Impact of growth substances applications on yield parameters of wheat under water stress

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Abstract

A greenhouse experiment was conducted during three consecutive years at Ayub Agricultural Research Institute, Faisalabad (Pakistan) to find out the effect of drought stress on yield parameters of wheat. From the study it was reported that water deficit decreased grains per spike; 1000-grain weight, total biomass, grain yield and harvest index significantly while application of growth substances improved them. Pre-sowing seed soaking in ethephon solution produced the highest 1000-grain weight of 44.39 g, increased per hectare yield by 37 percent and harvest index by 8 percent in comparison with control. Biological yield was significantly decreased by shortage of moisture supply. While number of productive tillers per plant was decreased under moisture stress conditions by 6 percent, this was enhanced by application of growth substances. Growth substances application though was found not to be much beneficial under normal moisture supply, but under moisture stress economic returns were enhanced significantly. Thus, the maximum increase of 36 percent in net income was obtained from ethephon application under drought stress.

Keywords: wheat; osmotic; drought stress; growth hormones; ontogenesis; seed soaking; foliar spray


Introduction

Drought is an important issue of the day in Pakistan, as silting of dams has curtailed their storage capacity to an alarmingly low level. Thus, production of wheat like other field crops is being adversely hampered in irrigated areas of Pakistan. In different parts of the world growth substances are used to grow wheat under stress conditions. There are various strategies to encounter the adverse effects of drought on plants including management practices, improved irrigation systems and growing drought tolerant plant varieties. But the most fascinating and readily available strategy is the use of plant growth regulators (PGRS) to improve the drought tolerance (Hamada, 2000). Water stress results in an aberrant change in physiological processes and it has the potential to produce injury as a result of aberrant metabolism and may be expressed as reduction in growth, yield, value or...
death of the plant or a plant part. Moisture deficiency especially at critical growth stages of wheat (Robertson et al., 1994; Khan, 2003) such as sowing, crown root development (Chaudhry et al., 1975), tillering (Schneider et al., 1969); jointing (Day and Sukhawari, 1970), heading (Iqbal et al., 1999) milking and grain filling (Ali et al., 1987) may ultimately lead to drastic reduction in grain yield. In a study water stress at crown root stage decreased grain yield by 17 percent (Akram and Iqbal, 2003). The impact of water stress at early stages of germination and immediately following radical emergence has been well documented. Water is a vital constituent of plant tissues and its deficiency severely affects plant growth and grain yield (Talukder et al., 1989). Duywar (1984) reported linear yield-water relationship for wheat in drylands. Moursi et al., (1979) found that grain yield increases linearly with the increase in availability of moisture. Svihra and Hudcova (1986) observed that water stress and high temperature reduced the development of grains per ear. In wheat genotype TAM-101, 57% of the tillers produced grain bearing heads under well watered conditions, whereas, under drought only 43% of the tiller produced grain-bearing heads. Cabeza et al. (1993) observed that water stress imposed by cessation of watering affected secondary tillers, their number, size and foliar growth. Gupta et al (2001) noted that imposition of water stress at boot stage caused a greater reduction in number of tillers in wheat. Umar et al., (1993) found that in sorghum water stress adversely affected dry matter accumulation and yield components. Yasin et al., (1993) examined the effect of moisture stress on growth, maturity and nutrients uptake of wheat in green house. Stress conditions decreased both grain and straw yield of all varieties. Khanna et al., (1994) found that water stress affected accumulation of dry matter. Both grain number and grain weight were reduced in response to stress. Mogensen et al. (1994) exposed barley plants to water stress and found that grain yield was decreased by 2.2% and total dry matter by 1.9% per stress day. Drought caused reduction in biomass, grain yield, and number of heads per plant, kernel weight and harvest index (Schonfeld et al., 1988). In a study Ashraf et al. (1996) recorded 60% reduction in wheat grain yield under terminal drought.

Similarly, Abayomi and Wright (1999) reported that water stress during growth stages of 32-65 days after sowing decreased spikelet fertility, number of grains per ear and grain yield. In a study Akram (1993) found that harvest index decreased from 41 in well watered to 34 in drought conditions. In study moisture stress greatly affected the biological and economic yield and the harvest index (Khan 1991). Robertson and Giunta (1994) studied response of wheat under water stress and found that spike biomass was reduced at anthesis from 58 to 90% compared with control. Christen et al. (1995) investigated the effect of temporary water shortage at different stages and noted that dry weight and number of tillers per plant were reduced as compared to control. Subedi et al. (1997) found that in a pot experiment wheat sterility was increased by water stress. Reduction in grain yield by 44% and significant reduction in biomass, grain and straw yield per plant was reported by Ashraf (1998). Similarly tiller abortion was more extreme under drought than under well watered conditions. Ahmad and Arian (1999) found that water stress especially during terminal and post anthesis stages in bread wheat, decreased grain weight. Reduction in endosperm due to water deficit could be the probable cause for low grain weight. The effect of water stress on yield and yield components of two durum wheat varieties was studied by Iqbal et.al., (1999) at various growth stages and was found that withholding irrigation at any growth stage adversely affected their yield and yield components.

In a study on wheat it was noted that the harvest index, 1000-grain weight, number of tillers per square meter and grain yield were significantly affected by CO₂ and water stress (Pleijel et al., 2000). In an experiment 30 wheat cultivars were tested under near optimum and drought stress conditions and it was found that number of kernels per spike, 1000-grain weight and grain yield were more sensitive to drought stress than plant height and number of spikelets per spike (Dencic et al. 2000). Ahmadi and Baker (2001) noted that water stress caused pre mature grain desiccation and resulted in a marked
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decline in grain sucrose and grain weight. Brisson et al., (2001) studied the effect of drought at early vegetative growth stages and concluded that among yield components long grain filling period and higher harvest index was the most favorable traits for drought tolerance contributing to grain yield. In a pot experiment Gupta et al., (2001) noted that water stress at boot and anthesis stages decreased shoot dry weight, number of grains, biological yield, grain yield and harvest index to a greater extent. Foulkes et al., (2001) reported a larger decrease in wheat biomass due to water stress. Desalgen et al., (2001) subjected 18 bread wheat genotypes to water stress and noted that grain yield, 1000-grain weight, plant height and days to maturity were greatly affected by stress and there were significant differences among varieties in this regard. Water stress reduces plant growth and manifests several morphological and biochemical alterations in plants leading to massive loss in yield (Leruitt, 1980).

Material and Methods

This field experiment was undertaken in Pakistan. In this experiment five grains of wheat variety Inqulab-91 were sown in buckets employing factorial design having three replications in the greenhouse. Two moisture levels viz., no stress (M₁) and moisture stress (M₂) at crown root stage were randomized in main plots and growth substances including distilled water (T₁), ethephon @ 400 mg l⁻¹ (T₂), paclobutrazol @ 300 mg l⁻¹ (T₃), SADH @ 2000 mg l⁻¹ (T₄) and triadimefon @ 200 mg l⁻¹ (T₅) in the sub-plots. Whereas, stages of their application, i.e., pre-sowing seed treatment (S₁), foliar spray at crown root development (S₂), heading (S₃), and grain filling stage (S₄) were kept in sub-sub-plots. Water stress at crown root development stage was imposed simply by withholding irrigation. Fertilizer NPK was applied @ 150-100-50 kg per hectare and all the other agronomic practices were kept uniform. Kernels per spike of three randomly selected plants were counted and mean was calculated. With the help of an electric balance 1000-wheat grains, total biological yield and economic yield (grain yield) per plant were weighed in grams. Dividing the economic yield by biological yield and multiplying by 100 harvest index was computed. The data collected were subjected to analysis of variance employing the method given by Steel and Torrie (1980) using factorial design. Comparisons among the treatment means were made using the computer statistical program MSTAT-C (Freed and Eisensmith, 1986) and Pearson’s simple correlation coefficient (r) of different wheat plant parameters was calculated against the tabulated values given by Snedecor and Cochran (1989). The computer package “HARVARD GRAPHIC” was used to prepare the graphs.

Results

Plant height

Plant height of any crop is a consequence

![Fig. 1. Plant height as affected by moisture stress and growth substances (Mean of 3 years)](image-url)
of interaction between environmental and genetic factors and contributes a lot towards biological yield. Plant height was suppressed from 58.32, 58.42 and 58.36 cm in normal moisture conditions to 49.12, 46.58 and 47.98 cm under moisture stress during 1994-95, 1995-96 and 1996-97, respectively.

The application of growth substances affected plant height significantly; however, a differential response under various treatments in this respect was observed. During 1994-95 distilled water and paclobutrazol application produced the highest plants of 56.47 and 56.25 cm height, respectively. The same trend of effect in this connection was noted during the other two years of study.

Plant height was also significantly affected by the application of growth substances at different growth stages. Eventually, the application of growth substances as pre-sowing seed treatment and as foliar spray at crown root development had more drastic effect on plant height during all the three years of study as the shortest plants (51.89 and 52.40 cm) were produced in these cases as compared with other stages.

The differences among the means of interaction between moisture conditions and growth substances treatments varied significantly (Fig. I) and almost the same trend was found during all the three years of investigation. The application of distilled water and paclobutrazol during 1994-95, under normal soil moisture condition produced the highest plants of 60.85 and 59.03 cm, respectively. Whereas, the shortest plants of 45.33, 45.26 and 47.44 cm were observed in case of SADH application during 1994-95, 1995-96 and 1996-97, respectively under moisture stress.

As regards interaction between moisture conditions and stages of growth substances application, the differences among their means were significant and the same pattern of effect was noted during all the three seasons of study. The maximum plant heights of 59.71, 59.42 and 58.95 cm were found when distilled water was applied under optimum soil moisture. Whereas, the minimum plant heights of 45.24, 45.14 and 46.98 cm were observed in case of ethephon application under limited water supply during 1994-95, 1995-96 and 1996-97, respectively.

Interaction between growth substances treatments and stages of their application had a significant effect on plant height (Fig. II). Thus, the maximum plant heights of 56.92, 56.89 and 56.58 cm were recorded during 1994-95, 1995-96 and 1996-97, respectively in case of distilled water application at grain filling stage. Whereas, the shortest plants of 49.02, 49.15 and 49.58 cm were found in case of paclobutrazol application as pre-sowing seed soaking during 1994-95, 1995-96 and 1996-97, respectively.

Among the interactions of moisture conditions, growth substances treatments and stages of their application, the highest plants of 61.4, 61.1 and 61.2 cm were produced with the
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application of distilled water as seed treatment under optimum soil moisture conditions during 1994-95, 1995-96 and 1996-97, respectively. On the contrary, the shortest plants of 39.94, 42.10 and 43.96 cm were found when SADH was applied at crown root development under moisture stress during 1994-95, 1995-96 and 1996-97, respectively.

Productive tillers per plant

Number of productive tillers per plant plays a pivotal role in wheat grain yield. Moisture stress at crown root stage on an average of three years of work reduced productive tillers by about 6%; however, statistically the reduction was non-significant (Table 1). Contrary to this, the application of growth substances enhanced number of productive tillers per plant significantly during 1994-95 and 1996-97 but was non-significant during 1995-96 (Table 2). During the 1st year of study ethephon application had a more positive effect with 6.21 productive tillers per plant followed by paclobutrazol and triadimefon with productive tillers of 5.96 and 5.92 per plant, respectively and these growth substances were statistically on par with each other. The same trend was observed during the other two years of study.

Among the stages of growth substances application as a mean of three years of work, pre-sowing seed treatment was found to be the best

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**Table 1**
Effect of moisture conditions on productive tillers

<table>
<thead>
<tr>
<th>Treatments</th>
<th>1994-95 N.S</th>
<th>1995-96 N.S</th>
<th>1996-97 N.S</th>
<th>Mean N.S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Moisture (M1)</td>
<td>6.08</td>
<td>5.87</td>
<td>5.97</td>
<td>5.97</td>
</tr>
<tr>
<td>Moisture Stress (M2)</td>
<td>5.68</td>
<td>5.43</td>
<td>5.77</td>
<td>5.63</td>
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</table>

**Table 2**
Effect of growth substances application treatments on productive tillers

<table>
<thead>
<tr>
<th>Treatments</th>
<th>1994-95</th>
<th>1995-96 N.S</th>
<th>1996-97</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control (T1)</td>
<td>5.50 c</td>
<td>5.58</td>
<td>5.50 b</td>
<td>5.53 c</td>
</tr>
<tr>
<td>Ethephon (T2)</td>
<td>6.21 a</td>
<td>5.87</td>
<td>6.08 a</td>
<td>6.05 a</td>
</tr>
<tr>
<td>Paclobutrazol (T3)</td>
<td>5.96 b</td>
<td>5.62</td>
<td>5.83 a</td>
<td>5.80 b</td>
</tr>
<tr>
<td>Succinic acid (T4)</td>
<td>5.83 b</td>
<td>5.54</td>
<td>6.04 a</td>
<td>5.80 b</td>
</tr>
<tr>
<td>Triadimefon (T5)</td>
<td>5.92 b</td>
<td>5.62</td>
<td>5.88 a</td>
<td>5.81 b</td>
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</table>

**Table 3**
Effect of stages of growth substances application on productive tillers

<table>
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<th>Treatments</th>
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<th>1995-96</th>
<th>1996-97</th>
<th>Mean</th>
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<td>Seed Treatment (S1)</td>
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<td>6.03 a</td>
<td>6.40 a</td>
<td>6.24 a</td>
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<tr>
<td>Spray at Crown Root (S2)</td>
<td>5.97 b</td>
<td>5.80 ab</td>
<td>5.97 b</td>
<td>5.91 b</td>
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<tr>
<td>Spray at Anthesis (S3)</td>
<td>5.63 c</td>
<td>5.47 bc</td>
<td>5.67 c</td>
<td>5.59 c</td>
</tr>
<tr>
<td>Spray at Grain filling (S4)</td>
<td>5.63 c</td>
<td>5.30 c</td>
<td>5.43 c</td>
<td>5.45 cd</td>
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with the highest number (6.24) of productive tillers followed by spray at crown root development and anthesis with productive tillers of 5.91 and 5.59, respectively (Table 3). However, foliar spray at grain filling stage had the least effect on number of productive tillers per plant. Interaction between moisture conditions and growth substances treatments during 1994-95 was significant whereas, during 1995-96 and 1996-97 it was non significant (Table 4). Thus, during 1994-95 productive tillers were the maximum (6.42) in case of ethephon and paclobutrazol application under normal moisture supply. The minimum (5.50) number of productive tillers was produced with distilled water and paclobutrazol application under limited moisture supply. Similar results were noted during the other two years of research work. Interaction between moisture conditions and stages of growth substances application during all the three years of study did not exist (Table 5).

Similarly, interactions of growth substances treatments and stages of their application remained statistically non significant. Interaction between moisture conditions, growth substances treatments and stages of their application did not exist during all the three years of investigation. However, pre-sowing seed soaking in 400 mg l-1 ethephon solution produced the highest number of productive tillers under optimum soil moisture during all the three years of study.

Table 4
Effect of interaction between moisture conditions and stages of growth substances application on productive tillers

<table>
<thead>
<tr>
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<tbody>
<tr>
<td></td>
<td>M1</td>
<td>M2</td>
<td>M1</td>
</tr>
<tr>
<td>S1</td>
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<td>6.20</td>
<td>6.33</td>
</tr>
<tr>
<td>S2</td>
<td>6.10</td>
<td>5.80</td>
<td>5.00</td>
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<tr>
<td>S3</td>
<td>5.93</td>
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<td>5.60</td>
</tr>
<tr>
<td>S4</td>
<td>5.87</td>
<td>5.40</td>
<td>5.53</td>
</tr>
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</table>

Table 5
Effect of interaction between moisture conditions and growth substances treatments on productive tillers

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<th>1995-96 N.S</th>
<th>1996-97 N.S</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M1</td>
<td>M2</td>
<td>M1</td>
</tr>
<tr>
<td>T1</td>
<td>5.50 d</td>
<td>5.50 d</td>
<td>5.92</td>
</tr>
<tr>
<td>T2</td>
<td>6.42 a</td>
<td>6.00 bc</td>
<td>6.00</td>
</tr>
<tr>
<td>T3</td>
<td>6.42 a</td>
<td>5.50 d</td>
<td>5.92</td>
</tr>
<tr>
<td>T4</td>
<td>6.00 bc</td>
<td>5.67 cd</td>
<td>5.67</td>
</tr>
<tr>
<td>T5</td>
<td>6.08 ab</td>
<td>5.75 bcd</td>
<td>5.83</td>
</tr>
</tbody>
</table>
Grains per spike

Moisture stress adversely affected the grains number per spike. As an average of three years of study grains per spike under normal moisture supply were 55.57 and were reduced to 46.29 under moisture stress. Growth substances treatments had a significant effect on grain number per spike. On the average of three years of work, the maximum numbers of grains (52.82) were observed in case of ethephon application. It was followed by SADH application with the grains of 51.46 per spike. Similarly, stages of growth substances application also affected the number of grains per spike significantly. Eventually, pre-sowing seed soaking surpassed all the other stages with the maximum grains number of 53.50 per spike. Spray at crown root development remained at par with it with the grains number of 52.33 per spike.

Interaction between moisture conditions and growth substances treatments was significant (Fig. III) during all the three years of study. Ethephon application @ 400 mg/l produced the maximum grains under both the moisture conditions. Thus, under optimal soil moisture supply it produced 54.41, 5.50 and 55.27 grains per spike. Under moisture stress ethephon application produced 46.86, 4.75 and 45.64 grains per spike during 1994-95, 1995-96 and 1996-97, respectively.

Interaction between moisture conditions and stages of growth substances application was significant during all the three years of study (Fig. IV). Thus, as an average of three years of research work, pre-sowing seed soaking showed better results under both moisture conditions with the maximum grains per spike under normal

![Fig.III. Grains per spike as affected by moisture stress and growth substances (Means of 3 years)](image)

![Fig.IV. Grains per spike as affected by moisture stress and stages of growth substances application (Means of 3 years)](image)
moisture (54.54) supply and under moisture stress (45.28) as well.

Interaction between growth substances treatments and stages of their application also was significant during all the three years of study. Eventually, ethephon application as pre-sowing seed soaking performed better with the maximum grains of 53.11, 52.09 and 54.30 followed by spray of the same at crown root initiation with the grains of 52.43, 51.86 and 53.65 per spike during 1994-95, 1995-96 and 1996-97, respectively.

Significant interaction between moisture conditions, growth substances treatments and stages of their application was noted during all the three years of study. Thus, pre-sowing seed soaking in ethephon solution under both the moisture conditions produced the highest number of grains per spike. Grains in this case under optimal moisture supply were 54.46, 53.91 and 55.25 whereas; under drought conditions these were 49.92, 48.88 and 50.90 per spike during 1994-95, 1995-96 and 1996-97, respectively. The minimum grains of 48.59, 47.55 and 49.83 were observed when triadimefon was sprayed at grain filling under moisture stress during 1994-95, 1995-96 and 1996-97, respectively.

### 1000-grain weight

A perusal of the data revealed that 1000-grain weight of wheat was adversely impaired by soil moisture stress at crown root development stage. Under normal moisture supply 1000-wheat grain weight was 42.96, 42.93 and 43.02 g whereas, under limited soil water conditions it was 39.98, 39.87 and 39.55 g during 1994-95, 1995-96 and 1996-97, respectively. Thus average reduction in 1000-grain weight during the three years of investigation due to moisture stress was calibrated to be about 7%.

Growth substances application during all the three years of study enhanced 1000-grain weight significantly. Eventually, the application of ethephon surpassed all the other treatments with 1000-grain weights of 42.57 m 42, 45 and 42, and 34g during 1994-95, 1995-96 and 1996-97, respectively. It was followed by the application of Paclobutrazol and triadimefon with 1000-grain weights of 41.76 and 41.74 g., respectively as an average of three years of study.

Stages of growth substances application also showed significant differences among their individual means. Thus, pre-sowing seed soaking gave better results with the highest 1000-grain weights of 42.68, 42.72 and 42.79 g, followed by foliar spray at crown root development with 1000-grain weights of 42.23, 42.26 and 41.86 g during 1994-95, 1995-96 and 1996-97, respectively.

Interaction between moisture conditions and growth substances treatments was highly significant during all the three years of study (Fig. V). Thus, the highest 1000-grain weights of 43.98, 44.32 and 44.86 g were observed in case of
ethephon application under normal moisture supply followed by triadimefon application with 1000-grain weights of 43.72, 43.41 and 43.40 g during 1994-95, 1995-96 and 1996-97, respectively. The application of paclobutrazol however, remained at par with triadimefon application. Under moisture stress conditions too, ethephon application was found to be the best in this respect with the maximum 1000-grain weights of 41.17, 40.58 and 40.81g during the three years of work, respectively. Significant interaction between moisture conditions and stages of growth substances application was also observed during all the three years of research. Thus, the application of growth substances as pre-sowing seed soaking under both normal moisture supply and moisture stress conditions exhibited best performance with the highest 1000-grain weights. Under normal moisture supply the maximum 1000-grain weights of 44.28, 44.56 and 44.46 g were observed during 1994-95, 1995-96 and 1996-97, respectively in this case. This was followed by foliar spray at crown root development with 1000-grain weights of 44.13, 44.31 and 44.35 during 1994-95, 1995-96 and 1996-97, respectively.

Interaction between growth substances treatments and stages of their application was highly significant during all the three years of study. Ethephon application as pre-sowing seed soaking under both normal moisture availability and water shortage gave better results in this regard. Thus, its application exhibited the maximum 1000-grain weights of 46.54, 46.71 and 46.80 g under normal moisture supply and that of 41.82, 40.95 and 41.50g under moisture stress during 1994-95, 1995-96 and 1996-97, respectively. The effect of interaction between moisture conditions, growth substances treatments and stages of growth substances application on 1000-wheat grain weight was highly significant.

**Grain yield per plant**

The application of growth substances substantially enhanced wheat grain yield per plant. However, differential response to different growth substances in this regard was observed. Eventually, ethephon application came up on the top with wheat grain yield of 14.66, 14.38 and 14.52 g per plant. It was followed by SADH

![Fig.VI. Effect of moisture stress and stages of growth substances application on 1000-grain weight (Mean of 3 years)](image)
application with grain yields of 14.22, 13.96 and 14.18 g per plant during 1994-95, 1995-96 and 1996-97, respectively. The minimum positive effect was noted in case of distilled water application with grain yields of 12.84, 12.62 and 12.67 g per plant during 1994-95, 1995-96 and 1996-97, respectively.

Mean of stages of growth substances application differed significantly. Pre-sowing seed soaking in solutions of growth substances was found to be the best with the highest wheat grain yield of 13.94, 13.74 and 13.97 g per plant. It was followed by foliar spray at crown root development with the grain yields of 13.81, 13.66 and 13.60 g per plant during 1994-95, 1995-96 and 1996-97, respectively.

Interaction between moisture conditions and growth substances treatments was significant during all the three years of study. The application of ethephon showed excellent results under both the moisture conditions as it depicted the maximum wheat grain yields of 17.00, 16.50 and 16.86 g per plant under normal soil moisture availability while this was 12.33, 12.26 and 12.18 g under water deficit during 1994-95, 1995-96 and 1996-97, respectively. Highly significant interaction between moisture conditions and stages of growth substances application was observed during all the three years of study. Pre-sowing seed soaking in solutions of growth substances was found to be the best with grain yields of 16.77, 16.91 and 16.83 g per plant under normal moisture supply while they were 11.12, 11.08 and 11.11 g per plant under moisture shortage conditions during 1994-95, 1995-96 and 1996-97, respectively. The lowest grain yields of 16.57, 16.30 and 16.45 g per plant were observed during normal moisture and those of 10.66, 10.69 and 10.80 g per plant under limited soil moisture supply with the application of growth substances as foliar spray at grain filling during 1994-95, 1995-96 and 1996-97, respectively.

Significant interaction existed between moisture conditions, growth substances treatments and stages of their application during all the three years of study. The application of ethephon as pre-sowing seed soaking produced the highest grain yields of 15.05, 14.72 and 15.02 g per plant (Fig. VII). It was followed by the foliar spray of ethephon at crown root development with grain yields of 14.65, 14.34 and 14.43 g per plant during 1994-95, 1995-96 and 1996-97, respectively.

Significant interaction existed between moisture conditions, growth substances treatments and stages of their application during all the three years of study. Ethephon application as pre-sowing seed treatment under normal

Fig.VII. Grains per spike as affected by moisture stress and growth substances (Means of 3 years)
moisture supply as well as under water deficit conditions out-yielded with the grain yields of 17.19, 16.60 and 17.25 g per plant under normal soil moisture supply and this was 12.91, 12.83 and 12.80 g per plant under moisture stress during 1994-95, 1995-96 and 1996-97, respectively. It was followed by spray of ethephon at crown root development during all the three years of investigation. However, foliar spray of distilled water at grain filling produced the lowest grain yield of 8.77, 8.73 and 8.80 per plant as a mean of the three years of investigation, respectively.

Biological yield per plant

Biological yield was significantly decreased when wheat plants were subjected to water stress at crown root development. The average reduction in biological yield due to water deficit during the three years of research was computed to be about 39 percent.

Growth substances treatments and stages of growth substances application had a significant effect on biological yield. The application of distilled water and paclobutrazol produced the highest biological yield. Similarly, among the stages of growth substances application grain filling stage was found to be the most beneficial in this regard with an average biological yield of 42.51 g per plant during the three years of study.

Significant interaction between moisture conditions and growth substances treatments was observed in this regard during all the three years of study. The application of distilled water produced the highest biological yield per plant under both the moisture conditions with values of 53.17, 53.52 and 52.79 g under normal moisture supply, whereas it was 32.70, 32.76 and 32.70 g under water shortage conditions during 1994-95, 1995-96 and 1996-97, respectively. This was followed by paclobutrazol application under both moisture levels.

Significant interaction between moisture conditions and stages of growth substances application was found during all the three years of study (Fig. IX). Effect on biological yield in case of grain filling was less pronounced under both moisture conditions and was followed by anthesis. Thus, the maximum biological yields of 52.79, 52.51 and 52.42 g per plant under normal moisture and 32.65, 32.40 and 32.29 g per plant under moisture stress were found during 1994-95, 1995-96 and 1996-97, respectively. Moisture stress and pre-sowing seed soaking in growth substances solution adversely affected biological yield. Thus, the minimum biological yields of...
31.43, 31.34 and 31.25 g per plant were observed in case of pre-sowing seed soaking under water deficit conditions during 1994-95, 1995-96 and 1996-97, respectively.

Interaction between growth substances treatments and stages of growth substances application was there during all the three years of study. Distilled water application at anthesis stage affected biological yield to a very low extent and produced the highest biological yield in comparison with all the other interactions during all the three years of investigation. Thus, the maximum biological yields of 43.13, 43.60 and 42.90 g per plant during 1994-95, 1995-96 and 1996-97, respectively were observed in this case. It was followed by foliar spray of distilled water at grain filling stage, whereas the minimum biological yield of 41.10, 40.51 and 40.60 g per plant were produced in case of pre-sowing seed soaking in 400mg/l ethephon solution during 1994-95, 1995-96 and 1996-97, respectively.

Interaction between moisture conditions, growth substances treatments and stages of growth substances application was highly significant during all the three years of study. Eventually, the maximum biological yields of 53.70, 53.99 and 53.00 g were obtained in case of pre-sowing seed soaking in distilled water under normal moisture supply which was followed by foliar spray of distilled water at anthesis stage with biological yields of 53.45, 53.85 and 52.80 g per plant during 1994-95, 1995-96 and 1996-97, respectively. The minimum of 30.00, 30.15, and 30.95 were observed in case of ethephon application as seed soaking under moisture stress during 1994-95, 1995-96 and 1996-97, respectively. Whereas, the maximum biological yields of 33.16, 33.29 and 33.07 g per plant were harvested in case of ethephon spray at grain filling stage under moisture stress during the three years of research, respectively.

**Harvest index**

The application of growth substances further decreased harvest index significantly. Ethephon application showed the maximum harvest index of 35.51, 35.65 and 35.68 during 1994-95, 1995-96 and 1996-97, respectively.

The effect of stages of growth substances application on harvest index was also significant. Pre-sowing seed soaking found to be the most efficient in this regard with the highest harvest indexes of 33.81, 33.63 and 34.04 during 1994-95, 1995-96 and 1996-97, respectively.

It is evident from the data that interaction between moisture conditions and growth substances application was significantly high during all the three years of study (Fig. X). The highest harvest indexes of 38.55, 39.25 and 38.44 during 1994-95, 1995-96 and 1996-97, respectively was found in case of ethephon application under normal moisture supply. It was followed by SADH application under normal moisture and the minimum values of it were found in case of distilled water application under water deficit during all the three years of research.
Interaction between moisture conditions and stages of growth substances application was also high during all the three years of study (Fig. XI). Thus, the highest harvest indexes of 35.51, 32.48 and 35.40 were found in case of normal moisture supply and pre-sowing seed treatments whereas, the lowest of 32.04, 33.41 and 34.04 were noted in case of foliar spray at grain filling under moisture stress during 1994-95, 1995-96 and 1996-97, respectively.

Interaction between growth substances treatments and stages of their application was significant during all the three years of study. Eventually, the maximum harvest indexes of 37.98, 37.59 and 37.84 were observed in case of ethephon application as pre-sowing seed soaking. The minimum harvest indexes of 29.50, 28.37 and 29.08 on the other hand were noted with distilled water spray at grain filling during 1994-95, 1995-96 and 1996-97, respectively.

Significantly high interaction between moisture conditions, growth substances treatments and stages of their application was found during all the three years of study. Pre-sowing seed soaking in 400 mg/l ethephon solution under soil water deficit exhibited the highest harvest indexes of 43.03, 42.56 and 41.35 during 1994-95, 1995-96 and 1996-97, respectively. Whereas, the minimum harvest indexes of 26.98, 26.58 and 26.50 were noted by the foliar spray of distilled water at grain filling.
under water shortage conditions during 1994-95, 1995-96 and 1996-97, respectively.

Discussion

Among the agronomic traits, productive tillers, 1000-grain weight and grains per spike exhibited a strong and positive correlation with grain yield whereas, infertile spikelets showed significant but negative correlation with wheat grain yield.

The results are in agreement with those of Chaudhry et al. (1999), Chowdhry et al. (1995), Ramzan et al (1994) and Ali and Islam (1996) also reported a significant positive correlation of plant height, grains per spike and harvest index with grain yield; negative correlation between stomatal resistance and grain yield, positive and significant correlation between number of tillers per plant, 1000-grain weight and grains per spike with grain yield and strong positive correlation of effective tillers, biomass, physiological maturity and grain yield. Dencic et al. (2000) also stated that number of sterile spikelets displayed a negative direct effect, while grain weight per spike had a positive direct correlation with grain yield. A positive and significant correlation of stomatal conductance with grain yield was reported by Erchidi et al. (2000).

Conclusion

From this study it was observed that there was a substantial decrease in net economic returns due to limited moisture supply. This was attributed to decrease in grain yield and total biomass which resulted in lower economic returns. Each growth substance treatment employed in this study increased the net income per hectare by increasing grain yield to a varied degree. Etaphon surpassed all the other growth substances treatments with the maximum net income of Rs. 19078/- per hectare as against Rs. 12642/- in case of control (no spray) under moisture stress.

The results are in line with those of Llovers et al. (1990) and Havazvidi (1992) who also reported substantial increase in economic yield due to etaphon application under water stress. It is concluded that with the application of growth substances especially pre-sowing seed soaking in 400 mg/l etaphon solution wheat yield in drought prone areas can be increased by 37% and net income per hectare by 36% over control.

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