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Development of water production function for garden pea (*Pisum Sativum* L.) under mid hills of Meghalaya

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ABSTRACT

Pulses are the sources of low cost protein supplements and grown well under assured irrigation supply. However, potential productivity in pulse could not be assured due to erratic water inputs. Hence, considering all other parameters as constant, a relation between yield and water input needs to be developed, which ensures judicious water application. A field trail was carried out to assess the crop performance of garden pea cultivars at different moisture regimes and develop crop water production functions under mid hills of Meghalaya during 2021-22 winter seasons. Irrigation scheduling was done based on the maximum allowable depletion (MAD) of the available soil moisture to different varieties of garden peas. The agronomic field trial was laid under split plot design with four levels of irrigations, *i.e.,* (I_1: 20% of MAD, I_2: 40% of MAD, I_3: 60% of MAD and I_4: 100% of MAD) under main plot treatment, and with four different cultivars (V_1- VM 10, V_2 - VM 12, V_3 - VL Sabji Matar 15, V_4 - VL Sabji Matar 13) under sub plot and was replicated thrice. The highest water productivity was found in treatment I_4 (3.93 kg m^{-3}) over I_2 (3.56 kg m^{-3}) and I_3 (3.34 kg m^{-3}) and I_1 (2.63 kg m^{-3}). Crop water production functions of all cultivars, *i.e.*, relation between the yield and total water used (irrigation + effective rainfall) was obtained as $Y = -0.0001X^2 + 0.0633X - 1.5064$ (Y = yield in t ha^{-1} and X = amount of water used, mm); with $R^2 = 0.96$. Irrigation treatment with 20% of MAD resulted in higher green pod yield whereas higher water productivity was registered for irrigation scheduled with 100% of MAD.

1. Introduction

Pulses have a vital role to play not only in supplementing nutrient to diets but also restoring sustainable soil health in long run. After beans and chickpea, pea is third-most important legume of world, grown both for the purpose of fresh market and the food processing industry. In India after chickpea and lentil pea is the third most important winter pulse crop (Garai *et al.,* 2019). Pea contains high levels of digestible protein (7.2 g), vitamin-A (139 I.U (International units), carbohydrates (14.5 g), vitamin-C (9 mg), phosphorus (139 mg), magnesium (34 mg) and energy (81 kcal) per 100 grams of edible portion (Gopalan *et al.*, 2007). Garden pea is commonly known as 'matar' or 'pea', is an important winter season crop grown in India. Generally two types of pea are cultivated, *i.e.*, field pea used for dal making and garden pea as green vegetable (Damor *et al.*, 2017). Being a leguminous crop, it helps in maintaining soil fertility through the process of BNF (biological nitrogen fixation) with symbiotic bacteria *Rhizobium spe.* present in their root nodules and leaves behind 50-60 kg ha^{-1} of residual nitrogen in soil for the next following crop (Negi *et al.*, 2006). Globally, nearly 21.7 M t of garden pea is produced from an area of 2.78 M ha with an average productivity of 7.82 t ha^{-1}(FAOSTAT, 2019). In India the cultivated area, obtained production and per ha productivity of garden pea are as 0.55 M ha, 5.56 Mt, 10 t ha^{-1}, respectively. In Meghalaya 4,432 tons of pea is produced from cultivated area of 2,271 ha with an average crop productivity of 1.95 t ha^{-1} (Anonymous - I, 2016). Pea which is grown mostly during October and November is grown either based on residual *insitu* soil moisture or with assured irrigation supply.

Provision of providing irrigation water is a constraint in most parts of the North Eastern Region (NER) though these regions receive more amount of annual rainfall

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as compared to rest part of India and mainly concentrated during rainy season. However, crops grown during winter season experience moisture stress, which is one of reason for low productivity of pulses grown during winter season (Akarsh *et al.*, 2020). Improper irrigation scheduling with limited amonuts of available water leads to moisture stress during the crop growing period, causing a reduction in yield and growth parameters. But, proper utilization of irrigation water under such moisture stress situations can increase water productivity and also economic yield. Deficit irrigation is a method of managing water use on farms under water-scarce conditions, wherein the crop's evapotranspiration (ET) needs are met with water given in less than what is necessary without compromising the crop's potential yield (Rudnick *et al.*, 2017).

It is necessary to quantify the yield response trends as a result of the water deficit. Crop water production functions (CWPFs) can be used to derive an explanation for the yield response to the applied water. CWPF is defined as, the relationship between the harvested economic or marketable yield and the total amount of water absorbed by the crop through evapotranspiration. The need for estimating CWPF’s is to regulate the deficit irrigation under water scarce situations. In order to maximize the economic value from the available irrigation water, CWPF's are utilized to establish water allocation (Varzi, 2016).

Considering the importance and paucity of water availability under hilly region during winter season, an effort has been made to develop a crop water production function to correlate the yield obtained under a given irrigation regime.

2. Materials and Methods

A field trail was conducted in mid hills of Meghalaya during 2021-22 winter season, at the experimental farm of College of Postgraduate Studies in Agricultural Sciences, Umiam, Ri-Bhoi district, Meghalaya.The experimental site is located at an altitude of 950 m above the mean sea level (MSL) between 91° 18’ to 92° 18’ East longitude and 25° 40’ to 26° 20’ North latitude. The climate of Ri-Bhoi is categorized as subtropical humid type with cold winters and high rainfall. The Monsoon rainfall is normally sets in at the first fortnight of June and extends up to end of September. Withdrawal of monsoon takes place in October first week with a deceasing rainfall trend from September onwards. The experimental site experiences an average annual rainfall of 2617.10 mm with some pre-monsoon showers during March to May (Ray *et al.*, 2012). The location of experiment site and standard meteorological parameters observed during the crop growth period have been shown in Fig 1 and Fig 2.

The field experiment was laid under a split plo experimental design with 4 irrigation levels under main plot an 4 cultivars of garden pea under sub plot and was replicate thrice. Surface method of irrigation method was adopted. Th seed rate followed was 75 kg ha^{-1}, with spacing of 30 × 10 cm and recommended doses of fertilizer application as (20: 60: 4 kg ha^{-1}) of N: P_2O_5: K_2O. The details of experimental treatmen are presented in Table 1.

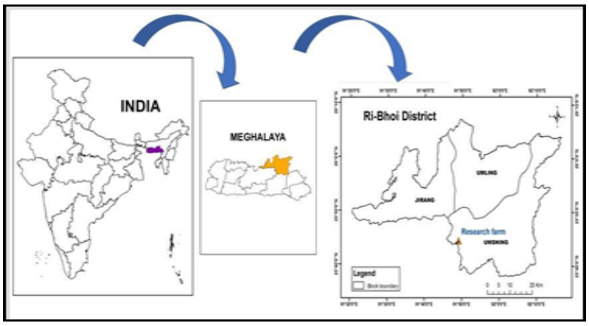

Figure 1. Location of experiment

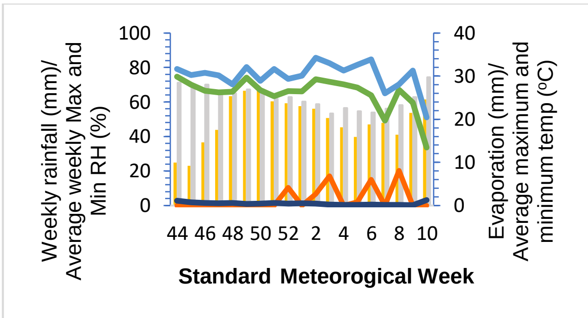

Figure 2. Weekly weather data prevailed during crop growing season

Table 1. Details of treatment combinations

Main plot treatment Levels of irrigations (04)	Sub-plot treatment Garden pea cultivars (04)
I1 - 20% of MAD (Maximum Allowable Depletion)	V1 - VM 10
I2 - 40% of MAD	V2 - VM 12
I3 - 60% of MAD	V3 - VL Sabji Matar 15
I4 -100% of MAD	V4 - VL Sabji Matar 13

Soil moisture monitoring

Standard procedures were followed to monitor *in-situ* soil moisture up to 15 cm of soil depth. Gravimetric soil moisture estimation (Eq. 1) was used to find out the moisture content and readings were taken regularly for all the treatment at regular interval. Scheduling of irrigation was done based on (MAD) maximum allowable depletion of available soil moisture.

Soil moisture content (%) = (Weight of soil moisture/ weight of oven dry soil) × 100 …. (1)

Effective rainfall and depth of irrigation

Quantum of rainfall as and when received was quantified using a standard rain-gauge and the effective depth of rainfall was estimated by finding the difference between available soil moisture present and field capacity. Similarly amount of irrigation water given at each time was calculated from the Eq. 2.

d = [(F.C. – Mbi)/ 100] × root zone depth × bulk density... (2)

Where,

d = depth of irrigation water applied in mm; F.C. = Field capacity, Mbi = moisture before irrigation; root zone depth in mm.

Water productivity (kg m^{-3})

Water productivity of crop was calculated as the ratio of economic yield to amount of water applied as presented in Eq. (3).

Crop water productivity = (Economic yield / total amount of water applied) .... (3)

Crop water production function

Function is the relationship between the one independent variable with one or more independent variables. Here, for establishing crop water production function a relationship was built between obtained economic yield and total water used, yield is taken as dependent factor and total water used by crop as an independent factor. The water production functions may be a linear form as in Eq.4 or the function may be a quadratic as given in Eq. 5.

$Y = a + b (X)$ ... (4)

Y = the actual crop yield (pod yield/ total dry matter) in t ha^{-1}

X = water requirement (mm)

a = Y-axis intercept, b and c = Regression coefficient representing the magnitude of production or yield variation (ha^{-1}) per unit increase in crop water applied (mm).

$Y = a + b (X) + c (X)^2$

3. Results and Discussions

The analysed data of various plant growth parameters, *viz.*, number of branches per plant, plant height, dry matter accumulation / plant, plant root length and phonological parameters on garden pea is presented in Table 2.

Plant height and number of branches per plant

Plant height and the number branches per plant reduced as the amount of water applied reduced. The significantly highest plant height - 65.85 cm was recorded in treatment I_1 where irrigation was given at 20% Maximum allowable depletion (MAD). However, the plant height in treatment I_2 (64.46) was at par with treatment I_1. The reason might be due to better soil moisture availability during the entire season due to frequent irrigations in treatment $I_1$and I_2. Similar results were reported by (Arunadevi *et al.,* 2022) under real time soil moisture-based irrigation scheduling in garden pea. Among the cultivars the significantly highest plant height was reported in V_4 – VL Sabjimatar 13- (62.01 cm) which was at par with V1-VM 10 (61.95 cm). It may be because of difference in genetic makeup of breeding material, and the environment in which it is grown respectively. These results agreed with (Mohsen *et al.* 2013; Khichi *et al.*, 2017). The treatment I_1 has shown the highest number of branches per plant (13.75) which was at par with I_2 (13.59). Among the cultivars, significantly highest numbers of branches were found in cultivar V_4 – VL Sabji Matar 13- 62.01cm. These results agreed with (Arunadevi *et al.,* 2022; Douh *et al.*, 2021; Khichi *et al.*, 2017) in chickpea.

Dry matter accumulation (g plant^{-1}) and root length (cm)

Highest dry matter accumulation was reported during entire season for treatment I_1- 20% of MAD-(7.33 g), which was at par with I_2-(7.11 g). According to Hirich *et al.* (2014) this might be due to frequent irrigations which retained the root zone to be at optimum level of soil moisture which led to improved plant growth due to better absorption of nutrients. Similar results were reported among the cultivars significantly highest dry matter accumulation was recorded in cultivar V_1 VM 10-(6.65 g) than other cultivars. According to Mimi *et al.,* 2016; De Costa *et al.*, 2002, the differences in accumulation of dry matter among cultivars might be due to the tolerance of different cultivars to moisture stress at different plant growth stages during the entire crop season. Significantly, highest root length was observed in treatment I_4- 23.33 cm. The lowest root length in treatment I_1 might be due to inadequate aeration in soil due to frequent irrigations. The frequent application of irrigations in treatment I_1 replaced the oxygen concentration from the effective root zone depth. Similar results were reported by (Yathish *et al.*, 2021; Arunadevi *et al.,* 2022). However, the effect of irrigation regimes garden pea cultivars was found non-significant.

Phonological parameters

The effect of irrigation was found significant for number of days taken for 50% flowering and maturity. The data given in Table 2 shows that, treatment I_4-100% of MAD took minimum no. of days (56 days) for 50% flowering and (96.92 days) for 50% maturity. However, significantly highest number of days for 50% flowering and maturity were recorded in the treatment I_1-100% of MAD. This showed that, days for 50% flowering and maturity shortened by water stress in proportionate yield reductions. The increase in irrigation frequency led to increase in days to flowering. Similar results were reported by (Ambachew *et al.,* 2014; Saroch and Sandal, 2014; Akarsh *et al.*, 2020; Gopinath *et al.*, 2009).

Effect of irrigation regimes on yield and yield attributes of garden pea cultivars

The mean data of yields and yield parameters are given in Table 3.The soil moisture regime when irrigated at 20% of MAD, due to frequent irrigations during the crop growth led to better absorption of nutrients by plants which led to improvement in dry matter accumulation and registered highest number of pods (11.81). Similarly, the number of pods per plant in treatment I_2 - 40% of MAD -(11.28) (which was maintained at 60% of field capacity) was at par with I_1 treatment. Similar findings were reported by (Akarsh *et al.*, 2020; Arunadevi *et al.,*2022; Saroch and Sandal, 2014). The results for no. of pods per plant was significantly highest in cultivar V_4- VL Sabji Matar 13 (10.92). These results agree with (Yathish *et al.*, 2021). Significantly highest pod weight was recorded in treatment I_{1-} 20% of MAD-(45.19 g) which was at par with I_2-(43.10 g). Similar, results were reported by (Hirich *et al.*, 2014; Dasila *et al.*, 2016). The increased green pod weight per plant was mainly due to adequate soil moisture availability during growth stages of crop and increased nutrients uptake throughout the crop growth stages resulted in higher dry matter accumulation due to higher photosynthetic efficiency leading to beneficial effect on yield contributing factors. Similarly, the significantly highest pod weight per plant (g plant^{-1}) was found in cultivar V_4- VL Sabji Matar-13 -(40.91 g). These results agree with findings of (Ali, 2017). Among the different irrigation levels significantly highest green pod yield (8.19 t ha^{-1}) and biological yield (14.80 t ha^{-1}) were found in the treatment I_1-20% of MAD. The economic yield of I_1 was 35% and found to be 107% higher over I_3 and I_4. Similar, results were reported by (Sincik *et al.,* 2008; Mc Donald, 1995; Malliswari *et al.,* 2008). The water deficit can decrease pod yield to the different levels dependingon the extent of the stress and on stage at which the stress occurred. The effect of cultivars was significant on all yield parameters. The cultivar V_4- VL Sabji Matar 13 recorded highest green pod yield (7.23 t ha^{-1}), and biological yield (13.54 t ha^{-1}) compared to all other cultivars. These results agree with (Ali, 2017; Yathish *et al.*, 2021) where different genotypes of garden pea cultivated under irrigated and rainfed conditions. This might be due to genotypic variability of different cultivars with respect to growing conditions.

Table 2. Effect of irrigation regimes on growth parameters of garden pea cultivars

Treatment	Plant height (cm)	No. of branches/ plant (no.)	Dry matter (g plant^{-1})	Root length (cm)	Days to 50% flowering	Days to 50% maturity
Main plots						
I1	65.85	13.75	7.33	18.23	62.42	107.00
I2	64.46	13.59	7.11	20.06	60.08	104.42
I3	55.53	9.05	5.18	21.01	58.83	98.75
I4	51.16	8.95	4.15	23.33	56.00	96.92
SEM ±	1.82	0.47	0.29	0.95	1.21	2.16
C.D	6.29	1.63	1.00	3.29	4.20	7.46
Sub plots						
V_1	61.95	11.80	6.65	20.88	59.67	101.25
V_2	56.48	9.83	5.31	20.16	60.33	102.83
V_3	56.55	10.79	5.19	20.14	59.33	102.08
V_4	62.01	12.93	6.62	21.46	58.00	100.92
SEM ±	1.55	0.39	0.22	0.51	1.26	2.08
C.D	4.53	1.13	0.63	NS	NS	NS

Table 3. Effect of irrigation regimes on yield parameters and water productivity of garden pea cultivars

Treatment	No. of Pods per plant	Pod weight per plant (g $plant^{-1}$)	Green pod yield (t ha^{-1})	Biological yield (t ha^{-1})	Water productivity (kg m^{-3})
Main plot treatments (Levels of irrigation)					
I_1	11.81	45.19	8.19	14.80	2.63
I_2	11.28	43.10	7.91	14.36	3.56
I_3	9.31	32.51	6.03	11.95	3.34
I_4	7.61	25.27	3.95	8.71	3.93
SEM ±	0.36	1.26	0.15	0.32	0.08
C.D	1.24	4.36	0.51	1.11	0.26
Sub plots treatments (Cultivars)					
V_1	10.58	38.99	7.04	13.41	3.60
V_2	9.06	31.81	5.67	11.17	2.96
V_3	9.44	34.37	6.16	11.69	3.21
V_4	10.92	40.91	7.23	13.54	3.70
SEM ±	0.25	0.85	0.15	0.37	0.08
C.D	0.73	2.49	0.45	1.09	0.24

The mean data of water productivity was presented in table 3. The significantly highest value of water productivity was noticed treatment I_4, where irrigation was given at 100% of Maximum allowable depletion. The water productivity of treatment I_4 was 14%, 11% and 10% highest over I_1, I_3 and I_2. Similar results were reported by (Jabow *et al.*, 2015; Rao *et al.*, 2016) The water productivity for the 4 irrigation treatments were arranged as I_4(3.93 kg m^{-3}) > I_2(3.56 kg m^{-3}) > I_3(3.34 kg m^{-3}) > I_1(2.63 kg m^{-3}).This showed that the application of more amount of water due to frequent irrigations in I_1 increased the high moisture loss due to evapotranspiration (Fereres and Soriano, 2007). This also suggests that, under water limiting situations to obtain optimum water productivity with marginal reductions in yields the irrigation treatment I_2 may be recommended resulting saving of 86.6 mm of water over I_1.

Soil Moisture Content and irrigation scheduling of garden pea

Fig. 3 shows the irrigation depth that was applied throughout the crop growing period. To plan irrigation scheduling with a precise depth of irrigation and frequency of irrigation, the impact of various soil matric potential levels on pea crops was to be studied. Observations of volumetric soil moisture content is the prerequisite for effective irrigation scheduling. The depths of irrigation for I_1: 20% of MAD, I_2: 40% of MAD, I_3: 60% of MAD and I_4: 100% of MAD are 12.1, 20.3, 28 and 37 mm, respectively, per irrigation cycle in order to bring the soil moisture closer to the field capacity level.

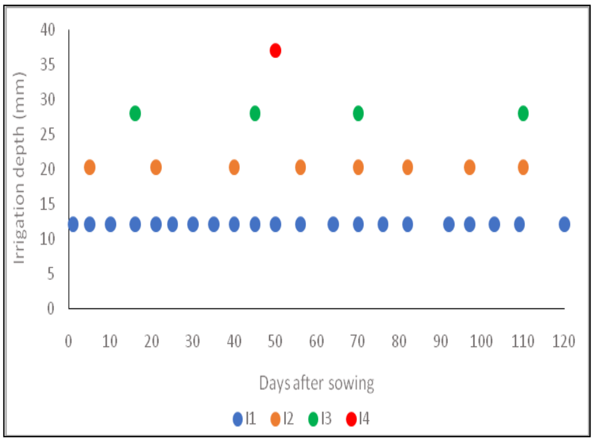

Figure 3. Irrigation depths (mm) and frequency of irrigations at I_1, I_2, I_3 and I_4.

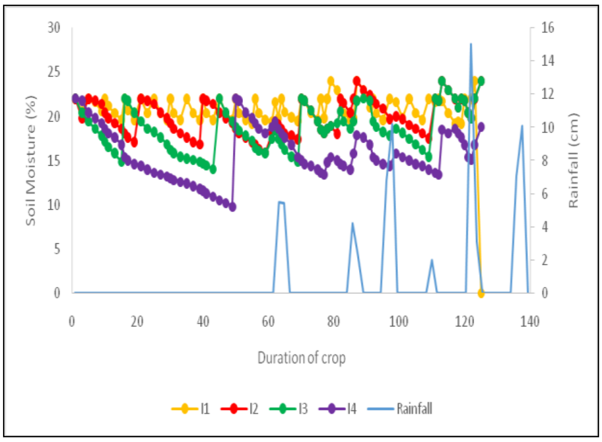

Figure 4. Soil moisture content at irrigation regimes I_1, I_2, I_3 and I_4.

Fig. 4 shows the distribution of soil moisture content under different irrigation (I_1, I_2, I_3, and I_4) treatments throughout the crop growing period. When the soil moisture range was between (FC) field capacity and (PWP) permanent wilting point, and not more than 50% of the (MAD) maximum allowable depletion range, it was discovered that the plants were receiving enough irrigation water.

Irrigation regimes on water productivity of garden pea cultivars

Total number of irrigation provided under different irrigation regimes, depth of water applied, total amount of rainfall received, effective rainfall and total amount of water absorbed by the crop is presented in Table 4. It may be noted that, under irrigation treatment I_1 total number of irrigation applied was 21 which was maximum and the total quantum of water used was estimated to be 308.7 mm. Similarly irrigation treatment I_4 total number of irrigation applied was only one (1) which was minimum and the total quantum of water used was estimated to be 101.1 mm

Crop water production functions

The relationship between pod yield and total water applied was quadratic / second degree polynomial as shown in Fig. 5.The quadratic function fits best for all cultivars with coefficient of determination R^2 as 96% on pooled basis. At 222.1 mm of total water used by the crop, *i.e.,* I_2 there was a marginal reduction in yield (7.91 t ha^{-1}), but the yield obtained was at par with the maximum yield (8.19 t ha^{-1}) obtained by using 308.8 mm of total crop water use, *i.e.,* I_1. Also, water productivity of I_2 was comparatively higher over I_1 because of less water use compared to I_1. Hence, under water limiting situation irrigation of garden pea at 40% depletion of available soil moisture can obtain yield which will be at par with yields of treatment I_1 (20% depletion of available soil moisture) resulting saving of 86.6 mm of water, hence higher water productivity over I_1. For many crops, *i.e.*, chickpea, (Ilhe *et al.*, 2009; Dogan *et al.*, 2013), wheat (Zhang and Oweis,1999; Zhang, 2003; Kang *et al.*, 2002; Malve*et al.,* 2016) Maize (Trout and DeJonge, 2017; Bahramloo and Nasseri, 2019) *etc.*, similar quadratic relations between crop yield and total water used were reported.

Table 4. Quantification of water used by the crop

Irrigation/ rainfall / effective rainfall	Irrigation regimes			
	I_1	I_2	I_3	I_4
No. of Irrigations	21	8	4	1
Depth of irrigation at each irrigation (mm)	12.1	20.3	28	37
Total Rainfall received(mm)	71.8	71.8	71.8	71.8
Effective rainfall (mm)	54.6	58.6	61.8	61.8
Total water used by crop (mm) (IW + ER)	308.7	222.1	176	101.1

Where IW= irrigation water and ER = Effective rainfall

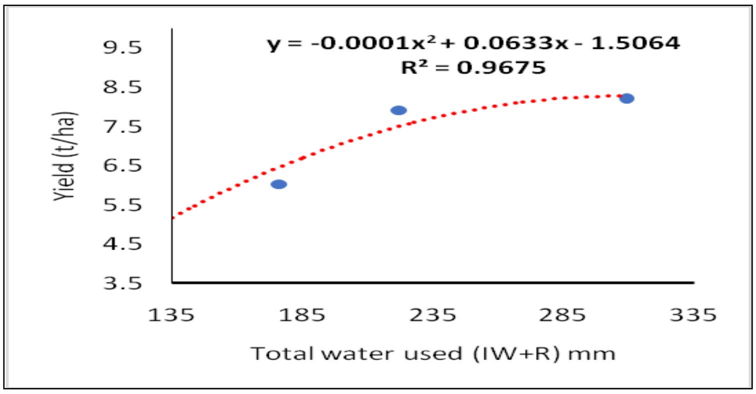

Figure 5. Relation between garden pea yield to total amount of water used

4. Conclusion

An important limiting factor in agricultural production systems is the availability of soil water. In order to improve farm level water management and yields of crops , effective irrigation plans need to be developed by using knowledge of how crops respond to water supply, under both limited and full irrigation situations. Quadratic polynomial CWPF was developed which are helpful for predicting yield in response to total water applied or crop water used as $Y = -0.0001X^2 + 0.0633 X - 1.5064$; ($R^2 = 0.96$). This expression ensures that, as irrigation amount increases the increase in yield was decreasing. In order to obtain maximum possible yields maintaining field at 60% of field capacity is necessary. Among the cultivars V_4 (7.23 t ha^{-1}) was yielding highest over others. Based on (MAD) maximum allowable depletion of available soil moisture criterion, maximum potential yields are obtained under irrigation treatment I_1 (8.19 t ha^{-1}), which was 107% higher than I_4. Under water limiting situations I_2 may be recommended where water is applied at 40% depletion of available soil moisture. This treatment results in green pod yield of 7.91 t ha^{-1} which is 100% higher over I_4, eventually resulting in higher water productivity (35% higher) over I_1.

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