Response of Broccolli to Irrigation Scheduling and Methods under Drip, Sprinkler and Surface Irrigation

S. K. Himanshu, A. K. Singh, S. Kumar, P. Kalura

Abstract - The aim of this study was to identify the best irrigation method and scheduling that will help in the development of vegetable industry. Field study was carried out during the winter crop growing season of 2009-2010 (December to March) on clay loam soil in Allahabad of India in order to evaluate the effect of irrigation methods and schedules on marketable yield, irrigation production efficiency and economic return of broccoli under semi arid climate. The irrigation during corp growing season was applied when sum of the daily USWB class A open pan reached approximately the predetermined value of 16.3 mm after accounting the rainfall. Irrigation at 150% of pan evaporation replenishment resulted in higher marketable yield of primary and secondary flowers, but irrigation production efficiency was higher with irrigation at 50% of pan evaporation replenishment. The drip irrigation method resulted in slightly higher marketable yield of primary flowers, and irrigation production efficiency as compared with micro-sprinkler irrigation method. The surface irrigation method gave considerably lower yield of primary and secondary flowers and irrigation production efficiency. The irrigation at 150% of pan evaporation replenishment resulted in higher gross return, net return and benefit cost ratio for micro-sprinkler followed by drip and surface irrigation methods. The seasonal water applied/ irrigation schedules and gross return, net return and benefit cost ratio for different irrigation methods exhibited strong quadratic relationship which in-turn can be used for optimizing economic return under limited water resource condition. In spite of higher initial investment, the micro irrigation system (drip and micro-sprinkler) is highly economical for broccoli production in this region.

Key Words: Drip irrigation, Sprinkler irrigation, Surface irrigation, Lateral spacing, Irrigation schedule, Marketable yield, Irrigation production efficiency, Pan Evaporation.

I. INTRODUCTION

Water being the limited resource, its efficient use is essential in order to increase agricultural production per unit volume of water and per unit area of crop land. Due to increase in population, the competition of limited water resources for domestic, industrial and agricultural needs is increasing considerably.

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Water for irrigation is becoming scarce and expensive due to depletion in surface and subsurface of water caused by erratic rainfall and over exploitation. It is therefore, essential to formulate an economically viable water and other input management strategies in order to irrigate more land area with existing water resources and to enhance crop productivity. Right amount and frequency of irrigation is vital for optimum use of limited water resources for crop production and management.

Broccoli is highly perishable, and it is held for only a brief period as needed of orderly handling or marketing. It should be hydro cooled or packed in ice immediately after harvest. Broccoli is one of the best liked dark green vegetables and is delicious if properly prepared. Broccoli also called as “Crown of Jewel Nutrition” because it is rich in minerals and contains 33% of protein and it is good source of vitamins A, B, B_2 and C. It has higher of iron and calcium and is non-fattening food.

Irrigation scheduling is a critical management input to ensure optimum soil moisture status for proper plant growth and development as well as for optimum yield, water use efficiency and economic benefits. It is defined as deciding when to irrigate and how much water to apply and is governed by various complex factors of which micro climate plays the most important role. Therefore it is essential to develop irrigation scheduling strategies under local climatic conditions to utilize scarce water resources efficiently and effectively. Numerous studies have been carried out in past elsewhere on development and evaluation of irrigation scheduling techniques under wide range of irrigation systems and management, soil, crop and climatic conditions [1], [2]. Irrigation scheduling is to increase efficiencies by applying the exact amount of water needed to replenish the soil moisture to the desired level. Appropriate irrigation schedule saves water and energy. Therefore, it is important to develop irrigation scheduling techniques under prevailing climatic conditions in order to utilize scare water resources effectively for crop production [3]. Numerous studies were carried out in the past in the development and evaluation of irrigation scheduling under a wide range of irrigation systems and management, soil, crop and agro climatic conditions. The meteorological based irrigation scheduling approach such as pan evaporation replenishment and cumulative pan evaporation and ratio between irrigation water and cumulative pan evaporation have been used by many researches due to its simplicity, data availability and higher degree of adaptability at the farmer’s level [4], [5], [6].

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The meteorological approach such as pan evaporation replenishment, Cumulative pan evaporation and ratio between irrigation water applied and cumulative pan evaporation were used by many researches due to its simplicity, data availability and adaptability at the farmers level. It was reported that growth, help and essential oil yield on perennial aromatic grass, Palma Rosa increase marketable yield of broccoli, cabbage, rape and carrot with irrigation at 80% of pan evaporation replenishment [7], [8], [9], [10]. Furthermore, the irrigation production efficiency of broccoli, rape and cabbage was maximum at 20%, 60% and 80% of pan evaporation replenishment did not influence the production efficiency of carrot. It was reported the higher yield of cabbage, carrot, spinach, tomato, and onion, but rape gave higher irrigation production efficiency at CPE of 33-35 mm [11].

Drip irrigation is characterized as localized and frequent application of water. It restricts the fluctuation in soil water potential within a narrow range, with favorable soil water regime, leading to high yield [12], [13], [14]. Drip irrigation has been proved advantageous under saline conditions. Many reports have shown higher yield under drip irrigation in non-saline conditions [15], [16]. Drip irrigation system in place of conventional furrow irrigation was recommended at Coimbatore due to economic water utilization to the extent of 87.4%without any loss of yield [17]. 60.1% of higher of okra with water saving of 39.5% under drip as compared to conventional furrow irrigation was reported by Khade [18].

The economic return in relation to irrigation methods and irrigation levels is of important aspects to decide the future strategies for efficient water resource management and sustainable crop production. Numerous studies have been carried out in the past clearly indication that micro irrigation is highly portable for vegetable and food production. It was reported that in case of banana the net return was maximum for one plant at 2m spacing and the highest return in investment was obtained at 4m spacing with 2 plants per location under trickle irrigation system.

In order to optimize crop production in limited water resource conditioned it is important to understand the relationship between water applied and crop production. The relationship between water applied and crop yield is defined as water production function. Information of water production function is important for assessing the priorities for allocating limited irrigation within and between the crops. Surface irrigation is the most common method for field, vegetable and fruit crop in India. The overall efficiency of surface irrigation method is considerably low as compared to modern irrigation method such as drip, micro-jet/micro sprinkler and over head sprinkler. Drip irrigation method with its ability to apply small but frequent water application has been found superior in terms of water economy yield, quality and water use efficiency [19]. It also makes possible the application of fertilizers and other chemical along with water application to match the plants requirements at various growth stages. The drip irrigation system impedes the growth of weeds as it wets only a fraction of the soil surface. This explicates the preponderance of drip irrigation system overall other irrigation methods of irrigation, however, its adoption by the farmers of the region has largely been limited owing to its high cost of installation and lack of information of irrigation scheduling techniques even though the government subsidy is available on its purchase.

Efficient use of water by irrigation system is becoming increasingly important particularly in arid and semi-arid regions. The drip irrigation systems with its ability to apply small but frequent irrigation have numerous advantageous over other methods in terms of water economy, yield and quality [20]. Water application efficiency in the drip irrigation is higher than other methods of irrigation.

II. EXPERIMENTAL WORK, METHODS AND SCHEDULINGS

The field experiment was be conducted at Allahabad (25° 27'N, latitude 81° 44'E longitude, 98m above mean sea level) during Rabi season of 2009-2010 in order to study the response of Broccoli to variable irrigation under drip, micro-sprinkler and surface (check basin) irrigation methods. The climate in this part of country has been classified as semi-arid with cold winter and hot summer. The soil of the experimental field was fertile clay loam, (35.5% sand, 25.8% silt and 38.6% clay) with average bulk density of 1.31 g/cm^3.

The experiment was laid out in two factor randomized block design (irrigation schedules and irrigation methods) with three replications. The area of experimental plot was 7.5m^2 (3x2.5). A buffer zone spacing of 1.0m and 0.5m was provided between the plots and blocks. Broccoli (F1-Hybrid) seeds were sown on 1st November 2009 in the nursery at a depth of 0.05m with a spacing of 10cm between the rows. The seedlings were replanted on 1st December 2009 with a spacing of 50cm between plants and rows. The experimental field received 72kg/ha of Nitrogen, 21kg/ha P_2O_5 and 90kg/ha K_2O. The experimental field received 72kg/ha of Nitrogen at the time of transplanting, 6 weeks and 5 weeks after transplanting.

The experiment consists of four irrigation levels and three irrigation methods. The details of the treatments are presented below.

Irrigation Methods:

D - Drip

M - Micro-sprinkler

S - Check basin

Irrigation Schedules:

I_1 - Irrigation at 50% of pan evaporation Replenishment

I_2 - Irrigation at 100% of pan evaporation Replenishment

I_3 - Irrigation at 150% of pan evaporation Replenishment

I_4 - Irrigation at 200% of pan evaporation Replenishment

The daily USWB class-A open pan evaporation data for a period of 5 years (2004-2008) were collected from meteorological station, SHIATS. The crop was irrigated when the sum of daily mean (5 years) of pan evaporation reached to a predetermined value of 16.3 mm (rooting depth in m × plant available water mm/m × permissible soil moisture depletion in fraction). The crop was irrigated by drip, micro sprinkler and check basin irrigation methods. Screen filter was installed to minimize dripper and micro sprinkler blockage. PVC pipes of 50 mm diameter and LDPE of 12 mm diameter were used for main/sub-main and lateral lines respectively. In case of check basin method water was applied through pipe conveyance system. In micro-sprinkler system, plants were irrigated at a rate of 16 l/hr. In case of drip irrigation method, plants were irrigated at a rate of 4 l/hr.

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The crop was harvested from 15th Feb to 25th March 2010 depending upon the maturity of primary and secondary flowers. The harvesting was done manually.

In order to assess the economic viability of different system under variable irrigation, both fixed and operating costs were included.

The total cost of production, gross return and net return under different irrigation level were estimated under following assumptions:

Salvage value of the components = 0

Useful life of tube-well, pump motor & house = 25 yrs.

Useful life of drip & micro sprinkler system = 8 yrs.

Useful life of open channel conveyance system = 5 yrs.

Useful life of weeding and spraying equipments = 7yrs.

Interest rate = 12.5%

Repair and maintenance = 7.5%

Number of crops/year = 2

The fixed costs which include tube well, pump, motor pump house and irrigation systems, PVC pipe for main and sub main and LDPE pipes for lateral, fertilizer tank, pressure gauges, water meter, drippers, spraying and weeding equipments and other accessories were calculated. The annual fixed cost for irrigation and other accessories were calculated by the following approach

$$CRF = \frac{i(1+i)^n}{(1+i)^{n-1}}, \quad (1)$$

Where

CRF = capital recovery factor

i = interest rate (fraction)

n = useful life of the components (years)

$$\text{Annual Fixed cost/ha} = \text{CRF X fixed cost/ha} \quad (2)$$

$$\text{Annual cost /ha/season} = \frac{\text{Annual fixed cost /ha}}{2} \quad (3)$$

The gross return for different irrigation methods and schedules was calculated taking into consideration of marketable yield and wholesome price of broccoli. Subsequently, the net return of broccoli was calculated considering total cost of production (fixed and operating) and grosses return.

Net return (Rs/ha) =Gross return (Rs/ha) – Total cost of production (Rs/ha)

The benefit cost ratio (B/C) under different irrigation methods and scheduled was calculated as follows:

B/C = Gross return (Rs/ha)/Total cost of production (Rs/ha)

III. RESULTS AND DISCUSSION

A. Yield components and irrigation production efficiency

Irrigation schedules had marked effect on number of the primary flowers/m^2, mean flower weight, marketable yield of primary and secondary flowers and irrigation production efficiency of broccoli. The mean marketable yield of primary flower for different irrigation schedules ranged from 17.92 to 31.23 t/ha. The higher mean marketable yield of primary flowers (31.23 t/ha) was obtained when irrigation during crop growing season was applied at 150% of pan evaporation replenishment. A further increase in irrigation level resulting from 200% of pan evaporation replenishment reduced the marketable yield of primary flowers (26.70 t/ha) significantly due to significant reduction in number of primary flowers/m^2 and mean flower weight. The result revealed that mean flower weight was more affected due to irrigation levels as compared with mean number of flowers/m^2. The irrigation levels had marked effected on irrigation production efficiency of broccoli. The irrigation production efficiency of broccoli ranged from 6.35 to 17.06 kg/m^2. The significantly higher irrigation production efficiency (17.06 kg/m^2) was recorded with irrigation at 50% of pan evaporation replenishment because reduction in marketable yield was less as compared with seasonal water applied. The irrigation production efficiency decreased significantly with an increase in irrigation level (irrigation amount) because increase in yield was much less as compared with seasonal water applied. The significantly minimum irrigation production efficiency (6.35 kg/m^2) was recorded when irrigation during crop growing season was applied at 200% of pan evaporation replenishment because it increased seasonal water applied considerably but decreased the marketable yield. The irrigation methods had significant effect on yield, yield component and irrigation production efficiency (Table-1).

The marketable yield of primary flowers was slightly higher (2%) in drip irrigation as compared with micro sprinkler, whereas surface irrigation method resulted in considerably lower yield (24%) due to poor water distribution. Drip and micro- sprinkler methods resulted in significantly higher irrigation production efficiency.

The overall result presented in Table 1.0, clearly revealed that both irrigation methods and irrigation schedules considerably influenced yield; yield components and irrigation production efficiency of broccoli. The higher marketable yield was recorded when irrigation during the crop growing season was applied at 150% of pan evaporation replenishment, whereas irrigation production efficiency was higher with irrigation at 50% of pan evaporation replenishment. Both drip and micro-sprinkler irrigation methods resulted in almost same marketable yield and irrigation production efficiency whereas; surface irrigation method resulted in considerably low marketable yield and irrigation production efficiency of broccoli.

Table-1 Effect of irrigation schedules and irrigation methods on marketable yield, yield components and irrigation production efficiency of broccoli

Treatments	Mean yield of primary flower, t/ha	Mean irrigation Production Efficiency, kg/m^3
Irrigation schedule: (Pan Evaporation Replenishment, %)		
50	17.92	17.06
100	25.48	12.13
150	31.23	9.91
200	26.70	6.35
Irrigation methods:		
Drip	27.65	10.53
Micro sprinkler	27.18	10.35
Surface	21.17	8.06

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B. Economic return

The total cost of production, gross return, net return and benefit cost ratio of broccoli in relation to irrigation methods and schedules are presented in Table 4.2. The total cost of production increased slightly with an increase in irrigation levels due to increase in pumping cost induced by variation in seasonal water application. The total cost of production for drip, micro-sprinkler and surface irrigation methods varied from 73682 to 77226, 67997 to 71541 and 62236 to 65780 Rs/ha respectively. The total cost of production in drip irrigation was considerably higher as compared with micro-sprinkler irrigation mainly due to variation in irrigation system cost. The labour cost of perform major farm activities represented 30.18 to 41.36% to the total cost of production. The fixed cost contributed 9.8 to 32.88% to the total cost of production depending on the irrigation systems. The repair and maintenance for water development, irrigation system and weeding and spraying equipments etc. contributed 0.49 to 1.64% to the total cost of production. The land preparation, seeds, fertilizers, chemicals and land rent contributed to 29.23 to 40.05% to the total cost of production. The pumping cost contributed 6 to 8.22% to the total cost of production. The gross return under different irrigation schedules for drip, micro-sprinkler and surface irrigation methods ranged from 216900 to 332200, 211000 to 325700 and 180500 to 262100 Rs/ha respectively. The increase in gross return obtained when irrigation during crop growing season was applied at 150% of pan evaporation replenishment due to considerably higher marketable yield.

A further increase in irrigation level resulting from 200% of pan evaporation replenishment reduced the net return considerably due to reduction in gross return. The micro-sprinkler irrigation methods gave higher net return as compared with drip irrigation system mainly due to lower system cost. In spite of lower system cost, the surface irrigation methods gave considerably low net return as compared with drip and micro-sprinkler irrigation systems mainly due to lower gross return. The benefit cost ratio for drip, micro-sprinkler and surface irrigation methods ranged from 2.94 to 5.70, 3.10 to 5.33 and 2.89 to 4.47 respectively. The benefit cost ratio increased with an increase in irrigation levels up to 150% of pan evaporation replenishment due to significant increase in gross return. A further increase in irrigation levels resulting from 200% of pan evaporation replenishment reduced the total cost of production. The micro sprinkler irrigation system resulted in higher benefit cost ratio followed by surface and drip irrigation systems (Table-2).

Table-2 Economic return of broccoli under different irrigation schedules and irrigation methods

Treatments (Pan evaporation replenishment), (%)	Total cost of production (Rs/ha)			Gross return (Rs/ha)			Net return (Rs/ha)			Benefit cost ratio		
	Drip	Micro	Surface	Drip	Micro	Surface	Drip	Micro	Surface	Drip	Micro	Surface
50	73682	67997	62236	216900	211000	180500	143284	143003	118264	2.94	3.10	2.89
100	74863	69178	63417	321300	312200	231000	246503	243022	167583	4.28	4.50	3.63
150	76044	70359	64598	406300	404800	289200	330256	334441	224602	5.70	5.33	4.47
200	77226	71541	65780	332200	325700	262100	255007	254159	196320	4.29	4.55	3.97

C. Water supply and yield

In spite of some variation, the seasonal water applied and marketable yield of broccoli for drip (R^2 = 0.97), micro-sprinkler (R^2 = 0.960) and surface (R^2 = 0.946) irrigation methods exhibited strong quadratic relationship. The marketable yield of broccoli increased with increase in seasonal water applied up to 339, 347 and 400 mm for drip, Micro-sprinkler and surface irrigation methods respectively and thereafter, yield tended to decline (Fig.-1).

The pan evaporation replenishment (irrigation schedules) and marketable yield of broccoli for drip (R^2 = 0.970), micro-sprinkler (R^2 = 0.946) and surface (R^2 = 0.960) irrigation methods exhibited strong quadratic relationship. The broccoli attends the maximum yield at 145, 148 and 159% of pan evaporation replenishment (irrigation schedules) for drip, micro-sprinkler and surface irrigation methods respectively and thereafter, yield tended to decline (Fig.-2).

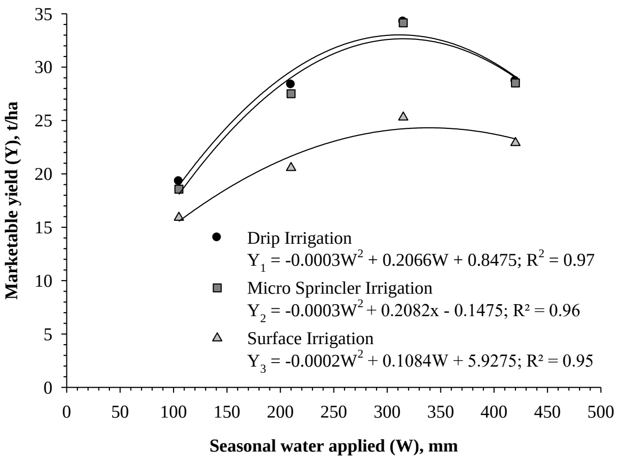

Fig.-1: Relationship between seasonal water applied and marketable yield of broccoli for different irrigation methods

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D. Water supply and economic return

The gross return increased with an increase in seasonal water applied up to 320, 321 and 352 mm for drip micro-sprinkler and surface irrigation methods respectively and thereafter, gross return tended to decline. The results revealed that higher seasonal water application beyond above mentioned values did not increase the gross return. The broccoli attend the maximum gross return at 150, 150 and 165% of pan evaporation replenishment for drip, micro-sprinkler and surface irrigation method respectively and thereafter, the gross return tended to decline.

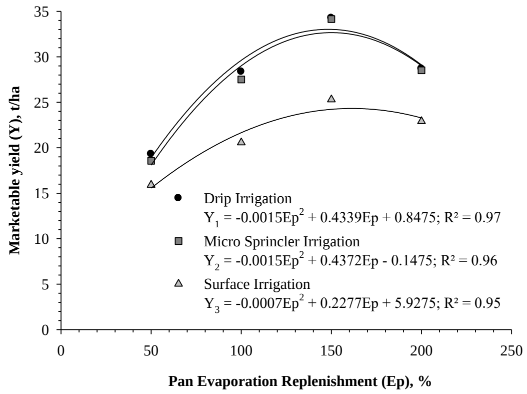

Fig.-2 Relationship between pan evaporation replenishment and marketable yield of broccoli for different irrigation methods

The seasonal water applied and net return of broccoli under drip (R^2 = 0.942), micro-sprinkler (R^2 = 0.928) and surface (R^2 = 0.930) irrigation method exhibited strong quadratic relationship. Broccoli attend the maximum net return at 315, 350 and 320 mm of seasonal water application for drip, micro-sprinkler and surface irrigation methods respectively and thereafter the net return tended to decline (Fig.-3).

Pan evaporation replenishment and net return of broccoli under drip (R^2 = 0.942), micro sprinkler (R^2 = 0.928) and surface (R^2 = 0.930) irrigation methods exhibited strong quadratic relationship. The broccoli attained the maximum net return at 150, 150and 162 for drip, micro-sprinkler and surface irrigation methods respectively and thereafter, the net return tended to decline (Fig.-4).

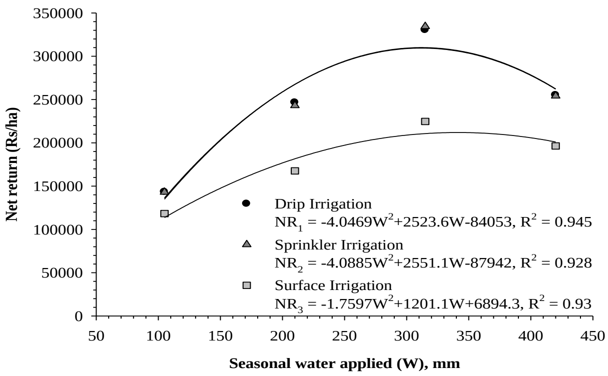

Fig.-3 Relationship between seasonal water applied & net return of broccoli under different irrigation condition

The seasonal water applied and benefit cost ratio of broccoli under drip (R^2 = 0.888), micro-sprinkler (R^2 = 0.979) and surface (R^2 = 0.921) exhibited strong quadratic relationship. The broccoli attained the maximum benefit cost ratio at 352, 322 and 359 mm of seasonal water application for drip, micro-sprinkler and surface irrigation methods respectively and thereafter, benefit cost ratio tended to decline (Fig.-5).

The pan evaporation replenishment and benefit cost ratio of broccoli under drip (R^2 = 0.888), micro-sprinkler (R^2 = 0.979) and surface (R^2 = 0.921) irrigation methods exhibited strong quadratic relationship. The broccoli attained the maximum benefit cost ratio at 142, 126 and 155% of pan evaporation replenishment for drip, micro-sprinkler and surface irrigation methods respectively and thereafter, the benefit cost ratio tended to decline (Fig.-6)

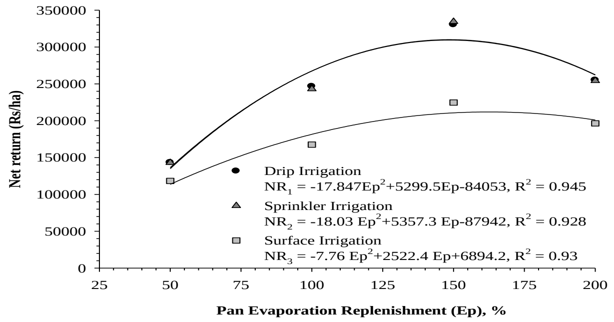

Fig.-4 Relationship between pan evaporation replenishment & net return of broccoli under different irrigation conditions

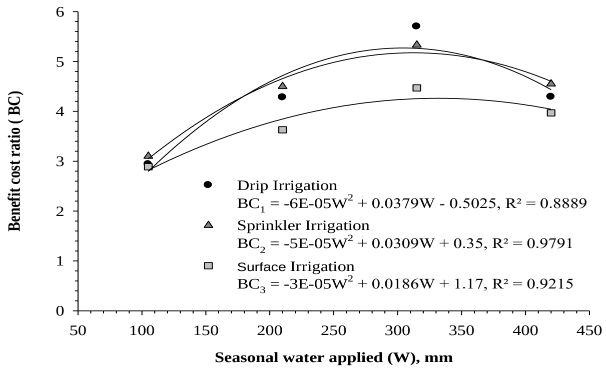

Fig.-5 Relationship between seasonal water applied & benefit cost ratio of broccoli under different irrigation conditions

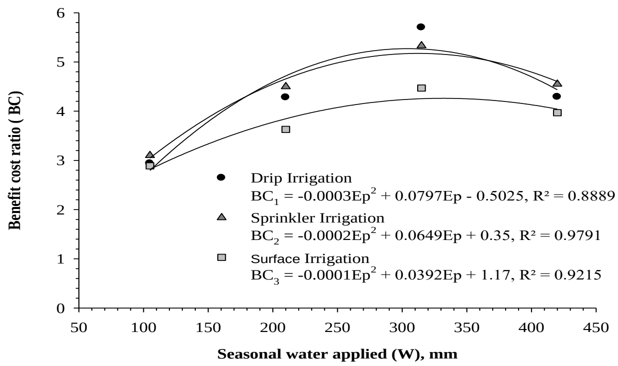

Fig.-6 Relationship between pan evaporation replenishment & benefit cost ratio of broccoli under different irrigation

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IV. CONCLUSIONS

Irrigation at 150% of pan evaporation replenishment resulted in higher marketable yield of primary and secondary flowers of broccoli, but irrigation production efficiency was higher at 50% of pan evaporation replenishment.The drip irrigation method result in slightly higher marketable yield and irrigation production efficiency of broccoli as compared with micro-sprinkler irrigation method, but surface irrigation method gave considerably lower marketable yield and irrigation production efficiency. Irrigation at 150% of pan evaporation replenishment gave higher gross return, net return and benefit cost ratio. The seasonal water applied/irrigation schedules and marketable yield of broccoli exhibited strong quadratic relationship which in turn can be used for allocating limited water resource within and between the crops efficiently. The seasonal water applied irrigation schedules and gross return, net return and benefit cost ratio exhibited strong quadratic relationship which in turn can be used for optimizing economic return of broccoli under limited water supply conditions. Finally, the overall result clearly revealed that in order to obtain higher marketable yield and net return of broccoli under the semi arid climate of Allahabad region, the crop should be irrigated at 150% - 160% of pan evaporation replenishment with drip or micro-sprinkler irrigation system.

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