AICRP - IRRIGATION WATER MANAGEMENT

Objectives

1. To develop optimum irrigation scheduling and water management technology to boost the productivity of major crops.
2. To maximize water use efficiency particularly under limited water supply conditions.
3. To study the drainage requirements of different crops and varieties grown in the *Kharif* season.
4. To characterize physical and chemical properties of soil in the command areas.
5. To evaluate various moisture conservation practices.
6. To study the fertilizer irrigation interaction in relation to crop yields in presence of shallow water table conditions.
7. To survey existing, socio-economic conditions, cultural practices and working out the economics of irrigation practices for important crops in the command area.
8. To study and develop the design criteria of various surface irrigation methods for efficient use of water
9. To evaluate and design water measuring/regulating instruments.
10. To evaluate existing water management practices on the farmers field in the command area of *Tarai* and *Bhabhar* of Uttarakhand

1. Significant Achievements:

Theme 1: Assessment of surface and ground water availability and quality at regional level and to evolve management strategies using Decision Support Systems (DDS) for matching water supply and demand in agricultural production systems.

1.1 Resource optimization in lower Bhakra canal command of Uttarakhand

The study was conducted in the command of Lower Bhakra canal system, comprising of Mukrandpur minor, Ulhatpur minor and Nakatiya minor, of district Udham Singh Nagar, to develop an area allocation model for maximizing the net return of the farmers at different water availability; to determine the optimal cropping pattern suitable for the area. The area allocation model (linear programming model) was used to allocate optimal area under different crop activities, varying irrigation water availability situations and irrigation water requirement under deficit, normal and surplus rainfall conditions for two optimization plans, one by taking summer rice into considerations and other by neglecting it. It was observed that *kharif* rice, wheat and soybean are the major crops that decide the net return of the farmers of the canal command under study.

The compiled optimal pattern and net return for the entire Lower Bhakra canal system command under normal, deficit and surplus rainfall show that under deficit rainfall pattern the Lower Bhakra canal system can only cater the water requirement of about 68% during *Kharif* season and about 45% during *Rabi* season. Under normal rainfall conditions, the canal system is capable to achieve the irrigation in wheat occupying an area of about 60% during *Rabi* season.

The optimal cropping pattern for maximum return from the lower bhakra canal system command under deficit rainfall condition is rice (43.26%), soybean (37.84%) and wheat (51.08%); under normal rainfall conditions rice (57.85%), soybean (39.43%) and wheat (72.79%) and under surplus rainfall conditions rice (97.28%) and wheat (96.36%). However, under surplus rainfall conditions, 3% increase in net return has been observed by shifting from kharif rice to summer rice.

1.2 Optimization of irrigation scheduling under different establishment methods of wheat in *Bhabhar* condition of Uttarakhand

The study, aimed to assess the impact of irrigation scheduling on wheat under different establishment methods, was conducted in *Bhabhar* area of Uttarakhand. The study revealed that grain yield did not reduce due to reduction in extent of tillage operations. It also had higher water productivity than conventional tillage practice. Therefore, it could be a better option for improving wheat and water productivity in this area. Application of limited irrigation recorded 11.5% higher productivity than conventional irrigation practice but produced comparable grain yield. The time/ energy required to plough same area under reduced tillage was almost 35% less as compared to conventionally prepared fields. Reduced tillage saved energy and cost of production. Reduced tillage practice earned Rs 4170/ha higher net return and also exhibited 21.4 per cent higher B:C ratio than conventional tillage treatment. Skipping II irrigation in wheat gained 14.1 per cent higher B:C ratio than conventional irrigation practice. It indicates that for light texture loamy sand soil, reduced tillage is appropriate. Second irrigation applied during low ET months can be curtailed.

It can be concluded that for wheat in medium texture soils of *Bhabhar* area for reduced tillage is equally good to that conventional but requires 35% less energy. Second irrigation to wheat can be omitted without reduction in grain yield.

1.3 Rainfall based optimization plan for Nandpur minor of Udham Singh Nagar (Uttarakhand)

The study was conducted to analysis the rainfall pattern in the study area in respect of probability level and drought conditions and to optimize the resource utilization in the command on the basis of rainfall analysis and available water under different rainfall probability levels. In Nandpur minor command area, the monthly rainfall probability distribution analysis (on the basis of 25 years rainfall data), shows that the area receives sufficient rainfall during *rabi* season (52.39 mm during October – March). But this trend is observed every alternate year (50% probability level). The rainfall ceases to 33.74 mm at 60%, 18.62 at 70% and 6.21 mm (with no rain during October to December) at 80% probability levels, respectively. The farmers totally depend upon the canal flows or the ground water. The weekly analysis indicate that the area receives 1.2 – 7.45 mm rains each week every alternate year (50% probability) during *rabi* season which ceases to zero at 80% probability level. This trend can also be verified from the yearly drought analysis which showed that the area received 16 times normal or surplus rainfall out of 25 years leaving only 9 drought years. The analysis could be helpful in educating the farmers of the area about the irrigation planning through conjunctive use of surface and ground water every alternate year for optimal crop production.

Optimal cropping pattern at 50 percent probability level of expected rainfall : The optimal cropping pattern for Nandpur minor canal at 50 percent probability level of rainfall was observed as *kharif* rice, sugarcane and wheat crop occupying the area of 88.12 percent, 11.88 percent and 88.12 percent, respectively. *Kharif* rice, wheat and sugarcane were the three crops that decided the net return from the command based on chance of expected rainfall and available canal irrigation water. It is also observed that the entire command area was occupied by crops during *kharif* and *rabi* seasons. The maximum net return of Rs. 35648920.00 was observed under this condition where more than 80 percent of area was occupied by kharif rice and wheat and no area is occupied by pea during *rabi* season.

Optimal cropping pattern at 80 percent

probability level of expected rainfall : The optimal cropping pattern for Nandpur minor commands under 80 per cent probability level was observed to be *kharif* rice, wheat and sugarcane crops occupying the maximum area of 47.44 percent, 86.54 percent and 11.58 percent, respectively. Under this probability condition rice during *kharif* and wheat and sugarcane during *rabi* were the main deciding crops. Wheat during *rabi* season occupied the maximum area of 86.54 per cent and 1.87 per cent area remained unoccupied due to restricted water availability from canal. During *kharif* season, *kharif* rice occupied about 47.44 percent area and about 40.98 percent area remained unoccupied due to less seasonal rainfall and restricted water availability from canal.

1.4 Optimal utilization of land and water resources in Nanakmatta canal command under different rainfall probability conditions.

The study was conducted probability analysis of the rainfall pattern in the study area and to optimize the land & water resources under different rainfall probability levels. In the study revealed the average annual rainfall and the rainfall at 50 percent probability level were considered as the two levels of variable rainfall conditions for optimization of the land and water resources in the canal command, since the annual rainfall record indicated that in 40.47 percent cases the normal rainfall (average ± 19%) was received in the study area whereas the percent of below normal and above normal rainfall was found as 33.33 and 26.20 percent, respectively. The annual rainfall at 50 percent probability level was estimated as 1479.93 mm against 1548.29 mm average rainfall. The optimal plan under 50% probability rainfall additional 25 percent canal water was consumed to cater irrigation water demand as compared to that under normal rainfall conditions.

More area could be brought under sowing through re-scheduling of canal water flows during higher water demanding months namely February, March, October and November. This will not only increase the net return but will also increase the net sown area in the command and reduced burden over the groundwater draft. The irrigation department is being informed about the re-scheduling of the canal flows during the months of peak demand (October, November and January) to reduce the burden over the ground water.

1.5 Ground water behavior and fluctuation in Baur-Behgul inter basin.

The study was undertaken to study the trend of water table in various regions of the inter basin; to identify the favourable areas for artificial recharge and to suggest suitable recharge techniques to augment the aquifer system in Baur-Behgul inter basin of western Uttar Pradesh and Uttarakhand. The Baur-Behgul Inter-basin comprises of Udham Singh Nagar district of Uttarakhand and Rampur & Bareilly districts of Uttar Pradesh. The existing cropping pattern in the area showed that wheat, paddy and sugarcane were the major crops grown in the area which may be treated as high water demanding crops. There is an urgent need to change the prevailing cropping pattern by occupying more area under low water demanding crops, reducing pressure on groundwater upto certain extent. This may be achieved by introducing more area under pulses and oilseed crops such as *Arhar*, *mung*, *urd*, gram, pea, lentil, mustard etc.

The decline in depth of pre-monsoon water table was found in Barua bagh, CRC Pantnagar, University Bhatta, Satuia, Semalpura, University Gymnasium, Gularbhoj, Jhagarpuri, Khanpur, Chhatarpur, Motipura, Bazpur and Kelakheda of Udham singh Nagar district, whereas rise of water table was recorded in Bara, Bari and Sisauna during the period 1990 - 2010. Apart from this, the decline in depth of post-monsoon water table was found in all the places of Gadarpur and Rudrapur blocks of Udham singh Nagar district during the year 1990 - 2010.

In Rampur district, depth to pre-monsoon water table was having declining trend in Bilaspur, Swar and Milak blocks of the study area from 1990 - 2010. As the figures witnessed that water table is declining continuously in almost all the places of the Bilaspur, Swar and Milak blocks of the study area from 1990 - 2010 for post-monsoon period In Bareilly district, the decline in the depth to water table was observed in Baheri, Shergarh and Meerganj blocks of the study area for both pre-monsoon and post-monsoon periods from 1990 to 2010.

The areas under Swar and Milak blocks of Rampur district, and Shergarh and Meerganj blocks of Bareilly district of the study area were identified as the main problematic areas where the condition of groundwater mining was prevailing and need immediate attention and suitable remedial measures to manage the problem well within time. The canal network may be extended to the problematic areas to supply water for irrigation and also to serve as a potential source for recharging underground aquifer.

The problem of declining water table was experienced in the study area mainly because of a lack of proper planning of a systematic groundwater extraction programme. The trend clearly showed the physical scope of recharging of groundwater in the area lying near the banks of the rivers. None of the study areas were, however, observed under waterlogged condition. This means that some part of the total area is drastically facing the problem of groundwater depletion.

1.6 Pollution of water resources due to industries in Kashipur industrial cluster of Uttarakhand

The study was conducted to investigate the problems of pollution faced by the people of nearby areas of industrial cluster near Kashipur to study the physico-chemical properties of surface and ground waters of surrounding area of industrial cluster near Kashipur and water of Kosi and Bahela rivers where effluent is being discharged; to study the suitability of surface and ground waters for drinking, and irrigation uses and to asses spread of pollution load on water resources of the area.

The physico-chemical analysis of the water samples revealed that the water of Kosi river was having higher value of BOD. Therefore, the effluent discharge in Kosi river was the main cause for its pollution. It was also observed that as per BIS norms, TDS and alkalinity in the ground water, at Sugarcane center gate, Glycol gate no.1 and Dhouri Pratha I near the effluent channel-I, and at most of the sampling sites near the effluent channel-II, were found on higher side of permissible range. It revealed that the ground water at these locations was being polluted by the effluents of industries.

Assessment of the effluent for irrigation revealed that the effluent, at all sampling locations of both the channels was not suitable for irrigation without proper drainage facilities, as it could cause salinity hazards to soil. The ground water at all the places except Parmanandpur I, Parmanandpur II was suitable for irrigation. The ground water observation points at Parmanandpur I and Parmanandpur II were at downstream side of effluent channel-II (towards Kosi River) from Cheema Paper Mill and Multiwal Paper & Board Factory. The ground water at these sites was found in C3-S2 class which indicated that the ground water at these two locations was under moderately alkaline in nature and cannot be used for irrigation on all type of soils without proper drainage practices.

The ground waters at all the observation points were not found suitable for Brewing, Confectionery, and Pulp and paper industry on the basis of TDS, hardness, alkalinity. The ground water at DhouriPratha I was not suitable for any industry, except for air conditioning. The ground water sampling site at DhouriPratha I was very close to Indian Glycol Ltd. which indicated that the Indian Glycol Ltd. was the main source of ground water pollution in the vicinity of the industry. The water of Kosi river was also not suitable for industrial uses except for Air conditioning.

It was concluded that effluents of both the effluent channels were affecting the ground water resources as well as crop production in the area.

1.7 Study on contamination of water resources due to heavy metals & effect of industrial pollution on soil near the industrial cluster of Kashipur town of Uttarakhand State.

From the physico-chemical analysis of soils at University Sugarcane center, it was found that the soils of agricultural fields at this center were having pH in moderately alkaline range (7.4-8.4) which may affect the plant growth as well as availability of micronutrients. The deficiency of potassium, magnesium and calcium was also found in the soils at University Sugarcane Center. The deficiency of these macronutrients may affect the plant cell structure as well as growth of the plants. The higher value of all physio-chemical parameters was also observed at the surface of the soil which indicated the effect of water logging due to effluent in the agriculture fields.

The effluents at Dhouri Pratha culvert, Sugarcane center site I on the effluent channel-I, and at Cheema outlet, Multiwal outlet and Kosi bank on the effluent channel-II were having very high concentration of arsenic, lead and iron. The higher concentration of arsenic and lead was also found in the water of Kosi River. It was also observed that the water of Kosi River was unsuitable for irrigation as well as for drinking purposes. The concentration of arsenic, lead and iron in the ground water at all the observation sites, around the industrial cluster, was out of permissible limit for drinking purpose.

The high concentration of arsenic, lead and iron was found in the ground water of nearby area of industrial cluster at several locations which can cause several diseases in human body such as increase in blood pressure, cardiac arrest, skin, bladder and lungs cancer. It may also affect the crop growth in terms of shrink of root, stem, chlorosis, turning of young leaves into white and necrotic which can be resulted into decrease in grain yield.

1.8 Studies of ground water quality and its suitability for domestic and irrigation uses in the command area of Mahadev distributary using GIS approach.

The studies on groundwater quality for drinking purposes of pre-monsoon season shows that nearly 63.25 percent area is covered by the ground water with a decent and about 31.0 percent area is covered by the ground water moderately suitable for drinking purpose and remaining 5.74 percent command area falls under the class unsuitable for drinking purpose. The post monsoon ground water quality of 52.49% and 47.51% area was found as suitable and unsuitable, respectively, for drinking purpose .

The ground water quality map for irrigation purpose during pre-monsoon season on the basis of EC salinity shows that the ground water quality of 1.02%, 89.74% and 9.24% area were under the class excellent, good and permissible, respectively. The ground water quality of 9.24% of the study area was under the class "permissible" in pre-monsoon season. During post-monsoon season 82.99% area was found under the class "good" and remaining 17.01% area was found under the class "permissible" for irrigation purpose. The ground water quality classification, on the basis of % Na, in post-monsoon season shows that about 26.99% command area was found under the class "permissible", 67.32% command area was found under the class "doubtful" category and the ground water of remaining 5.67% area was unsuitable for irrigation purpose.

On the basis of sodium absorption ratio (SAR), the ground water quality of 27.17%, 51.60%, 11.22% and 5.67% of the command area were found under the class excellent, good, doubtful and unsuitable, respectively, for irrigation purpose.

1.9 Pollution of water resources in vicinity of Bajpur industrial area of Uttarakhand

The study revealed that turbidity and nitrate, in the effluent at all the points of both the Channels and total hardness at all the points except at Samadhi of Channel I, were out of permissible limits as per norms for the discharge of effluent in the water body. *Therefore, the industries located in the industrial area of Bajpur were not following the norms for the discharge of effluent in the water body and it appears that these industries are discharging untreated effluents.*

In the physico-chemical analysis of ground waters samples it was found that in the close vicinity of the Bajpur Sugar Factory was not suitable for drinking purposes. *It showed that the factory effluent is polluting the ground water even in deep aquifers.*

The concentration of most of the parameters along the course of both the effluent channels was very high. *It showed that all industries are polluting the surface water streams along the course of channels*. Water quality of effluent of Stream I at all the points except at Petrol pump and at all the points of stream II as well as the ground water at Samiti DHP and Factory Colony were found to be under C3 Class of Salinity. *It showed that the effluent of Channels as well as ground water of these points were not suitable for irrigation without proper drainage Facilities. This could cause salinity and sodium hazards to soil it use for irrigation.* The effluent at petrol pump of channel I was having very high salinity and not suitable for irrigation. The ground water at Samiti HP ,Samiti DHP and factory colony was not suitable for all of industries studied except air conditioning and textile. *These three points are very close to sugar factory which showed contamination of ground water due to pollution.*

The Physico-Chamical analysis of soil of the agriculture fields located very close to both the effluent channels showed the decreasing trend in salt concentration with the depth of soil between 0 to 50 cm. In agricultural fields along the channel I the pH was found more than 7.0 at the most of the point for the depth from surface to 5.0 cm. While it was less then 7.0 below the depth of 5.0 cm. *It appears that the salts on surface were being deposited due to the high rise of channel water during the rainy season.* It was also found that the salt concentration in the soil of stream bed was very high and the value of pH from 7.2 to 8.1 in both the channels.

1.10 Water productivity and profitability of Sugarcane + Cucumber intercropping system in *tarai* area

The study was aimed to study the performance of sugarcane as sole versus intercropped with cucumber and to find out the benefits of cucumber intercropping towards water and system productivity in *tarai* area of Uttarakhand. The results of 2 years study revealed that intercropping of cucumber with sugarcane in additive series showed better performance as it gave 13 % higher sugarcane equivalent yield than the sole planting of sugarcane. Due to additional yield of cucumber, it gave Rs. 28,603/ ha higher net return than the sole planting of sugarcane. The B:C ratio of intercropping system was also higher by 5.6% than the sole sugarcane. Water productivity (ratio of output, 'SEY' to total water applied) was also higher in intercropping system by a margin of 12.5 per cent.

It can be concluded that inter space between 2 pairs of sugarcane can be utilized for growing cucumber crop. It is a viable proposition both for higher net returns and water productivity. However, two important pre – requisites for success of this system are, timely availability of irrigation water (cucumber is more sensitive than sugarcane) and availability of labours. Local market availability for cucumber is another aspect. Therefore, taking cucumber in spring planted sugarcane (paired planting) is a viable proposition, both for higher returns and water productivity than sole sugarcane.

Theme 2: Design, development and refinement of surface and pressurized irrigation systems including small holders' systems for enhancing water use efficiency and water productivity for different agro-eco systems

2.1 Study on raised bed, conventional and zero tilled plots for improving water use efficiency of wheat crop in medium texture soils

The study was aimed to study the water use efficiency of wheat under different sowing methods and to optimize the water use efficiency. The study showed that among the sowing methods, raised bed method saved 27.5 per cent water as compared to the conventional. Similarly, it also had 37.4 and 27.3 higher water productivity than conventional and zero tillage methods, respectively. The comparative economics of different treatments revealed that IW:CPE 1.00 treatment was found to be the best among different irrigation levels as it gained the maximum gross (Rs. 47,856/ha) and net returns (Rs. 26,156/ha) and also the B:C ratio (1.22). These parameters were the lowest with IW:CPE ratio 0.75. Among different sowing methods, the zero tillage sowing was superior to the rest of the treatments as it gave the maximum gross (Rs. 47,445/ha) and net returns (Rs. 28,113/ha). Likewise, it also had higher values of B:C ratio being higher by 43.6 and 33.0 per cent over conventional and raised bed treatments, respectively.

Based on the percent study, it can be concluded that wheat crop did not give response beyond 3 irrigations under sandy loam conditions of *tarai*. In terms of water saving, IW: CPE 0.75 was found to be the best but economically IW: CPE 1.00 ratio was superior. All the tested methods produced comparable yields, but raised bed saved more water as compared to conventional and zero tillage treatments. Zero tillage method was found economically the most viable method.

2.2 Productivity and water use efficiency of wheat under modified raised beds system for resource poor conditions

The study revealed that considering the effect of crop establishment methods on water saving, the modified raised bed 60/25 treatment saved the maximum amount of water (47.1%) followed by MRB 40/25 (32.9%) and RB 45/15 (27.1%) treatments against the flat planting (21.0 cm). Similarly, irrigation WUE in modified raised bed 60/25 treatment was also found to be superior to the rest of the treatments and it recorded 84.2 per cent higher irrigation WUE than flat planting. Modified raised bed 40/25 and raised bed 45/15 also had 47.4 and 32.1 per cent higher irrigation WUE, respectively over flat planting.

The results of the study over the years shows that wheat crop did not respond beyond 3 irrigations applied under IW:CPE 0.80 in sandy loam soil under *tarai* conditions. Economically also this level was more viable. No doubt, the maximum grain yield and net returns were obtained from flat planting but from water saving and B:C ratio point of view, the MRB 60/25 showed superiority to rest of the treatments, thus can be advocated for resource poor areas, for water economization and getting reasonably good yields.

2.3 Performance evaluation of Nandpur minor of Udham Singh Nagar (Uttarakhand)

The performance evaluation of Nandpur minor of the Jonar Canal System in Udham Singh Nagar district of Uttarakhand was evaluated in terms of adequacy, efficiency, dependability and equity. In each month of the rabi season the adequacy was measured more than 0.80, while the value of efficiency calculated was less than 0.7 showed the poor performance with respect to efficiency during whole rabi season. The seasonal value of dependability was found to be 0.54 and the seasonal value of equity as 0.25; both showed the poor performance. On the basis of the study the water delivery performance of Nandpur minor relative to efficiency, dependability and equity was adjudged as “poor”.

2.4 Drip fertigation study in maize for green cob during spring season.

The study was conducted to evaluate the comparative performance of flood v/s drip irrigation in Maize Green Cob and to study the water and fertilizer saving through drip fertigation in spring maize. The study revealed that green cob yield both with husk and without husk, was affected significantly due to irrigation levels and nutrient dose. The cob yield with and without husk increased significantly as the irrigation level was increased from 60% to 80% CPE and from 80% to 100% CPE. Application of 100% NPK produced significantly higher values of cob yield (with & without husk) over 75% NPK level. However, variable P & K splitting failed to cause significant variation in the cob yields. Among all the moisture regimes, the highest depth of irrigation (39.0 cm) was required in surface flood (IW: CPE 1.0) without mulch followed by drip irrigation at 100% CPE (38.3 cm). As compared to surface flood without mulch treatment, the saving of irrigation water was 40.5% (60% CPE drip), 21.3% (80%

CPE drip), 1.8% (100% CPE drip) and 15.3% (surface flood with mulch). Among all the treatments, the higher IWUE (477 kg/ha-cm) was noted for drip irrigation at 60% CPE, while the lowest was with surface flood method without mulch (320 kg/ha-cm). Drip irrigation at 60 & 80% CPE recorded higher IWUE than both surface flood method with mulch & without mulch treatments.

From the study it may be concluded that spring maize needs to be drip irrigated at 100% CPE at 2 days interval. The crop responded upto 100% recommended NPK dose (120-60-40 kg/ha). For P & K application 70/30 (70% till tasseling 30% thereafter) approach should be followed.

2.5 Performance evaluation of water delivery system in Nanakmatta canal command area

The performance evaluation study in terms of adequacy, efficiency, dependability and equity has been conducted in the Nanakmatta canal command in Udham Singh Nagar district of Uttarakhand. The performance measures are studied for *rabi* season during which the water is delivered for irrigation through 36 number of outlets and cover 1234 ha of command area.

The adequacy (PIA) was measured less than 0.80 at head, middle and tail ends in the *rabi* season, while the value of dependability (PID) was more than 0.20, showing the "poor" performance during all the years. The value of dependability (PID) was found more than 0.20 in head, middle and tail ends during the *rabi* season showing "poor" performance of the Nanakmatta canal. The value of equity (PIE) was found between 0.11 and 0.20 during *rabi* season in the study period showing the "fair" performance. The value of parameter PI_{EF} was more than 0.85 during all three years at head, middle and tail, respectably showed "good" performance. According to the performance standards, the water delivery performance of Nanakmatta canal related to adequacy and dependability was found "poor", efficiency was judged "good" and equity was adjudged "fair".

The performance assessment study revealed that the performance was "poor" as the canal is unable to meet the requirement of crops grown. The farmers depend on ground water to supplement the crop water requirement. The performance of the canal could be improved by growing less water requiring crop and altering the cropping pattern.

Theme 4: Basic studies on soil-water-plant-environment relationship under changing scenarios of irrigation water management.

4.1 Development of water production function for different crops under *tarai* conditions of Uttarakhand (Lysimeter study)

The study was conducted to optimize the ground water contribution under different water table depths and to develop seasonal water use and yield relationship in *Kharif* Rice, Yellow Mustard and Cow Pea. The results of the study are as follows:

Yellow Mustard (*Brassica juncea* L.)

The ground water contribution decreased as the water table depth increased. At 30 cm water table depth the ground water use was 273.1 mm, which decreased by 15.9 % at 60 cm and 36.5 % at 90 cm water table depth (Table 4.1.2). Between irrigation methods more ground water use by the crop was noted for sprinkler method than flood (219.7 mm). IW: CPE 0.50 the highest ground water contribution was found (253.2 mm). It decreased by 23.8 mm and 59.5 mm, respectively at IW:CPE 0.75 and 1.00. The total crop water use followed the similar trend to that of ground water use for water table depth and irrigation method, while for IW: CPE ratio the trend was reverse. The highest total water use was noted at IW: CPE 1.00 (350.7 mm). The mean seed yield decreased as the depth to water table lowered. However, the decrease was not substantial. Sprinkler method of irrigation produced higher seed yield by 14.1 % than flood method of irrigation (830 kg/ha). The highest ground water contribution (273.1 mm) towards crop water requirement was found at 30 cm water table depth. The mean seed yield was almost comparable at all the water table depths, with highest water use efficiency at 90 cm water table depth (3.08 kg/ha-mm). Sprinkler method of irrigation and application of irrigation at IW:CPE ratio 0.75 were found appropriate.

Cowpea (*Vigna unguiculata*)

The total crop water use decreased, as the depth to water table was increased being 991 mm at 30 cm water table depth and 813 mm at 90 cm water table depth. Difference in total crop water use was more between 30 cm and 60 cm (120 mm), than 60 cm and 90 cm (58 mm). The total crop water use was higher by 8.8% in flood method of irrigation than sprinkler method.

In a high rainfall season the grain yield was the highest at 90 cm water table depth (853 kg/ha). This treatment also had the highest WUE (1.05 kg/ ha-mm). The WUE decreased as the water table become shallower. Higher irrigation depth (3 cm) in summer season recorded higher grain yield of cowpea and WUE than low irrigation depth of 2 cm. Frequent irrigation at 100 mm CPE produced the highest grain yield of cowpea (940 kg/ha) which decreased substantially as the irrigation interval was widen. In a hot summer season, the highest ground water contribution towards cowpea water requirement was found at 30 cm water table depth (555 mm), but the grain yield was highest at 90 cm water table depth. Irrigation depth 3 cm was better than 2 cm for achieving higher grain yield. Application of irrigation at 100 mm CPE was optimum for cowpea during summer season.

4.2 Determination of crop coefficients for Yellow mustard and cowpea crops.

The average Kc (crop coefficient) for mustard cv. Pant Yellow Sarson-1 was 0.62, ranging from 0.14 (I week after sowing to 1.04 in 7th weed of sowing). For initial 4 weeks the Kc values were relatively low and from 5th onward started rising (Table 4.4.1). Between 6 and 8 weeks, it was close to one. From 9th week, the Kc value stared declining and noted as 0.31 in the last week of the crop period.

For cowpea (February to June), the mean Kc value of 0.57 was observed. The Kc value was close to 0.4 in the initial 2 weeks of sowing. From 3rd week, it started increasing and remained close to 0.60 till 7th week after sowing (Table 4.4.1). It was the maximum in the 8th week of sowing (0.83). Further it declined and reached the value 0.48 in the last week of crop period.

Theme 5: To evolve management strategies for conjunctive use of surface and ground water resources for sustainable crop production.

5.1 Conjunctive water use planning in Nanakmatta canal system command area.

The major crops grown in the command area are wheat, rice, and sugarcane. Other crops are pea, *lahi,* lentil, sunflower and *berseem*. The existing cropping intensity of the Nanakmatta canal command area is 194.07 percent. The estimated total crop water demand for existing cropping pattern is 1111.58 ha-m. The ground water available in the command area of Nanakmatta in safe category (65 percent of the net recharge) is about 584.37 ha-m. To find out the optimal cropping pattern, a linear programming model has been used considering the weekly canal water availability, available ground water for irrigation for different running hours of tube wells and irrigation water requirement. The crop appeared in Plan having canal water along with 6 hours running of tube wells, are wheat, pea, sugarcane, berseem, rice (summer) and rice *(kharif)* at a level of 26.50, 7.00, 690.0, 470.0, 35.0, 30.0 and 732.0 hectares, respectively with 16.50 percent increase in the aggregate net return over the existing crop plan. The study also revealed that utilizing 545.19 ha-m ground water (within 65 percent of net recharge) can be proposed for the Nanakmatta canal command area.

5.2 Water management studies of Dhimri canal command of Uttarakhand.

The existing cropping intensity of the crop in Dhimri canal command was 1.26 which has been found to be increased to 1.48 under the proposed scheme without use of ground water recharge and 1.52 when fifty per cent of ground water recharge was considered to be used along with the surface water. On using the 50 per cent of ground water recharge along with surface water only for irrigation in Dhimri canal command, did not have substantial impact on the profit to the farmers.

6. Technologies Introduced for Adoption

6.1 Prediction of crop yield using weather data

Using weather data, rice and maize yields in the monsoon season have been predicted successfully. The multiple regression equations obtained with rainfall for rice and maize are

Rice :

$$Z = 19.40 + 1.799\ T + 10^{-4} \sum_{i=1}^{24} (33.23\ t_i^0 - 7.246\ t_i^1 y_i + 0.0199\ t_i^2 y_i)$$

Maize :

$$Z = 38.66 - 0.652\ T + 10^{-4} \sum_{i=1}^{16} (179.46\ t_i^0 - 67.43\ t_i^1 y_i + 2.706\ t_i^2 y_i)$$

Where Z is the yield in q/ha, t_i is the number of week of 7 day period i.e. i^{th} week since planting in which y_i mm rainfall received. T is the year number i.e. number of the year of data used for estimating average weekly rainfall. The correlation coefficient R^2 for rice and maize were 0.975 and 0.676, respectively.

6.2 Studies on Rai, Mustard and Toria crop

Two irrigations in the mustard crop first at 25 or 45 days after planting and the second at 85 days after planting gave optimum seed yield of this crop.The lahi crop gives the optimum seed yield with single irrigation given at the beginning of the flowering i.e. 25 - 30 days after planting.Single irrigation scheduled at 3 weeks' stage or at the beginning of flowering which occurs at 6 weeks' stage has been found to be sufficient for near optimum yields of rai, raised under shallow ground water situation.Performance of Toria was poor over the water tables at 0.3 m and 0.6 m depths in medium to fine textured soils of *Tarai.* Grain yield over the water table at 0.3 m depth was less than 60 percent of those at 0.9 m and 1.5 m depths. Considering rainfall around 25 days from sowing as one irrigation, one additional irrigation was necessary in the soil over the water table at 1.5 m depth.Grain yield of *Toria* under rainfed conditions decreased significantly as the water table declined from 0.3 to 1.5 m depth but the reverse was true under irrigated conditions. Irrigation schedules based on climate-crop-soil data showed significant influence on Toria yield. Grain yield of *Toria* was optimum over the water tables deeper than 0.9 m. The influence of water use (ET) on grain yield was linear. The correlation *coefficient* was highly significant.

6.3 Studies on Wheat Crop

The wheat crop grown on medium textured soil with ground water table deeper than 1.5 m responds to 5 irrigation schedule at the crown root initiation, late tillering, booting, flowering and milk stages. Considerable economy could, however, be achieved in the water use by means of reduced depth of irrigation to $2/3^{rd}$ of the normal depth without adversely affecting the yield in case the crop received 5 irrigation at different growth stages mentioned above. For wheat crop grown under high water table conditions following rice crop, only 3 irrigation scheduled at the crown root initiation, booting and milk stages have been found to be optimum.Irrigation scheduling in wheat should take into account the depth to water table. If water table are shallow (50 - 100 cm deep), two to three irrigations are enough for optimum yields. If water tables are up to 200 cm, four irrigations are needed. However, if water tables are deep, the beneficial effect of 5-6 irrigations is observed. Where water tables do not contribute to the crop water requirement (no upward flux into the root zone) the IW/CPE ratio of 0.8 to 1.0 may be used for scheduling of irrigation.

6.4 Studies on Rice Crop

Rotary puddler may be used for puddling of rice field. This has shown an increase of 11 percent of more yield and reduction of 26 percent in water requirement.Continuous submergence in transplanted paddy was not economically feasible. Irrigating rice fields 3 days after disappearance of ponded water necessitating irrigations at about weekly intervals were adequate for optimum yield of transplanted paddy in all requiring 8-10 irrigations during normal rainfall years.Drastic reduction in the grain yield of drilled paddy (dry seeded) occurs if the top soil gets depleted below field capacity level. Thus drilled rice also needs to be irrigated about 3 days after disappearance of ponded water for top yields.In a sandy loam soil with ground water table within 1.65 m depth from soil surface, the crop subjected to irrigations at 3 days after disappearance of pounded water (DADPW) caused a significantly increase in the grain yield increase was the order of 4.6 q/ha.

6.5 Studies on Maize crop

Seedling stage of maize was the most sensitive stage of the crop for waterlogging when adequate attention should be paid to facilitate drainage. Planting should be made on ridges or on raised bed in waterlogging prone areas and nitrogen should be applied in 4 splits giving 40 per cent N as basal and the remaining nitrogen 20 percent each at seedling, grand growth and tasselling stages.Yield of spring maize was highest over the water table at 0.6 m depth and irrigations scheduled at 50 percent depletion on the available soil moisture. The influence of water use (ET) on grain yield of spring maize was linear. The correlation coefficient was highly significant.

6.6 Studies on Surface Irrigation

Water requirement reduced approximately 50 percent when average undulation of the field was reduced to half by leveling; suggesting that efficiency of irrigation application is more when the fields are level.The water application efficiency and storage efficiency increases and decreases, respectively, with an increase in border width from 3 to 5 m. The crop yield and the water use efficiency was found more with 4 m width than with 3 and 5 m border width. It is, therefore, recommended to have a border width of 4 m for efficient use of water in medium textured soils.The 21.6% saving in water application in field and better distribution of water in root zone was obtained with land leveling followed by border irrigation. The total saving in water amounted to 33% indicating that 8% of saving of water is obtained through proper layout of irrigation Channel. The increase in the yield amounted to 32%.The distribution and application efficiency decreases as border width increases and vice-versa. For getting application efficiency more than 80%, the value of A/Q (Border Area/Flow Rate) ratio should be less than or equal to 15 m^2/lps. The value of distribution efficiency can be obtained more than 90% with A/Q ratio in between 10 to 20 m^2/lps.For furrow irrigation 1.5 lps and 2.0 lps may be used for 60-75 cm and 90 cm furrow widths respectively in silty clay loam of Nainital *Tarai.*Furrow irrigation in sandy loam soil showed that at 75% cutoff ratio, the distribution efficiency was maximum for all the discharge rates 2.5, 3.2 and 5.0 lit/sec for furrow grade 0.55% whereas application efficiency was the least at 80% cutoff ratio.For flow rates of 5, 7, 10 and 14 lps, the basin sizes of 100, 150, 200 and 300 m^2 respectively, should be selected for irrigating level fields of silty clay loam. For higher flow rates it is advisable to divide the flow for irrigating two or more check basins instead of irrigating one basin having the area larger than 300 m^2.Considering the size of stream, area lost in bunding, percolation losses and grain yield, the optimum sizes of checks were obtained as 245 m^2 and. 315 m^2 for the stream sizes of 7.05 lit/sec and 10.0 lit/sec respectively under silty clay loam soil conditions.

6.7 Rainfall based probabilistic crop irrigation water requirement

The study was carried out to estimate the effective rainfall, weekly, monthly and seasonal irrigation water requirement of major crops of Udham Singh Nagar district, comprising of Kashipur, Bajpur, Gadarpur, Rudrapur and Sitarganj blocks. The calculated evapotranspiration values were maximum, during the first two weeks after transplantation, for paddy; during 16^{th} and 17^{th} weeks after its sowing i.e. during March, for wheat and during the month of June for Sugarcane. Seasonal irrigation water requirement for paddy was found to be in the range of 782-1285 mm for the probability range of 70-80 percent for the Kashipur block, 765-1175 mm for Rudrapur block and 880-1186 mm for Sitarganj block of Udham Singh Nagar district. The annual average water irrigation requirement of the Udham Singh Nagar district was 1129.64 mm for paddy, 280.54 mm for wheat and 1118.13 mm for sugarcane crops at 80 percent probability. The total water requirement of the district was at its peak during the month of July.

6.8 Studies on zero-till borders

The results of the study indicate that to obtain optimum grain yield along with optimum water use and distribution efficiency in zero tilled borders, in soybean-wheat cropping sequence, the cutoff length of borders should be kept at 80 per cent of the border length. At this cutoff length nearly equal opportunity time were observed during experimentation resulting in a 99.95 per cent water distribution

6.9 Design and development of Pantnagar Foot ValveRelevance of the Technology:

Studies on the hydraulic evaluation of commercially available foot valves conducted at different places have shown that these foot valves offer excessive head loss due to friction. Keeping this in view a new design of foot valve named as *'Pantnagar foot valve'* has been developed. The foot valve was designed and developed for a 10 cm diameter suction pipe. It was 4 to 8 time more efficient than the commercial foot valves**.**

Description of the Technology:

Pant Nagar Foot valve consisted of a casing cum strainer and a valve system.

(i) Casing cum strainer: A 15 cm diameter pipe 25 cm long with a plate welded in the bottom, was used as casing cum strainer. Continuous slots were made on the circumference as well as after the bottom at one cm spacing. 25 slots of 1 cm width and 7 cm length were made on the circumference. Similarly, slots of 1 cm width at one cm radial spacing were made in the bottom plate. The perforated area was 3 times the cross sectional area of suction pipe of 10 cm diameter. A ring was welded inside the pipe just above the perforated portion to provide a proper seat to the valve. The thickness of the ring was 5 cm in the inner 3 cm width and 3 mm in the remaining width. A reducer of 15 cm x 10 cm was provided on the casing to connect the valve with the suction pipe.

(ii) Valve System : The valve system consists of the following components:

1. Leather washer, 2. Lower plate, 3.Upper plate, 4. Hinge and 5. Connecting plate

A leather washer of 3 to 4 mm thickness and 12.5 cm diameter was used. Cast iron circular plates of 3 to 4 cm thickness were put on the lower and upper sides of the washer. The lower plate was 9 cm in diameter and the upper plate was 10 cm in diameter. All the three components were tightened by nuts and bolts in the centre. The upper plate was provided a free hinge with a connecting plate of 3 mm width, 2 mm thickness and 7.5 cm in length. The connecting plate was provided with holes at two points to fix it with nuts and bolts with the casing wall. The valve rested on the internal ring when the pump was not in operation. It opened vertically almost full when the pump was in operation.

Output : The comparison of hydraulic performance of Pantnagar foot valve with commercially available foot valves, used in the region ,showed that the Pantnagar foot valve reduces the head loss and saves energy to a greater extent. The capacity of the pump with Pantnagar foot valve also increased by 6.3 lit/sec compared with the capacity of the pump with commercial foot valve. The Pant Nagar foot valve was found 4 to 8 times more efficient than the commercial foot valves at these discharge rates.

Views of Pantnagar Foot Valve

6.10 Design and development of Pant Nagar propeller pumpRelevance of the technology:

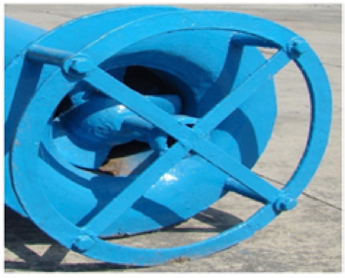
Several types of pumps are available for lifting irrigation water under different conditions of head and discharge. These include centri-fugal pumps, turbine pumps, submersible pumps, pro-peller pumps and mixed flow pumps. Centrifugal pumps are usually efficient at heads more than 4 meters. For lower heads, the efficiency of these pumps falls below the acceptable range. Turbine and submer-sible pumps are adopted to lift water from deep tube wells where cen-trifugal pumps cannot be installed near the water surface. However, many pumping jobs require efficient handling of large- quantities of water against low heads such as lifting of water from rivers, canals, ponds or open wells with shallow water table. In these situations, the propeller pump is best suited. It has relatively high discharge capacity and high efficiency, compared to other pumps for lifting water against low heads ranging from one to four meters. Propeller pumps have not become popular in India in irrigation practice. It has been observed that the prices of these pumps are disproportionately high and beyond the capacity of an average farmer. In such a situa-tion the farmers have no other choice, but to use the centrifugal pump which, because of low efficiency, requires high energy input and works at low heads. Keeping the above points in view a new low cost design of propeller pump, named as "*Pantnagar Propeller Pump*" has been deve-loped.

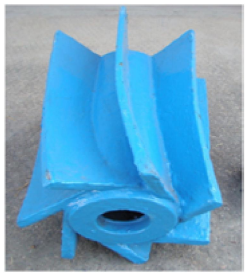
Description of the Technology:

Capacity : This Propeller pump has a capacity of 45 to 65 lit/sec Suitability : Lifting of water from rivers, canals, ponds or open wells with shallow water table. It has relatively high discharge capacity and high efficiency, compared to other pumps for lifting water against low heads ranging from one to four meters. Design Features :

- Casing: The casing is tapered from 22.5 cm in the lower most portion to 30 cm at the end of tapered length.
- Propeller: 3-vane propeller of 22 cm diameter made of Aluminum.
- Diffuser: It has 7 vanes with its diameters tapering from 22.5 cm to 30 cm. The hub diameter is 13.5 cm. The length of the diffuser is 45 cm. It is provided with two ball bearings.

Output : The pump performed best at a speed of 1440 rpm. The efficiency of the pump at this speed varied from 65 to 40 percent at a static head of 1.0 to 2.5 meter and discharge and horse power ranged from 65 to 30 lit/sec and 2.3 to 3.2 hp respectively.





Propeller Diffuser

PantnagarPropeller

6.11 Rejuvenation of Natural Springs Relevance of the Technology:

Drying up of natural springs are major problem in hilly region of Uttrakhand state. This problem is due to deforestation, grazing and trampling by livestock, erosion of top fertile soil, forest fires and development activities. These activities have reduced the infiltration rate and sponge action of the land and thus create the failure of natural spring. This has plunged mountain residents to severe water shortage for drinking water, so much that women and girl have to walk kilometers for potable water. In Uttarakhand, out of total 16000 villages 8800 villages have been placed as water scarce villages. Therefore, the real crux of the problem is how to increase the water retention in the fragile watersheds to augment a sustainable discharge. Keeping it in view, three natural springs (two perennial and one seasonal) located at different locations in Tehri Garhwal district of Uttarakhand were studied their hydrological trend and some treatment measures were tried to rejuvenate the springs for their sustainability.Description of the Technology .

Three natural springs (two perennial and one seasonal) located at different locations in Tehri Garhwal district of Uttarakhand, were selected to study their hydrological trend and engineering treatment measures were tried to rejuvenate the springs for their sustainability Due to steep sloping catchments area of the springs, a major quantity of rainfall water was going as runoff. Therefore, to increase the infiltration opportunity time of this rainfall water, staggered and continuous contour trenches were made according to the feasibility of the geographical area. Output The variation in discharge of Hill Campus spring and Ambar II spring for different years showed that the maximum weekly discharge was increased. The effect of engineering treatments like contour trenches and ditches constructed in the upper catchments increased in the discharge every year. During first year the spring discharge, of Hill Campus spring, increased by 22.64 per cent. Next year it again increased by about 38.95 per cent in comparison to previous year. In this way it increased by 70.4 per cent during these two years. The developed technology may be applied in different regions of Uttarakhand and other hill states to rejuvenate natural springs.

2. Research Publications:

A. Research Papers Published in National / International Journals

1. Gurvinder Singh, Subhash Chandra and Amit Bhatnagar. 2013. Response of spring sugarcane to irrigation scheduling and planting methods in sub-tropical India. *Madras J.Res.*100 (7-9): 709-712.

2. Jillani Asima, Akhilesh Kumar and Vinod Kumar (2014). Comparison of Infiltration Behaviour of Guar Gum and Carboxymethylcellulose (CMC) Polymer Treated and Untreated Soils. *In*: Proceedings National Seminar on "Natural Resource Management & Environmental Concerns" G.B. Pant University of Agriculture & Technology, Pantnagar (Uttarakhand), May 16-18, 2014, pp II127-II135.

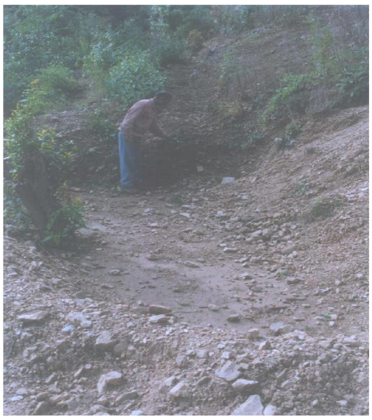
3. Sonakar, S. V. and Vinod Kumar (2014). Drought Investigation at Pantnagar. *In*: Proceedings National Seminar on "Natural Resource Management & Environmental Concerns" G.B. Pant University of Agriculture & Technology, Pantnagar (Uttarakhand), May 16-18, 2014, pp I80-I88.

4. Lalit Kumar, Gurvinder Singh, Subhash Chandra, Amit Bhatnagar and K.P. Raverkar. (2014). Yield quality and irrigation water use efficiency in sugarcane as influenced by pre-planting tillage and crop establishment methods in *tarai* belt of Uttarakhand. *Indian J. Agron* 59 (1): 175-178.

5. Amit Bhatnagar, Gurvinder Singh and Veer Singh (2015). Performance of spring maize (*Zea mays*) in spatial association with sunflower(*Helianthus annus*) and urdbean (*Vigna mungo*) in sub tropical north India. *Agricultural Research.* 4(3):231-2376.

6. Amit Bhatnagar, Subhash Chandra and Gurvinder Singh (2015). Weed control options for maize (*Zea mays* L.) and effects on succeeding wheat crop in Tarai region of Uttarakhand.. *International Journal of basic and applied Agricultural Research*. 13 (2):245-249.

7. Amol Babar, amit Bhatnagar, Rajeew Kumar and



Engineering Treatments : ditches and contour trenches

Gurvinder Singh (2015). Effect of Metal Nano Particles of Zinc Oxide and Titanium Oxide on germination and seedling vigour of maize. *Research Journal of Agricultural sciences*, 6(3):610-612.

8. Anchal Dass, Subhash Chandra, Anil K. Choudhry, Gurvinder Singh and S. Sudhishri. (2015). Influence of field re-ponding pattern and plant spacing on rice root-shoot characteristics, yield and water productivity of two modern cultivars under SRI management in Indian Mollisos. Paddy and water environment, DOI 10. 1007/S 10333-015-0477-2.

9. Asima Jillani, Akhilesh Kumar and Vinod Kumar (2015) Effect of Guargum polymer treatments on infiltration behavior of soils. Indian Journal of Soil Conservation. Vol.43, No. 3, pp 262-265, 2015.

10. Gurvinder Singh, Lalit Kumar, Subhash Chandra, Amit Bhatnagar and K. P. Raverkar. (2015). Response of summer planted sugarcane tillage practices and planting methods. *Madras J.Res.*102 (1-3): 46-51.

11. Nirdesh Kumar, Amit Bhatnagar, Subhash Chandra and Gurvinder Singh. (2015). Productivity and profitability of spring sugarcane (*Saccharum officinarum* L.) under different planting patterns designed for mechanized inter cultivation. *Madras J.Res.*102 (1-3):43-45

12. Amit Bhatnagar, Gurvinder Singh and Veer Singh .2015. Performance of spring maize (*Zea mays*) in spatial association with sunflower (*Helianthus annus*) and urdbean (*Vigna mungo*) in sub tropical north India. *Agricultural Research.* 4(3):231-237

13. Yurembam G. S., Harish Chandra and Vinod Kumar (2015) Status of Available Macro and Micronutrients in the Soils of Someshwar Watershed in Almora District of Uttarakhand. The Eco-Scan, 9 (3&4): 725-730, 2015.

14. Yurembam G.S., Harish Chandra, Vinod Kumar and A.K. Rabha (2015). Mapping of Soil Micronutrients in Someshwar Agricultural Watershed using IDW Interpolation Approach. International Journal of Emerging Technologies in Computational and Applied Sciences (IJETCAS), Issue 12, Volume 3, pp. 220-225, March-May, 2015.

15. Yurembum G. S., and Vinod Kumar (2015). Optimization of land and water resource in Nakatiya Minor Canal command area in Udham Singh Nagar, Uttarakhand, India. International Journal of Emerging Technologies in Computational and Applied Sciences (IJETCAS), Issue 11, Volume 3, pp. 213-216, December-2014 to February-2015.

16. Mohd. Aftab Alam, Yogendra Kumar and Harish Chandra Sharma (2016). New Agriculturist. Ground water modeling in Bellan canal Command Area of Allahabad District using Artificial Neural Network (ANN).Vol. 27 No. (2)

17. Alam, M. A., Y. Kumar, and H. C. Sharma (2016). Physico-Chemical Properties of Soils in Bellan Canal Command Area In Allahabad District of Uttar Pradesh Progressive Research Journal Volume11, No 1, Jan 2016

18. Sonakar, S.V., Vinod Kumar and A.S. Tomar. (2016). Drought Analysis for Udham Singh Nagar District of Uttarakhand (India). *International Journal of Research in Engineering and Applied Sciences* . Vol 6 (4):29-37.

19. Gurvinder Singh, V.K. Joshi, Subhash Chandra, Amit Bhatnagar and Anchal Dass (2016). Spring maize (Zea mays L.) response to different crop establishment and moisture management practices in north-west plains of India. *Res. On Crops,* 17(2): 226-230.

20. Gurvinder Singh, Lalit Kumar, Subhash Chandra, Amit Bhatnagar and K. P. Raverkar (2016). Energy Requirement under Different Planting Methods of Sugarcane with and without Preparatory Tillage. *Indian Journal of Ecology* 43(1): 75-79.

21. Gurvinder Singh, Subhash Chandra and Vinod Kumar. (2016). Wheat (*Triticum aestivum*) productivity, profitability, irrigation water use efficiency and energetics under different irrigation

levels and sowing methods. *Indian J. Agron*, 61(3): 336-341.

22. Gurvinder Singh, Subhash Chandra, S. K. Guru, Vimal Raj, Tanumay Mandal and Samarth. (2016). Late sown wheat (*Triticum aestivum* L.) response to crop establishment methods, chemical sprays and post flowering irrigation in *tarai* belt of Uttarakhand. *Res. On Crops* 17(4): 666-672.

23. Amit Bhatnagar, M.S. Pal and Gurvinder Singh (2016). Influence of weed management on growth and productivity of maize (Zea *mays* L.) and residual effect on succeeding wheat (*Triticum aestivum* L.).

24. D.K. Shukla, Chandrabhusan, V.K.Singh and Gurvinder Singh (2016). Effect of tillage levels on productivity, irrigation water use efficiency, Economics and Energetic of chickpea (*Ciceraretinum)* in tarai region. *International Journal of Bio-resource and stress management* 7(6):131-135

25. Krishan Kumar and Vinod Kumar. (2016). Morphometric Analysis of Gagas River Valley Watershed in Almora District of Uttarakhand using Remote Sensing and GIS. *International Journal of Engineering & Scientific Research.* 4(4): 144-157.

26. Krishan Kumar and Vinod Kumar. (2016). Prioritization of Sub-watersheds of Gagas River Valley using Remote Sensing and GIS. *International Journal of Research in Engineering and Applied Sciences.* Vol 6 (3):40-51.

27. Krishan Kumar, Vinod Kumar and Devendra Kumar. (2016). Land Use and Land Cover Change Detection In Gagas River Valley Watershed Using Remote Sensing and GIS. *International Journal of Research in Engineering and Applied Sciences.* Vol 6 (5):31-37.

28. Vivekanand and Vinod Kumar. (2016). Optimization of Land and Water Resources in Nanakamatta Canal Command of Uttarakhand using Fuzzy Linear Programming. *International Journal of Research in Engineering and Applied Sciences*. 6 (3):1-9.

29. Anchal Dass, Subhash Chandra, Norman Uphoff, Anil K. Choudhary, Ranjan Bhattacharyya and K. S. Rana. (2017). Agronomic fortiûcation of rice grains with secondary and micronutrients under differing crop management and soil moisture regimes in the north Indian Plains. *Paddy Water Environ*, DOI 10.1007/s10333-017-0588-9 Published online: 11 March, 2017.

30. Lal, M., Mishra, S. K., Pandey, A., Pandey, R. P., Meena, P. K., Chaudhary, A., Jha, R.K.,Shreevastava, A.K. and Kumar, Y. (2017). "Evaluationof the Soil Conservation Service curve number methodology using data from agricultural plots"Hydrogeology Journal, 25(1):151-167.

31. Lal, M.,Mishra, S. K.,Pandey, A., Kumar, Y. (2017). Runoff Curve Number for36Small Agricultural Plots at Two Different Climatic Conditions in India. International Springer Publishing AG 2017, V. Garg et al. (eds.), Development of Water Resources in India,Water Science and Technology Library 84, DOI 10.1007/978-3-319-55125-8_22

32. Vimal Raj Yadav, Subhash Chandra, Gurvinder Singh and Samarpal Singh. (2017). Productivity and economics of direct seeded rice (*Oryza sativa* L.) as affected by moisture regimes and seed priming under sandy loam and silty clay loam soils. *Res. on Crops* 18(1):1-5

33. Tanumay Mandal, Subhash Chandra and Gurvinder Singh. (2018). Productivity and economics of Rice-Wheat Cropping System under Irrigation, Nutrient and Tillage Practices in a Silty Clay Loam Soil .*Int.J.Curr.Microbiol.App.Sci* (2018) *7*(3): 823-831.

34. Gurvinder Singh, Tanay Saha, Subhash Chandra, Amit Bhatnagar and Samarth. (2018). Productivity of menthol mint (*Mentha arvensis* L.) and wheat(*Triticum aestivum*) as relay and sequential cropping system under different irrigation scheduling. *Indian Journal of Agronomy*(accepted)

35. Kala, D. C., Kushwaha, H.S., Bhatt, M. and Nanda, G. 2018. Development parameters, yield and agro meteorological indices of wheat as affected by different dates of sowing, compaction levels and irrigation schedules. *Journal of Pharmacognosy and Phytochemistry.* Vol 7(4): 1199-1203. *NAAS Rating*: 5.21. *Impact Factor*: RJIF 5.52.

36. Parbhakar, M., Kushwaha, H. S. and Kala, D. C. 2018. Effect of Establishment Methods and Moisture Regimes on Physical Properties of Soil in a Rice Field under Deep Water Table Conditions of Uttarakhand. *International Journal of Current Microbiology and Applied Sciences.* Vol 7(11): 749-759. *NAAS Score*: 5.38, ISSN:2319-7692

37. Kala, D. C., Kushwaha, H. S., Bhatt, Maneesh and Joshi, Renu. 2019. Effect of compaction levels and irrigation schedules on growth and development of wheat crop under different dates of sowing. *International Journal of Chemical Studies.* Vol 7(1): 120-126. *NAAS rating* 4.64 ISSNý: ý2321-4902

38. Kushwaha, H. S., Kala, D. C. and Rani Manisha. 2018. Customized Fertilizers and Their Role in Increasing Crop Production. *Indian Farmers Digest*. 51 Vol (12): 41-43 (ISSN No. 0537-1589).

3. Thesis Research:

1. Ph.D (Irrigation and Drainage Engineering) and Ph.D. Soil Science

1. Kumar, A. 2004. Ground water recharge planning on Ganga-Ramganga interbasin using GIS. Thesis, Ph.D in Irrigation and Drainage Engineering. Submitted to GBPUAT Pantnagar under guidance of Dr. H. C. Sharma.

2. Singh, R. 2006. Planning and Management of land and water resources in Nagini watershed of Uttarakhand using GIS and Remote Sensing. Thesis, Ph.D in Irrigation and Drainage Engineering. Submitted to GBPUAT Pantnagar under guidance of Dr. H. C. Sharma.

3. Tomar, A.S. 2010. Spatial Decision Support System for Natural Resource Management Planning. Thesis, Ph.D in Irrigation and Drainage Engineering. Submitted to GBPUAT Pantnagar under guidance of Dr. H. C. Sharma.

4. Srivastava, R.K. 2010. Land and water Resources Management of Badri Gad Watershed, Uttarakhand. Thesis, Ph.D in Irrigation and Drainage Engineering. Submitted to GBPUAT Pantnagar under guidance of Dr. H. C. Sharma.

5. Singh, R.K. 2011. Artificial Ground water Recharge planning for Jamrani Dam Command using GIS and Remote Sensing. Thesis, Ph.D in Irrigation and Drainage Engineering. Submitted to GBPUAT Pantnagar under guidance of Dr. H. C. Sharma

6. Mistry, P.K. 2017. Design and Development of Decision Support System for Natural Resource Management Planning for Bundelkhand Region. Thesis, Ph.D in Irrigation and Drainage Engineering. Submitted to GBPUAT Pantnagar under guidance of Dr. H. C. Sharma.

7. Alam, M.A. 2016. Development of Groundwater Simulation Models and Optimal Utilization Planning of Land and Water Resources for the Bellan Canal Command Area of Allahabad District Thesis, Ph.D in Irrigation and Drainage Engineering. Submitted to GBPUAT Pantnagar under guidance of Dr. Yogendra Kumar

8. Kumar, K. 2017. Land and Water Resource Management in Gagas River Valley Watershed using Remote Sensing and GIS. Thesis, Ph.D in Irrigation and Drainage Engineering. Submitted to GBPUAT Pantnagar under guidance of Dr. Vinod Kumar.

9. Kala, D.C. 2018. Effect of Compaction and Irrigation Schedules on Physico-Chemical Properties of a Sandy Loam Soil, Growth and Yields of Wheat (*Triticum aestivum* L.) and Their Simulation Using CERES-Wheat Model. Thesis, Ph.D in Soil Science Submitted to GBPUAT Pantnagar under guidance of Dr. H.S. Kushwaha.

10. Prabhakar, M. 2019. Effect of establishment methods and irrigation scheduling on physical properties of a sandy loam soil, growth, development and yields of rice (*oryza sativa* l.) And their simulation study using ceres-rice model. Thesis, Ph.D in Soil Science Submitted to GBPUAT Pantnagar under guidance of Dr. H.S. Kushwaha.

2. M. Tech Agricultural Engineering (Irrigation and Drainage Engineering), M.Sc (Ag) in Soil Science and M.Sc. (Ag) in Agronomy.

1. Kaushal, A.1992. Ground water modelling for Jamrani Dam command area. Thesis, M. Tech in Agricultural Engineering (Irrigation and Drainage Engineering). Submitted to GBPUAT Pantnagar under guidance of Dr. H.C. Sharma.

2. Pal, R. 2002. Hydrodynamic dispersion of urea in soil. Thesis, M.Tech in Agricultural Engineering (Irrigation and Drainage Engineering). Submitted to GBPUAT Pantnagar under guidance of Dr. H.C. Sharma.

3. Prasad, S. 2003. Dynamic modelling of spring discharge . Thesis, M.Tech in Agricultural Engineering (Irrigation and Drainage Engineering). Submitted to GBPUAT Pantnagar under guidance of Dr. H.C. Sharma.

4. Taley, S.S. 2004. Mathematical modeling for ground water recharge planning in Badaun District of Uttar Pradesh. Thesis, M.Tech in Agricultural Engineering (Irrigation and Drainage Engineering). Submitted to GBPUAT Pantnagar under guidance of Dr. H.C. Sharma.

5. Gupta, P.K. 2004. Artificial Neural network model based planning and design of water harvesting system for a watershed of Uttaranchal. Thesis, M.Tech in Agricultural Engineering (Irrigation and Drainage Engineering). Submitted to GBPUAT Pantnagar under guidance of Dr. H.C. Sharma.

6. Rawat, S.S. 2004. Artificial Neural network modelling of spring flow. Thesis, M.Tech in Agricultural Engineering (Irrigation and Drainage Engineering). Submitted to GBPUAT Pantnagar under guidance of Dr. H.C. Sharma.

7. Roy, M. 2005. Land and water resources planning and management of Bijnor District using remote sensing. Thesis, M.Tech in Agricultural Engineering (Irrigation and Drainage Engineering). Submitted to GBPUAT Pantnagar under guidance of Dr. H.C. Sharma.

8. Vitthal, P.V. 2006. Ground water modelling in Ganga-Ramganga interbasin using Fuzzy logic and ANFIS. Thesis, M.Tech in Agricultural Engineering (Irrigation and Drainage Engineering). Submitted to GBPUAT Pantnagar under guidance of Dr. H.C. Sharma.

9. Mishra, S.S. 2007. Natural resources management of Henval watershed of Uttarakhand using GIS and Remote Sensing. Thesis, M.Tech in Agricultural Engineering (Irrigation and Drainage Engineering). Submitted to GBPUAT Pantnagar under guidance of Dr. H.C. Sharma.

10. Santosh, P.S. 2008. Artificial ground water recharge planning in Ramganga- Kosi interbasin using GIS and Remote Sensing. Thesis, M.Tech in Agricultural Engineering (Irrigation and Drainage Engineering). Submitted to GBPUAT Pantnagar under guidance of Dr. H.C. Sharma.

11. Raundal, Y.A. 2009. Land use suitability and impact assessment of soil conservation and water resources development measures in Garhkundar-Dabar watershed. Thesis, M.Tech in Agricultural Engineering (Irrigation and Drainage Engineering). Submitted to GBPUAT Pantnagar under guidance of Dr. H.C. Sharma.

12. Bhivashen, K.M. 2014. Land and water resources management in garud watershed using remote sensing and g.i.s. Thesis, M.Tech in Agricultural Engineering (Irrigation and Drainage Engineering). Submitted to GBPUAT Pantnagar under guidance of Dr. H.C. Sharma.

13. Prasad, A. 2017. Natural resources management

planning for horticultural crops under drip irrigation in tamgarda-erani interbasin of uttarakhand. Thesis, M.Tech in Agricultural Engineering (Irrigation and Drainage Engineering). Submitted to GBPUAT Pantnagar under guidance of Dr. H.C. Sharma.

14. Kardam, S. 2017. Land Use/Land Cover Change Detection in Hill, *Bhabar and Tarai* Regions of Nainital and Udham Singh Nagar Districts of Uttarakhand By the Application of Remote Sensing and GIS. Thesis, M.Tech in Agricultural Engineering (Irrigation and Drainage Engineering). Submitted to GBPUAT Pantnagar under guidance of Dr. H.C. Sharma.

15. Berihum, W.M. 2000. Studies on micro irrigation with plastic mulching on cabbage and bitter gourd. Thesis, M.Tech in Agricultural Engineering (Irrigation and Drainage Engineering). Submitted to GBPUAT Pantnagar under guidance of Dr. Yogendra Kumar.

16. Shreshtha, S. 2001. Steady state seepage from a trapezoidal canal with impermeable bed at finite depth-A Hele-Shaw model study. Thesis, M.Tech in Agricultural Engineering (Irrigation and Drainage Engineering). Submitted to GBPUAT Pantnagar under guidance of Dr. Yogendra Kumar.

17. Teshome, W.F. 2003. Field investigation and design of surface and subsurface systems. Thesis, M.Tech in Agricultural Engineering (Irrigation and Drainage Engineering). Submitted to GBPUAT Pantnagar under guidance of Dr. Yogendra Kumar.

18. Piwlatkar, G.K.R. 2004. Study of sub-surface drainage of two layered soil with variable replenishment rate. Thesis, M.Tech in Agricultural Engineering (Irrigation and Drainage Engineering). Submitted to GBPUAT Pantnagar under guidance of Dr. Yogendra Kumar.

19. Shivaji, R.A. 2005. Land and water resources management planning for Chamba-Hanswan watershed using GIS. Thesis, M.Tech in Agricultural Engineering (Irrigation and Drainage Engineering). Submitted to GBPUAT Pantnagar under guidance of Dr. Yogendra Kumar.

20. Lal, N. 2008. Natural resources management at Chaubatia watershed using GIS. Thesis, M.Tech in Agricultural Engineering (Irrigation and Drainage Engineering). Submitted to GBPUAT Pantnagar under guidance of Dr. Yogendra Kumar.

21. Sadanand, B.P. 2009. Water resources management planning in a micro-watershed of Henval river using genetic algorithm, GIS and Remote Sensing. Thesis, M.Tech in Agricultural Engineering (Irrigation and Drainage Engineering). Submitted to GBPUAT Pantnagar under guidance of Dr. Yogendra Kumar.

22. Rajwade, Y.A. 2010. Pollution of water resources due to Pulp and Paper Mill in Tarai belt of Uttarakhand. Thesis, M.Tech in Agricultural Engineering (Irrigation and Drainage Engineering). Submitted to GBPUAT Pantnagar under guidance of Dr. Yogendra Kumar.

23. Bhimrao, P.V. 2013. Study of Pollution of Water Resources Due to Industries in Bazpur Area of Uttarakhand Thesis, M.Tech in Agricultural Engineering (Irrigation and Drainage Engineering). Submitted to GBPUAT Pantnagar under guidance of Dr. Yogendra Kumar.

24. Verma, A. 2014. Study on Pollution of Water Resources Due To Industrial Cluster Near Kashipur Town of Uttrakhand State. Thesis, M.Tech in Agricultural Engineering (Irrigation and Drainage Engineering). Submitted to GBPUAT Pantnagar under guidance of Dr. Yogendra Kumar.

25. Qureshi, S. 2017. Optimal Utilization of Land and Water Resources for Crop Planning in Dhora Canal Command. Thesis, M.Tech in Agricultural Engineering (Irrigation and Drainage Engineering). Submitted to GBPUAT Pantnagar under guidance of Dr. Yogendra Kumar.

26. Kandpal, J. 2017. Groundwater Modeling, in the

part of Udham Singh Nagar district and Rampur District, using Adaptive Neuro Fuzzy Inference System (ANFIS) and Wavelet Adaptive Neuro Fuzzy Inference System (WANFIS). Thesis, M.Tech in Agricultural Engineering (Irrigation and Drainage Engineering). Submitted to GBPUAT Pantnagar under guidance of Dr. Yogendra Kumar.27. Yurembam, G.S. 2012. Resources Optimization in lower Bhakra canal command of Uttarakhand. Thesis, M.Tech in Agricultural Engineering (Irrigation and Drainage Engineering). Submitted to GBPUAT Pantnagar under guidance of Dr. Yogendra Kumar.

28. Sonakar, S.V. 2014. Performance evaluation and resource optimization in Nandpur Minor. Thesis, M.Tech in Agricultural Engineering (Irrigation and Drainage Engineering). Submitted to GBPUAT Pantnagar under guidance of Dr. Vinod Kumar.

29. Nand, V. 2015. Optimization of Land and Water Resources in Nanakmatta Canal Command of Uttarakhand Using Fuzzy Linear Programming Approach. Thesis, M.Tech in Agricultural Engineering (Irrigation and Drainage Engineering). Submitted to GBPUAT Pantnagar under guidance of Dr. Vinod Kumar.

30. Bunkar, N. 2017. Assessment and indexing of groundwater quality of udham singh nagar district of uttarakhand. Thesis, M.Tech in Agricultural Engineering (Irrigation and Drainage Engineering). Submitted to GBPUAT Pantnagar under guidance of Dr. Vinod Kumar.

31. Tiwari, D. 2018. Optimal Scheduling Plan of Rotational Canal : A Case Study of Nandpur Minor of Udham Singh Nagar District. Thesis, M.Tech in Agricultural Engineering (Irrigation and Drainage Engineering). Submitted to GBPUAT Pantnagar under guidance of Dr. Vinod Kumar.

32. Joshi, V. K. 2014. Studies on crop establishment and moisture management practices in spring maize (*Zea mays* L.).. Thesis, M. Sc. Ag in Agronomy. Submitted to GBPUAT Pantnagar under guidance of Dr. Gurvinder Singh.

33. Gupta, A. 2014. Studies on the effect of various irrigation schedules on growth, development and seed yield of yellow mustard (*brassica juncea* l.) & nutrient uptake under varying water table conditions. Thesis, M.Sc. Ag. In Soil science. Submitted to GBPUAT Pantnagar under guidance of Dr. H.S. Kushwha .

34. Saha, T. 2015. Irrigation scheduling in mentha (*Mentha arvensis* L.) based relay and sequential cropping with wheat (*Triticum aestivum).* Thesis, M.Sc. Ag in Agronomy. Submitted to GBPUAT Pantnagar under guidance of Dr. Gurvinder Singh.

35. Yashpal. 2016. Drip fertigation study in spring maize (*Zea mays* L.). Thesis M.Sc. Ag. in Agronomy Submitted to GBPUAT Pantnagar under guidance of Dr. Subhash Chandra.

36. Kumar V. 2016. Seed priming and moisture regimes study in direct seeded rice under sandy loam and silty clay loam soils. Thesis M.Sc. Ag .in Agronomy. Submitted to GBPUAT Pantnagar under guidance of Dr. Subhash Chandra.

37. Mandal T. 2016. Tillage, nutrient and irrigation management in rice- wheat cropping system in a silty clay loam soil. Thesis M.Sc. Ag. in Agronomy . Submitted to GBPUAT Pantnagar under guidance of Dr. Subhash Chandra.

38. Bhatt, P. 2016. Water requirement, growth and yield of yellow mustard (*brassica juncea* l.*)* Through non-weighing lysimeters associated with shallow, medium and deep water table conditions. Thesis, M.Sc. Ag. in Soil science. Submitted to GBPUAT Pantnagar under guidance of Dr. H.S. Kushwaha.

39. Tiwari, R. 2017.Response of cowpea *(Vigna Unguiculta (L).Walp)* to varying water table conditions in tarai soil of Uttarakhand. Thesis, M.Sc. Ag. in Soil science. Submitted to GBPUAT Pantnagar under guidance of Dr. H.S. Kushwaha.

40. Joshi, R. 2018. Response of chickpea (*cicer arietinum* l.) to irrigation under varying water table conditions and crop coefficients through non-weighing lysimeters filled with silty clay loam soil. Thesis, M.Sc. Ag. in Soil science. Submitted to GBPUAT Pantnagar under guidance of Dr. H.S. Kushwaha.

4. Award/Honours:

1. Dr . Gurvinder Singh got Best teaching practices award for 2013 honored by College of Agriculture on January 1, 2014.
2. Mr. Vinod Kumar Joshi (Id .No. 35691) got Pooran singh Adlakha best M.Sc thesis award of Agronomy department under guidance of Dr. Gurvinder Singh
3. Dr. Gurvinder Singh got Best teaching practices award for 2017 honored by College of Agriculture on January 1, 2018.
4. Dr . Gurvinder Singh got Appreciation certificate for poster presentation in "efficient rain and irrigation water management" theme of national symposium on doubling farmers income through agronomic interventions under changing scenario held on October 24-26,2018 at Rajasthan college of Agriculture, MPUA&T Udaipur , Rajasthan.

5. Future Thrusts:

1. Conjunctive use study of surface and ground waters in the *Tumaria* canal command of Udham Singh Nagar district of Uttarakhand
2. Land and water resource management in Gagas river valley of Uttarakhand using remote sensing and GIS.
3. Water management in transplanted rice during initial phase for better weed control
4. Ridge planting of rice for higher crop and water productivity
5. Drip fertigation study in vegetable pea in a sandy loam soil
6. Drip fertigation scheduling in mint (*Mentha arvensis* L.) in sandy loam soil during spring season
7. Drip fertigation scheduling in basmati rice (*Oryza sativa* L.) in mollisols of Uttarakhand.
8. Study on sprinkler irrigation scheduling in lentil
9. Irrigation scheduling in chickpea under different sowing and irrigation methods
10. Response of sweet corn to crop establishment methods, mulch and irrigation schedules during spring season
11. Development of water production function for different crops under tarai conditions of Uttarakhand and development of crop coefficient for Gram crop
12 Groundwater behavior study in Udham Singh Nagar.