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Water management in wheat using non-traditional techniques

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सार - कृषि उत्पादन के लिए जल एक अत्यंत सीमित साधन है। वर्षा की अनियमितता के कारण अपेक्षित पैदावार के स्तर को प्राप्त करने के लिए प्रायः अतिरिक्त सिंचाई की आवश्यकता पड़ती है। किसान के लिए उपलब्ध सीमित जल से अधिकतम लाभ प्राप्त करने हेतु फसल को किस समय पानी देना तथा कितनी बार पानी देना है इसका निर्धारण करना अत्यंत महत्वपूर्ण कुशल निर्णयों में से एक है। यह निर्णय लेने के लिए कम्प्यूटर आधारित गतिकीय अनुकरित निदर्शों में विभिन्न पर्यावरणों के अंतर्गत प्रबंधन के विकल्पों का निर्धारण करने की क्षमता है। इस शोध-पत्र में नियमित रूप से मापित मौसम प्राचलों सहित कषि मौसम विज्ञान सलाहकार सेवाओं में प्रचालनात्मक उपयोग हेतु उत्तरी पश्चिमी भारत के लोकप्रिय गेहूँ जीन आकृतियों के लिए सीमित जल के अनुकूलतम अनुप्रयोग का परिमाण निर्धारित करने के लिए सी.आर.ई.एस.एस.-गेहूँ निदर्श V-3.5 का उपयोग किया गया है।

ABSTRACT. Water is one of the most limiting resources for agricultural production. Due to uneven distribution of rainfall, supplemental irrigation is often required to produce sustainable yield level. Timing and frequency of irrigation is one of the most important tactical decisions, which a farmer has to make to maximize profit from limited water availability. Computer based dynamic simulation models have the capability to assess management options under different environments to help in decision making. In this study, CRESS-Wheat Model V-3.5 has been utilized to quantify the optimum utilization of limited water for popular wheat genotypes of NW India for operational use in Agrometeorological Advisory services with routinely measured weather parameters.

Key words – Simulation, Potential, Genotype, Productivity, Irrigation.

1. Introduction

Water is essential for agriculture, for industry and for sustaining the environment. In recent decades, the demand for water has increased tremendously owning to rapid increase in cropping intensity, industrialization and population. Agricultural water users must now commit themselves to improving the efficiency of water consumption in numerous ways. As the amount of water used in irrigation is enormous, even small improvements in irrigation efficiency would release large amounts of water for agriculture, industrial and domestic use. Throughout the crop season, farmer must continually decide which crops to irrigate and which to leave dry when available water will not meet all of their needs. Weather based dynamic simulation models may be used as a tool for taking such tactical decisions like allocation of limited water to competing irrigated crops. The key to the simulation of an irrigation system using various water distribution rules is the response of crops to particular irrigation sequences or regimes. Irrigation should take place before the soil moisture becomes so depleted that plants come under stress conditions sufficient to reduce the yield or quality of crops harvested.

Singh (1976) concluded that where irrigation water supplies are limited, irrigation application should be managed in such a way that unavoidable water deficits coincide with growth stages that least influence the grain yield. Agronomic research done earlier had concluded that for optimal yield, wheat requires five irrigations at crown root initiation (CRI), tillering, jointing, anthesis and grain filling stages (Singh, 1986). However, some other studies have shown that optimal number of irrigations, required may be less (Sinha *et al*., 1985). Baldridge *et al*. (1985) have reported that the irrigation should be scheduled so that the available soil water in a 120 cm profile does not fall below 50 to 60 per cent to minimize water stress at all times. Moisture stress at any stage of growth of wheat reduced total dry matter production and the effects of moisture stress were more severe during vegetative stage mainly by affecting the leaf and stem dry weight (Talukdar, 1987). Yadav and Ram Deo (2000) reported that 2 irrigations to wheat at crown root initiation and milk stage under 60-90 cm water table and one irrigation at CRI under 35-55 cm water table conditions at farmers fields were optimum.

Though majority of wheat in India is irrigated, availability of irrigation water is limited. Hence, a judicious use of limited available water resources is essential. Further, the amount and time of water applied are also crucial for optimum growth, development and yield of wheat. Keeping the above realisation in view, an effort has been made to quantify the impacts of frequency and timing of irrigation on yield of different wheat genotypes, potential yield and Normalised Yield Gap Index (NYGI) in NW India using state-of-art dynamic simulation model with long-term weather records.

2. Material and methods

Evaluated CERES-Wheat Model V3.5 (Attri *et al.*, 1999; Attri, 2000) has been utilised to determine the potential and actual yields from long term weather data (1969-99) for popular wheat cultivars namely HD2329 (Ludhiana), WH542 (Hisar), HD2285 (Delhi), Sonalika (Pantnagar) and Raj 3765 (Jaipur) under different water management scenarios. Knowledge of the sensitivity of the model for the experiments conducted on irrigation management is necessary to quantify the potential grain yield in the absence of any kind of stress and the actual grain yield under rainfed and irrigated farming in which the growth is hindered by different kinds of stresses *viz*. thermal, moisture, nutrition, pest and disease attack etc. The potential yield, defined as the minimum possible yield, is primarily determined by the solar radiation and temperature where no stress (biotic or abiotic) exists to impede the growth and development of the crop. In case of model simulated yield, the stress only due to the moisture is taken into account. The difference between the potential yield and actual yield is referred as the yield gap. NYGI is used to normalise the effect of temperature and photo period to the possible extent. This index may be considered an indicator of management of water situation because soil water condition in the root zone is ultimately governed by the rainfall amount and its distribution in the season. This index was estimated as under :

$$NYGI = (PY - AY)/PY$$

TABLE 1

Frequency and period of irrigation

Treatment	Time of irrigation Days after sowing (DAS)
A1	21 (Crown root intiation stage)
A2	45 (Tillering stage)
A3	65 (Jointing stage)
A4	85 (Flowering stage)
A5	105 (Grain filling stage)
B1	21-85
B2	21-45
B3	21-65
B4	21-105
C1	21-45-85
C2	21-65-85
C3	21-85-105
D1	21-45-65-85
D2	21-45-85-105
D3	21-65-85-105
E1	21-45-65-65-105
E2	21-45-65-85-120*
E3	21-45-85-105-120

* Dough stage (120 days after sowing)

Where,

PY = Potential Yield and

AY = Actual Yields

The aim of simulation was to test the sensitivity of the model and quantify the allocation of limited water available during crop life cycle. Depending upon water availability, a decision has to be taken regarding timing of irrigation to obtain maximum yield. The evaluated CERES-Wheat model was utilised to simulate the impact of frequency and timing of irrigation on yield of different wheat genotypes with various irrigation treatments selected based on critical growth stages. Five critical growth stages vic. crown root stage, CRI [21 days after sowing (DAS)], tillering (45 DAS), jointing (65 DAS), flowering (85 DAS), milk stage (105 DAS) and dough stage (120 DAS) were selected. Irrigation treatments for 1 to 5 numbers of irrigations were formulated through combination of irrigations at these stages. Flooding is most commonly used irrigation method for most of

TABLE 2

Effect of irrigation frequency on yield gap in different wheat cultivars

Cultivars (Stations)	Potential yield (kg/ha)	Rainfed yield (kg/ha)	Yield under irrigated condition IR-1	IR-2	IR-3	IR-4	IR-5
HD 2329 (Ludhiana)	6215 (6.3)*	3217 (43.8)	4557 (25.9)	5105 (20.8)	5638 (14.7)	5850 (12.4)	5991 (10.6)
WH 542 (Hisar)	7298 (6.9)	942 (71.9)	1975 (76.9)	2710 (43.1)	3481 (36.2)	5024 (30.1)	6672 (19.2)
Sonalika (Pantnagar)	5578 (8.2)	698 (76.9)	2009 (75.3)	2510 (57.8)	3748 (38.7)	4572 (19.3)	5155 (11.2)
Raj 3765 (Jaipur)	6012 (7.9)	745 (78.0)	2174 (52.9)	2850 (32.3)	3150 (23.9)	3773 (20.7)	4595 (14.1)
HD 2285 (Delhi)	6702 (8.8)	1813 (37.5)	2928 (21.1)	3772 (18.6)	4992 (15.2)	5964 (14.4)	6390 (12.9)

IR-1 - One irrigation given at 21 days after sowing (DAS)

IR-2 - Two irrigations given at 21 and 85 DAS

IR-3 - Three irrigations given at 21, 45 and 85 DAS

IR-4 - Four irrigations given at 21, 45, 65 and 85 DAS

IR-5 - Five irrigations given at 21, 45,65,85 and 105 DAS

* - Figures in the paranthesis are the standard deviation (%)

wheat growing areas in India. As such, each irrigation of 50 mm has been considered in simulation programme.

It is an established fact that irrigation at CRI is most crucial in wheat while irrigation at flowering comes to next. These features were captured by the model in all the cultivars. Highest yield was observed in all the cultivars when irrigation was applied at CRI in case of availability of single post-sown irrigation and at CRI and flowering stages in case of availability of two post-sown irrigations. As such, irrigations at CRI in all B, C, D and E irrigation treatments and at CRI and flowering in C, D and E irrigation treatments were kept and various other irrigation combinations were chosen as depicted in Table 1. The amount of moisture at the time of sowing was assumed to be at field capacity.

The impact of irrigation frequencies in relation to seasonal climatic variability was tested for genotypes under study with long-term daily weather data (30 years) and mean of the yield distribution was computed in all treatments under different irrigation scenarios (1-5 irrigations). The simulated grain yields for each of 30 years were ranked so they could be plotted as a cumulative probability *versus* yield. The cumulative probability curve showing consistently higher yield under different irrigation regimes is taken as the preferred option.

TABLE 3

Normalised Yield Gap Index of various wheat genotypes

Stations	Rainfed	Irrigated condition IR-1	IR-2	IR- 3	IR-4	IR-5
WH 542	0.87	0.79	0.63	0.52	0.31	0.09
HD 2329	0.48	0.27	0.18	0.09	0.06	0.04
Sonalika	0.87	0.64	0.55	0.33	0.18	0.08
Raj 3765	0.88	0.64	0.53	0.47	0.37	0.23
HD 2285	0.73	0.56	0.44	0.26	0.11	0.05

3. Results and discussion

3.1. *Estimation of yield potential and yield gap*

The results indicate that the potential yields are different for different wheat cultivars and range from 5578 kg/ha in Raj 3765 at Jaipur to 7298 kg/ha in WH542 at Hisar (Table 2). The potential wheat yields of the order of 5.8-7.1 t/ha have been simulated by Sankarant *et al.* (1999), while actual yields of the order of 2.78 t/ha under rainfed, 4.29 t/ha under single irrigation, 5.36 t/ha

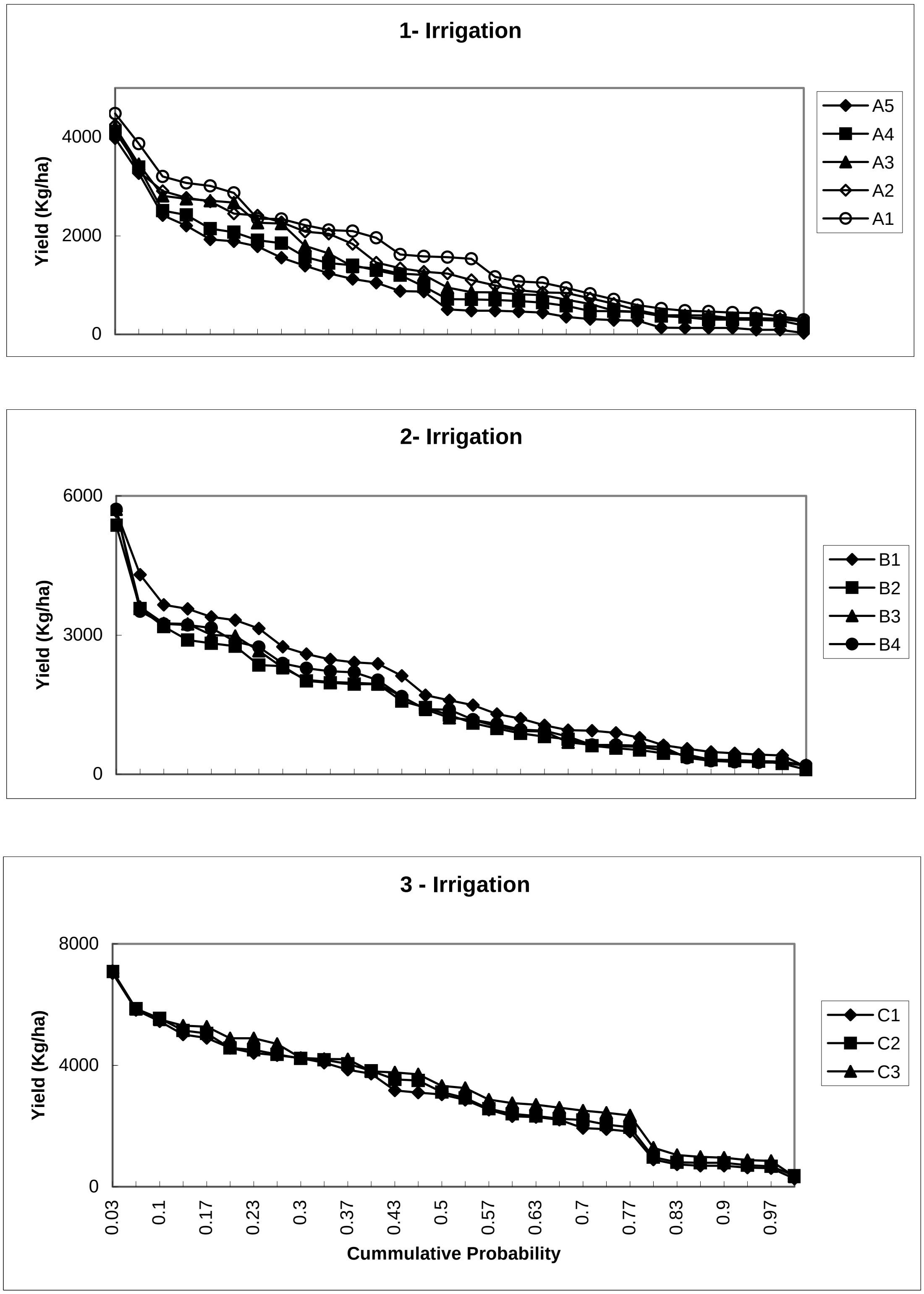

Fig. 1. Effect of time of irrigations on probability distribution of wheat yields in WH542 at Hisar

under two irrigations, 5.47 under three irrigations and 5.5.8 t/ha under five irrigations have been observed at Hisar by Jhorar *et al*. (2000). The genetic potential to yield is highest for WH542 (Punjab Agricultural University, 1998) and this feature has been well captured by the model. The increased in grain yield and reduction in its variations (Standard deviation) was observed with irrigation application. The yield variation was higher under rainfed conditions in all the cultivars which decreased with each irrigation from 1 to 5 applied at critical stages. Singh *et al*. (1999) ; Kalra and Aggarwal (1996) have reported similar results. The annual variation of yield at Jaipur was highest while it was lowest at Ludhiana. WH542 cultivar responded positively under 4 and 5 irrigation, while there was generally stabilisation of yield beyond three irrigations in other cultivars.

3.2. *Normalised Yield Gap Index (NYGI)*

The NYGI also called variability index (NYGI) ranged from 0.27 to 0.79 (upto one irrigation) to around 0.04 to 0.23 (beyond four irrigations) with intermediate values of 0.18 to 0.63 (two irrigations), 0.09 to 0.52 (three irrigations) and 0.06 to 0.37 (four irrigations) in different cultivars (Table 3). Similar results have been reported by Kalra and Aggarwal (1996). Variability seems to be dependent of the amount and time of water applied. It decreased with increase in post-sown water received by the crop indicating the reduced effect of climatic variability on yields under increased moisture availability conditions. The index is highest over Jaipur which may be due to higher seasonal rainfall variations. The result showed a sharp decrease in NYGI from I1 to I2 in all cultivars except WH542 which may be due to availability of sufficient soil moisture at critical flowering stage resulting in healthy development of ears and consequently enhancement in yield. WH542 has higher water requirements than other cultivars and responds upto 5 irrigation. The index decreased rapidly after two irrigations in Sonalika and HD 2285 and after three irrigations in WH 542 and Raj 3765. The value of index is lowest in HD 2329 at Ludhiana which may be due to availability of water throughout growing season. The least value of the index for HD 2329 among the cultivars studied is indicator of its supremacy under rainfed as well as irrigated condition. The index shows steady decrease upto three irrigations which becomes negligible afterwards. However, there was significant yield increase in WH542 but not much change in yields of other cultivars was observed beyond four irrigations .

Under rainfed conditions, WH 542, Sonalika and Raj 3765 showed very high index (0.87, 0.87 and 0.88 respectively) suggesting less suitably of these cultivars under rainfed conditions. However, WH542 and Sonalika exhibit satisfactory performance at IR-5 level but, Raj 3765 showed less productivity even if irrigated for five times.

3.3. *Impact of irrigation application on productivity of wheat genotypes*

The cumulative probability curves of yield distribution for normal and late sown cultivars under varying amounts of post-sown irrigations (1-3) are depicted in Figs. 1 and 2. However, such graphs for fourth and fifth irrigation are not presented, as variations in yield distribution were very small in most of the cultivars.

3.3.1. *Normal sown cultivars*

The effect of single post sown irrigation applied at different crop growth stages on yield of WH 542 at Hisar is depicted in Fig. 1. Applying only one post-sown irrigation anytime till vegetation phase did not change the yield much. However, further delay in application reduced the yield drastically. Grain yield was highest in A1 (irrigation at CRI) and lowest in A5 (irrigation at milk stage) treatment under single post-sown irrigation. It indicates that moisture stress at vegetative stage is not able to revive the crop even if it is irrigated at later stages. Similar results were given by Kalra and Aggarwal, (1996). The yield decreased with increase in number of days of irrigation after sowing. Increase of yield in all the treatments with second irrigation was observed. Highest and lowest yields were simulated in B1 (irrigations at CRI and at flowering) and B2 (irrigations at CRI and tillering) treatments, respectively. This indicates that wheat crop is able to compensate for growth reduction if first irrigation is applied at vegetative stage and second at reproductive stage. Once the grain development and then grain filling starts, there is reduction in grain yield depending upon level of water stress.

However, simulated yields were highest in C3 and lowest in C1 when 3 irrigations were applied. Further, steady increase in yield in WH 542 was observed with increase in number of irrigation up to five, but no significant difference were seen in yields in different treatments (timing) under fourth and fifth irrigation. The cultivar possesses highest potential yield among north-west Indian wheat cultivars which the model has also exhibited in terms of its response to higher irrigation frequencies.

Similar results were obtained in HD 2329 at Ludhiana upto 2 irrigations. However in case of 3

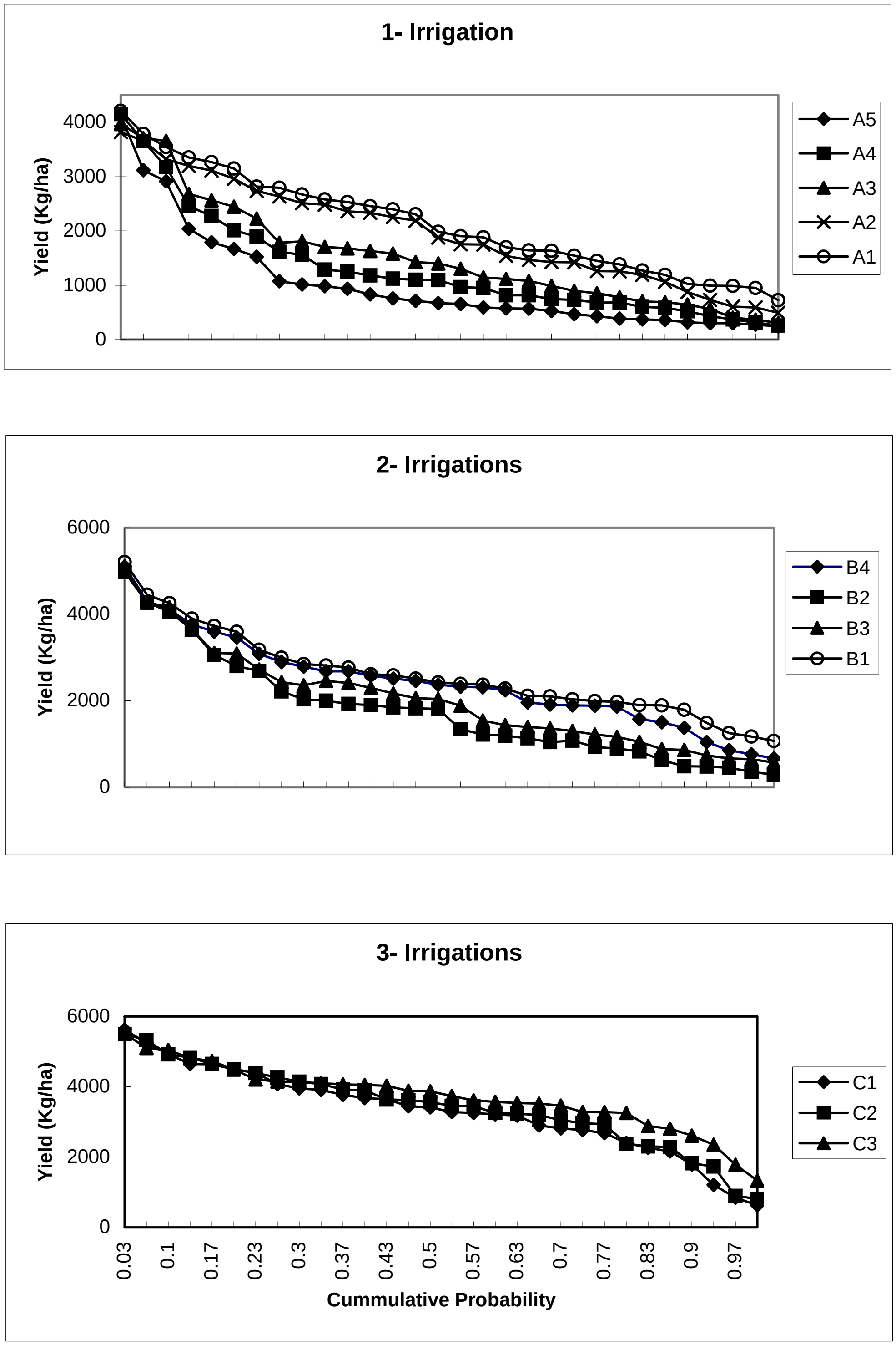

Fig. 2. Effect of time of irrigations on probability distribution of wheat yields in Sonalika at Pantnagar

irrigations, maximum yield was observed under C2 (irrigations at CRI, jointing and flowering) and minimum under C1 (irrigations at CRI, tillering and flowering). It indicates that once crop is established, irrigations at later stages result in healthy ear growth and better grain filling contributing to higher yields. However, yields were practically similar in various treatments with four and five irrigation.

3.3.2. *Late sown cultivars*

The results indicate that simulated yield was maximum in A1 (CRI) and minimum in A5 (Grain filling) treatments under single post-sown irrigation in Sonalika at Pantnagar. Steady decrease in yield was observed with increase in irrigation time after sowing. However, with second and third irrigation, yield maxima and minima were observed in B1 and B2, and C3 and C1, respectively. Similar results have been reported by Aggarwal and Kalra (1994). A general increase in yield was observed when irrigation frequency was enhanced from 1 to 5. But, there was no significant difference in yield among various treatments under 4th and 5th irrigation. It implies that farmers may choose any water availability period for 3 to 5 irrigations to obtain higher yields without disturbing irrigation at crown root initiation and flowering (Fig. 2). Similar results were obtained in HD 2285 at Delhi and in Raj 3765 at Jaipur.

4. Conclusions

(*i*) Skipping irrigation at CRI (21 days after sowing (DAS)) affected crop growth, development and yield most severely in all the genotypes. The yield level was minimal when only irrigation is applied at grain filling state (105 DAS).

(*ii*) Post-sown irrigations at CRI and flowering stages (21and 85 DAS, respectively) showed maximum return under two irrigations in all genotypes. However, minimum yield was obtained when irriagations were applied at CRI and tillering (at 21 and 45 DAS).

(*iii*) Under three irrigations, the yield was generally higher under irrigations at 21, 85 and 105 DAS and lower under irrigations at 21, 45 and 85 DAS scenarios.

(*iv*) Enhancement of yield in WH 542 was observed even upto 5 irrigations, while there was stabilisation of yield in other cultivars beyond 3 irrigations. However, yield did not vary much with selection of different timings under 4th and 5th irrigation once irrigation schedule at CRI and flowering was followed.

(*v*) Potential yield was found highest for WH 542 and lowest for Sonalika. However, variation of simulated yield was highest in Raj 3765 and lowest in HD 2329 under various irrigation scenarios.

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