus storing water available for plant establishment and to avoid desiccation is critical. Woodhouse and Johnson (1991) classified polymers into 3 groups: Starch-polyacrylonitrile graft polymers (starch copolymers), vinyl alcohol-acrylic acid co-polymers (polyvinylalcohols) and acrylamide sodium acrylate co-polymers (cross-linked polyacrylamides). All of these hydrogels when used correctly and in ideal situations will have at least 95% of their stored water available for plant absorbtion (Johnson and Veltkamp, 1985). These substances can hold 400-1500 g of water per dry gram of hydrogel (Woodhouse and Johnson, 1991; Bowman and Evans, 1991). Polyacrylamide degradation in soil was found to be approximately 10% year$^{-1}$ (Barvenik, 1994; Tolstikh *et al*., 1992). Evidence indicates polyacrylamids do not break down into their dangerous component of acrylamide (Barvenik, 1994). They have been studied intensively in recent decades for their promising applications in chemical engineering as sensors (Anderson *et al*., 2000), in the biomedical field as materials in medicine (Wichterle and Lim, 1960), in pharmacy as drug delivery systems (Peppas, 1986), in agriculture and industry as adsorbents and separation membranes (Abd El-Rehim *et al*., 2004; Abd El-Rehim *et al*., 1999), in solving some ecological problems (Abdel-Aal *et al*., 2003) and in other modern technologies (Hirasa, 1993). Polyacrylamide (PAM) can stabilize soil structure but does not remediate poor soil structure. In arid region of the world, PAM is being used quite to stabilize soil structure, which leads to increased infiltration and reduced erosion on furrow irrigated fields (Lentz and Sojka, 1994; Lentz *et al*., 1998; Trout *et al*., 1995; Wallace and Wallace, 1986; Zhang and Miller, 1996). Application of polyacrylamide at a rate of 20 kg ha$^{-1}$ increased infiltration rates by 10 flood on susceptible loess soils, especially in presence of electrolytes (Shainberg *et al*., 1990). Smith *et al.* (1990) found that addition of PAM at a rate of 20 kg ha$^{-1}$ resulted in increased final and cumulative infiltration by 7 to 8 fold compared to the control. Additionally, they observed decreased erosion by more than one order of magnitude compared to control (with out PAM). Along with reducing

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soil loss, polymers can reduce nutrient losses from soils. PAM treatments reduce sediment loss, thus improving runoff water quality parameters, such as total-P, $NO_3^-$ and biological oxygen demand (Lentz and Sojka, 1994; Lentz *et al*., 1998; Lentz *et al*., 2000; Entry and Sojka, 2003). Lentz and Sojka (1994) found that the addition of PAM into the irrigation water significantly reduced the runoff of phosphorous in sediment by 84% nitrogen in sediment by 83% and total sediment load by 57% in exposed Idaho soils. Hydrogels can be used as fertilizer release agents in the soil matrix. Mikkelsen (1994) showed that although polymers hold fertilizers tightly the plant can still access some of nutrients and the hydrogel acts as a slow release mechanism. The addition of superabsorbent polymers to a sandy soil changed the water holding capacity to be comparable to silty, clay or loam (Huttermann *et al*., 1999). Blodgett *et al*. (1993) found that adding superabsorbent polymers to the soil matrix increased the water holding capacity and also increased the water availability to be used plants. The superabsorbent polymers also prolonged water availability for plant use when irrigation stopped (Huttermann *et al*., 1999). The superabsorbent polymers media also allowed for 19 days to pass before plants started to die whereas in control (with out polymer) plants started to die after 5 days of drought (Huttermann *et al*., 1999). El-Amir *et al*. (1993) who showed that the amendment of the soil with Superabsorbent polymers prolonged the time until 50% of soil water was evaporated. Superabsorbent polymers usually have some effect on plant establishment with the greatest benefit for moisture loving plants planted in dryer conditions. Incorporation of superabsorbent polymers into sand soil media for *L. esculentum* (tomato) (Henderson and Hensley, 1986), *Lactuca sativa* (lettuce), *Rhaphanus sativa* (radish) and *Triticum aestirum* (wheat) (Johnson and Leah, 1990) increased dry weight and increased the time for irrigation stop to wilting. *Pyracantha cocinnea* (scarlet firehorn) and *Rhododendron* sp. (azalea) had increased survival and increased dry weights in container production when a superabsorbent polymer was incorporated into the media (Bilderback, 1987). Drought sensitive annual, such as *Petunia parviflora* (petunia), responded well to superabsorbent polymer in dry conditions and increased flower numbers and dry weight (Boatright *et al*., 1997). In tomato, seedling survival, growth and dry weight were unaffected by hydrogel incorporation in the soil (Bearce and McCollum, 1997; Bes and Weston, 1993; Adams and Lockaby, 1987; Pill and Jacono, 1984). The aim of present study is evaluation of the effect of four rates of superabsorbent polymer (0, 75, 150 and 225 kg $ha^{-1}$) and three irrigation intervals (6, 8 and 10 days) on growth and yield of soybean (cult. $L_{11}$) under field conditions.

## MATERIALS AND METHODS

The study was carried out during the spring and summer seasons of 2003 at the Agricultural Engineering Research Farm of the University of Tehran at Varamine. Soil in the test area was silty loam and organic matter content of approximately 0.9%. Saturated paste extract Electrical Conductivity (EC) of this soil was 1.39 dS $m^{-1}$ with $CaCO_3$ equivalent of 2% and pH of 7.3. The experimental design was a randomized complete block in a split-plot arrangement with three replications. Four rates of superabsorbent polymer (SAP) were taken in main plots and irrigation interval treatments were kept in subplots. Treatments were: 75, 150 and 225 kg SAP $ha^{-1}$ and a control (no SAP applied); 6, 8 and 10 days intervals irrigation. Soybean cult. $L_{11}$ was used. The tested superabsorbent polymer was Tarawat A200. Soil was inoculated with *Bradyrhizobium japonicum* bacteria (USDA 110). Soil moisture (water content) was measured directly by the gravimetric method. This entails sampling the soil with a core sampler on the day before irrigation, weighing the moist soil, then drying it in an oven (105°C) and then weighing the dry soil. Amount of required water was calculated on the basis of difference between moisture content before irrigation and at FC (Eq. 1):

$$Fn = (\theta 2 - \theta 1) rD \qquad (1)$$

Where:

Fn = The net irrigation depth (mm),
θ2, θ1 = Soil moisture content at FC and before each irrigation, respectively,
r = Soil bulk density and
D = Rooting depth (mm).

A 1 $m^2$ sampling area selected randomly from each experimental unit at weekly intervals from $V_2$ to $R_7$. The same three plants were separated into leaves, stems, pods and seeds. Dry weight samples were oven-dried at 60°C to a constant weight to determine growth on a dry-weight basis. Primary data consisted of dry biomass of Leaf (L), Stem (S) and Pods (P) and total plant biomass (W) which was calculated as the sum of the component dry biomass value (L+S+P). Sampling was not conducted in the center two rows of each experimental unit, as these were reserved for final grain yield estimation. Growth and development stages and plant height information were taken based on a sample of three plants randomly collected from the hand-harvested section. Plant growth stages were determined according to the methods of Fehr and Caviness (1977). Leaf area index was measured with a leaf area meter. The means of the primary data were transformed to natural logarithms to obtain homogeneity of errors (Steel and Torrie, 1980) and then were subjected to smooth curve fitting to describe the relationships between the primary measures and GDD. The relationship between primary total plant biomass data [ln (g $m^{-2}$)] and GDD (Growth Degree Days) may be written as Eq. 2 and between primary leaf area data [ln ($m^2$ leaf area $m^{-2}$ land area)] and GDD as Eq. 3 (the sample area was consistently 1 $m^2$).

$$\ln W = f_w(GDD) \quad (2)$$

$$\ln L = f_L(GDD) \quad (3)$$

Crop growth rate (CGR; g $m^{-2}$ land area per week) is the rate of change of the total plant dry biomass over time and was calculated as the first derivative of Eq. 1:

$$CGR = \exp[f_w(GDD)] \times f'_w(GDD) \quad (4)$$

## RESULTS AND DISCUSSION

The statistical analysis revealed that effect of different rates of polymer and irrigation intervals were significant for seed yield and Harvest Index (HI). The mean seed yield differed significantly between different rates of polymer ($p = 0.0047$) and irrigation intervals ($p<0.0001$). The highest increase in seed yield was achieved at 225 kg $ha^{-1}$ polymer (6417±468 kg $ha^{-1}$) and the lowest increase in seed yield occurred at 75 kg $ha^{-1}$ polymer (4424±276 kg $ha^{-1}$) compared to the controls (Table 1 and Fig. 1). The mean seed yield was the highest at 6 days irrigation interval. The mean seed yield for the irrigation interval of 8 days was much higher than that for 10 days interval (Table 1). Significant increases in total leaf area, dry weight and relative growth rate (Al-Harbi *et al*., 1999) and advanced flowering in tomato (Ouchi *et al*., 1990), were reported. Wallace and Wallace (1990) obtained high tomato yields with polymers.

Different rates of polymer and irrigation intervals influenced harvest index (HI). HI differed significantly under irrigation intervals ($p<0.0001$). The highest HI was observed at 6 days irrigation interval (%44±0.58). Application of polymer tended to increase HI of soybean compared to the controls (without polymer). HI at the highest rate of polymer (225 kg $ha^{-1}$) was in the top of quantity (Table 2 and Fig. 2).

Canopy height at the end of the experiment differed significantly among irrigation intervals ($p<0.0001$). The canopy height of soybean was greatest at 6 days irrigation intervals (98.83 cm). The mean canopy height for the irrigation interval of 8 days was much higher than that for 10 days interval (Table 3). There was no significant effect of polymer rates on canopy height.

statistical analysis for Total Dry Matter (TDM) showed that there was a difference among rates of polymer in response to irrigation intervals. As expected, with increasing rates of polymer, this criterion was

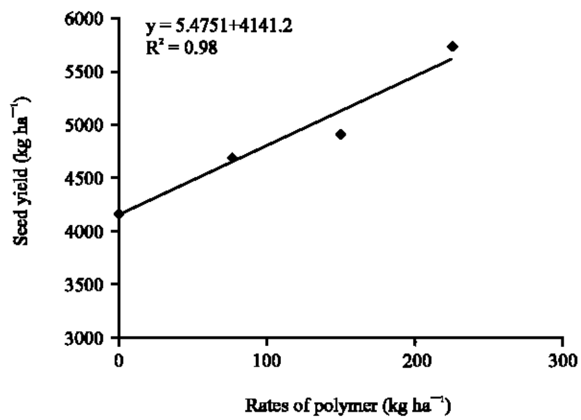


Fig. 1: Relationship between seed yield and rates of polymer

Table1: The effect of different rates of polymer and irrigation intervals on seed yield of soybean (*Glycine max* L.) (kg $ha^{-1}$)

| Irrigation intervals (days) | Rates of polymer (kg $ha^{-1}$) 0 | 75 | 150 | 225 | Mean values |
|---|---|---|---|---|---|
| 6 | 177±4533 | 347±4872 | 4982±69 | 6417±468 | 5201±416 |
| 8 | 4033±194 | 4542±239 | 4778±289 | 5079±112 | 4608±221 |
| 10 | 3950±150 | 4424±276 | 4482±234 | 4990±154 | 4461±212 |
| Irrigation mean | 4172±182 | 4613±134 | 4748±145 | 5495±461 | |

Table 2: The effect of different rates of polymer and irrigation intervals on harvest index (HI%) of soybean (*Glycine max* L.)

| Irrigation intervals (days) | Rates of polymer (kg $ha^{-1}$) 0 | 75 | 150 | 225 | Mean values |
|---|---|---|---|---|---|
| 6 | 0.57±41.51 | 41.99±0.34 | 43.63±0.25 | 44.00±0.58 | 42.65±0.70 |
| 8 | 38.27±0.21 | 38.31±0.13 | 39.53±0.12 | 39.63±0.21 | 38.93±0.37 |
| 10 | 36.46±0.22 | 36.58±0.13 | 38.00±0.13 | 38.61±0.41 | 37.41±0.53 |
| Irrigation mean | 38.58±1.32 | 38.96±1.60 | 40.39±1.68 | 40.75±1.65 | |

Table 3: The effect of different rates of polymer and irrigation intervals on canopy height of soybean (*Glycine max* L.) (cm)

| | Rates of polymer (kg ha$^{-1}$) | | | | |
|---|---|---|---|---|---|
| Irrigation intervals (days) | 0 | 75 | 150 | 225 | Mean values |
| 6 | 97.00±5.20 | 94.67±6.23 | 98.83±3.59 | 97.17±9.85 | 96.91±0.11 |
| 8 | 70.17±4.21 | 72.17±8.67 | 67.00±2.75 | 76.17±6.22 | 71.37±1.91 |
| 10 | 63.83±6.51 | 65.17±2.68 | 63.33±1.36 | 60.17±2.17 | 63.12±1.05 |
| Irrigation mean | 77.00±10.16 | 77.33±8.89 | 76.38±11.27 | 77.83±10.71 | |

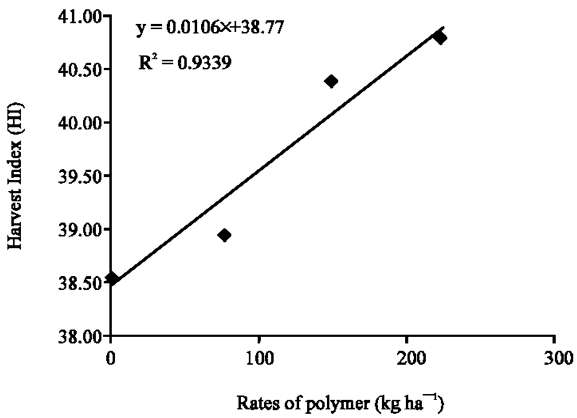


Fig. 2: Relationship between harvest index and rates of polymer

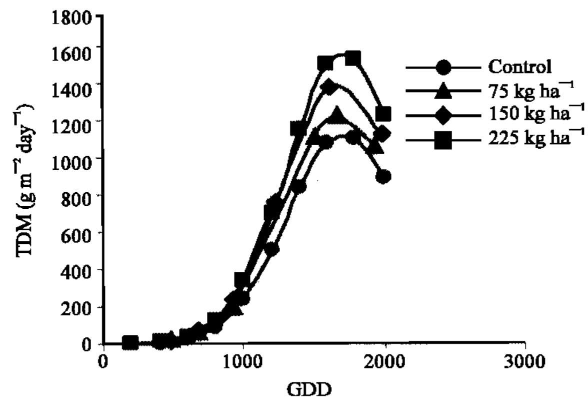


Fig. 4: The effect of different rates of polymer on TDM of soybean at 8 days irrigation interval

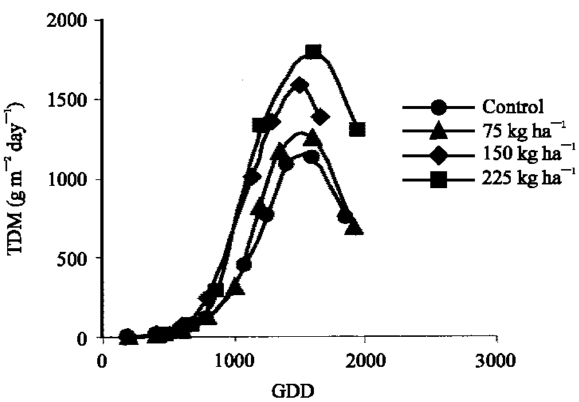


Fig. 3: The effect of different rates of polymer on TDM of soybean at 6 days irrigation interval

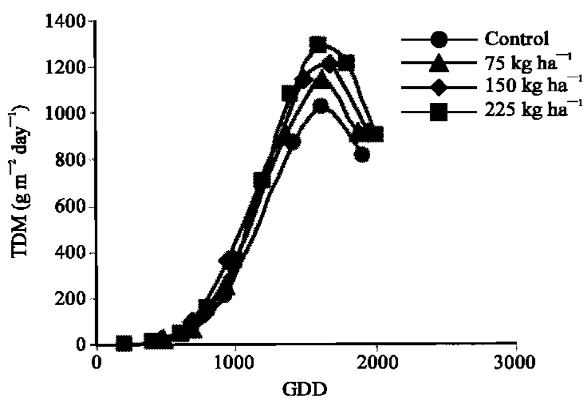


Fig. 5: The effect of different rates of polymer on TDM of soybean at 10 days irrigation interval

increased significantly. TDM (leaves+stems+pods) in all treatments increased to a maximum around R5/R6 and then declined. TDM at three irrigation intervals was increased at 225, 150, 75 kg ha$^{-1}$ polymer rates compared to the controls (without polymer) (Fig. 1-3). The greatest increase in TDM occurred at the highest rate of polymer at all irrigation intervals. Also the TDM was greatest at 6 days irrigation interval. TDM for the irrigation interval of 8 days was much higher than that for 10 days interval (Fig. 4 and 5). Bilderback (1987) found that *P. cocinnea* (scarlet firehorn) and *Rhododenron* sp. (azalea) had increased survival and increased dry weights in container production when a polymer was incorporated into the media.

The results from Fig. 6-8 show that the polymer increased Leaf Area Index (LAI) at all irrigation intervals. The plants which grew in soils with 225 kg ha$^{-1}$ polymer rate had the greatest LAI compared to the controls (without polymer). Water deficit (8 and 10 days irrigation intervals) reduced LAI. This measure was greatest at 6 days irrigation interval. Drought stress has been shown to reduce the rate of leaf initiation (Clough and Milthorpe, 1975) and leaf expansion (Watts, 1974), thereby resulting in smaller leaf area which can adversely affect yield (Hsiao *et al*., 1976). Similar reports from pot and plot trials showed that drought decreases the rate of leaf appearance and decreases the total assimilatory surface of leaves by up to 50% (Kazakov *et al*., 1988). Brevedan and

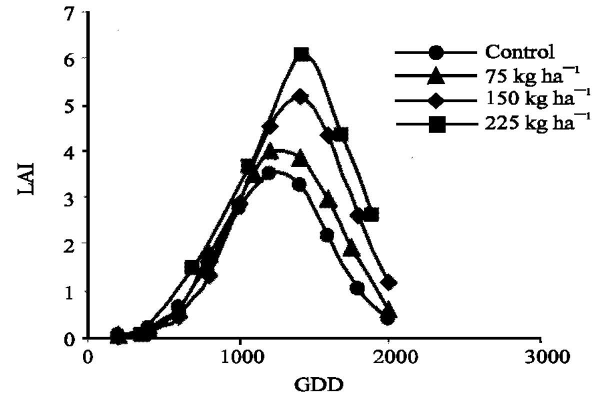


Fig. 6: The effect of different rates of polymer on LAI of soybean at 6 days irrigation interval

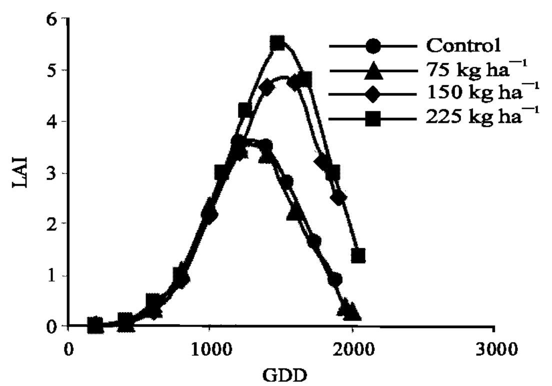


Fig. 7: The effect of different rates of polymer on LAI of soybean at 8 days irrigation interval

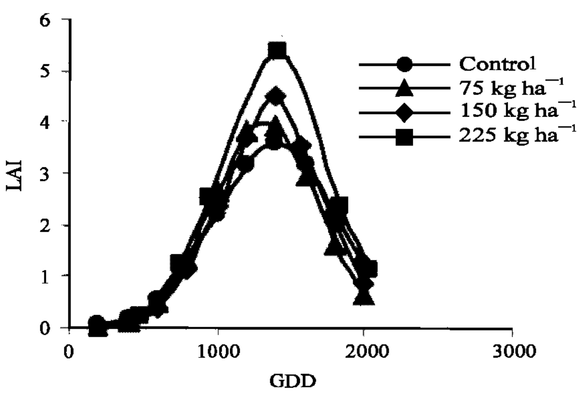


Fig. 8: The effect of different rates of polymer on LAI of soybean at 10 days irrigation interval

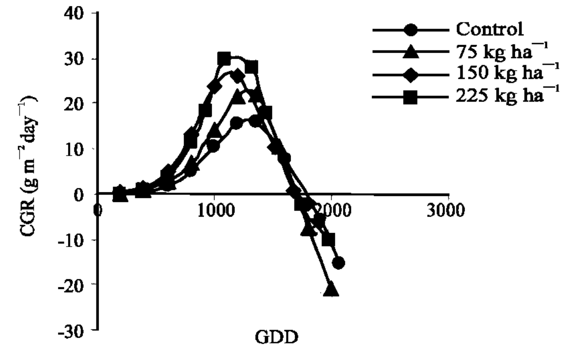


Fig. 9: The effect of different rates of polymer on CGR of soybean at 6 days irrigation interval

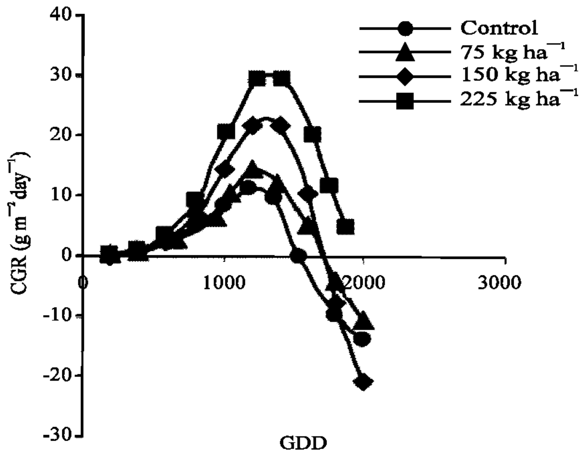


Fig. 10: The effect of different rates of polymer on CGR of soybean at 8 days irrigation interval

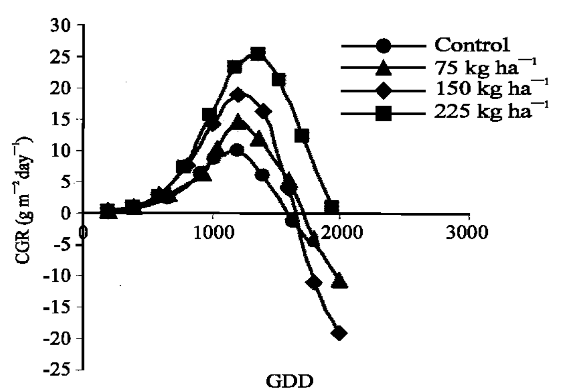


Fig. 11: The effect of different rates of polymer on CGR of soybean at 10 days irrigation interval

Egli (2003) showed that leaf area declined more rapidly in the continuous-stress treatment than in the no stressed control.

Crop Growth Rate (CGR) at three irrigation intervals was increased at 225, 150, 75 kg ha$^{-1}$ polymer rates compared to the controls (without polymer) (Fig. 9-11).

The greatest increase in CGR was achieved at the highest rate of polymer at all irrigation intervals. This measure was greatest at 6 days irrigation interval. CGR for the irrigation interval of 8 days was much higher than that for 10 days interval.

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