# Micro-irrigation in rainfed pigeonpea – Upscaling productivity under Eastern Gangetic Plains with suitable land configuration, population management and supplementary fertigation at critical stages

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**Water – a critical input for sustained crop production – is becoming limiting both under rainfed and irrigated condition. It calls for an effective on-farm management of water in field crops through micro-irrigation (drip-fertigation) that could take care of both drainage during rainy months and supplementary life saving irrigation thereafter. Therefore, the present field study involving three planting configurations and five drip-fertigation schedules were taken up in pigeonpea (long duration) during 2010–12 under Eastern Indo-Gangetic Plains at Kanpur, Uttar Pradesh, India. Significant grain yield advantage (19.6%) was with single drip-fertigation with half of N + K fertilizer at branching over farmers' practice (rainfed pigeonpea, 2858 kg/ha). Drip-fertigation at both branch and pod development also out-yielded (3468 kg/ha) over improved practice (furrow irrigation, 3262 kg/ha). These yield levels realized were close to potential yield (2.5–3.0 t/ha). Twice drip-fertigated plots also had higher yield attributes (pods/plant, 100 seed weight and harvest index), lower water use, greater soil profile water content and water use efficiency (65.1 kg/ha-cm), higher plant nutrient (N, P and K) uptake with improved soil nutrient availability and greater net return (INR 9650/ha) over farmers' practice. A case study on a micro-scale was also given which could explore the possibility of out-scaling the technology.**

**Keywords:** Critical stages, Indo-Gangetic Plains, micro-irrigation, pigeonpea, planting configurations, rainfed pigeonpea, supplementary fertigation.

PULSES are commonly grown as a rainfed crop all over Indian plains during rainy months (pigeonpea, mungbean and urdbean in Indian Plains and rajmash in North East Plains) and the *fall* (chickpea, lentil and rajmash). Among the pulses grown during rainy months, pigeonpea (*Cajanus cajan* L. Millsp.) is primarily grown for its dal (processed pulse) under diverse cropping systems including inter/mixed cropping. Pigeonpea is cultivated in an area of 3.89 m ha in India with production and productivity of 3.02 m tonnes and 776 kg/ha respectively[1]. While early and long duration genotypes are prevalent in North India, medium duration cultivars are widespread in rainfed South and Central Zones. The performance of the crop is solely attributed to varying length of growing season and its life cycle (duration of crop). The factors largely responsible for its average low productivity (729 kg/ha during 2014–15) in Indian subcontinent are mainly attributed to the abiotic stresses such as moisture and nutrient[1,2] although management of biotic phenomena is equally important[3]. Therefore, pigeonpea in India had a low compound growth rate (of 0.8%) in production between 1949–50 and 2004 (ref. 4).

During early stages of pigeonpea crop growth, the more relevant constraint is the availability of excess soil moisture or water logging condition rendering unfavourable soil-microenvironment for crop growth. This includes reduced aeration, hampered nodulation, reduced nutrient uptake, and favourable environment for blight and rot which result in reduced crop stand and poor yield[5–7]. Therefore, suitable management strategies or technologies to offset these adverse effects of abiotic stresses need to be mitigated by sustainable agronomic interventions, such as suitable land configurations (ridge and raised bed planting), proper plant population and other need-based soil/crop management techniques. On the other hand, water deficit during later stages of crop growth (terminal water stress) adversely affects the development of reproductive organs that may lead to depressed yields. Therefore, management of surplus water during rainy months and water supplementation to compensate soil-moisture deficit during post-rainy months is imperative for productivity enhancement in pigeonpea. As the crop requires 20–25 cm water to produce a tonne of grain (as the water requirement and consumptive use for pigeonpea dwindle around 30–50 cm and 40–50 cm

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respectively)[2,5], soil moisture related limitation (as a result of surplus/deficit rainfall) is the major constraint to higher productivity realization in this crop in Indian subtropics (Figure 1). More important is the effect of scanty rainfall accompanied with its vicious cycles (Table 1) experienced during the grand growth stage of crop (towards cessation of rainfall, i.e. beyond mid-October) and late reproductive stage (cessation during *fall*, i.e. mid-February for pod development) which limit both crop growth, development and its potential productivity. Therefore, supplementary irrigation(s) at these critical stages (in absence of precipitation) has a bearing on total productivity in most of the pulses including pigeonpea[1,2].

Many a time availability of water, its allocation priorities and economics of crop or commodity undertaken decide irrigation scheduling in many agricultural crops[8] including pulses although it is established that one or two need based life saving irrigations are shown to elevate crop performance further[1]. The effect of these above factors can be greatly improved when the same irrigation is applied to a high value crop with less water applied by an enabled technology (micro-irrigation or similar precision technologies) reinforced with high water-use efficiency (WUE) and multipurpose utility (provision for application of fertilizers, pesticide and even herbicides). Although it is impracticable and less remunerative to apply this technology in pulses as these are mostly grown in rainfed marginal lands with less care and management, it is now becoming more promising to grow these protein-yielding crops receiving better remuneration and acceptance (following appropriate policy decisions backed by higher support price; and marketability/storability of the produce in comparison to fruits and vegetables)[9]. In this context, economically viability (community sharing by cooperatives and village welfare schemes and adequate support from Governments in terms of providing subsidies and crop insurance) and better portability of micro-irrigation systems (such as drip and sprinklers) render its applicability even in pulses for fulfilling its demand right in place and right on time and quantity[10–12]. A more cursory look at agro-dynamics of field cultivation of pulses reveals that plant population or canopy arrangement may have pronounced effect on crop growth, development and productivity of crop. Thus, plant rectangularity (arrangement of plants in unit area) may possibly has direct bearing on final output (productivity) of the pulses because it decides both per plant productivity and the number of plants per unit area through influencing canopy photosynthesis and leaf area in a given area of the field. In particular reference to pulses, population dynamics has a tremendous role to play as a minimum threshold community of plants (crop) is required to be maintained for yielding a stable optimum productivity[1,2]. Unfortunately, population maintenance is more troublesome in early or initial stages of pulses during rainy months due to a number of constraints categorized under both abiotic and biotic phenomena (water logging, weed menace, blight, etc.). In addition, pulses being mostly grown under upland condition with proven root sensitivity to both excess and deficit in availability of moisture, these adverse conditions may cause plant mortality and reduction in plant stand/yield[2]. As the work on supplementary irrigation and fertigation through precision irrigation especially in rainfed pigeonpea is limited, an effort is made to focus on studying these aspects to enhance pulses productivity and farm income with higher resource use efficiency (RUE). Long duration pigeonpea is considered in the study as it faces two distinct moisture stress period (branch and pod development) so that it can judiciously utilize the supplementary irrigation for yield formation. Therefore, a field experiment was carried out for two years (2010–12) in Indo-Gangetic Plains to assess the critical stage based supplemental drip-fertigation in a long duration rainfed pigeonpea (maturity period of 260 days) within the ambit of an efficient on-farm irrigation scheduling strategy that should easily be adopted by farmers.

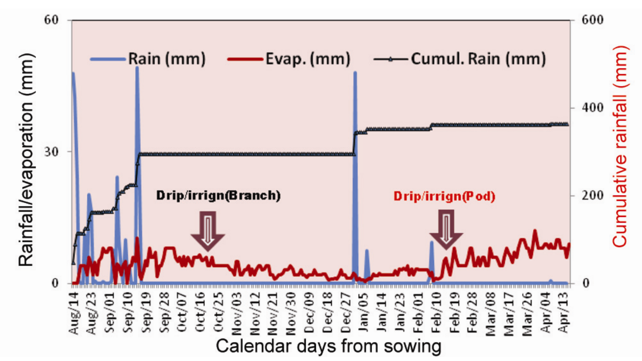


**Figure 1.** A typical meteorological condition at NEPZ (Eastern UP, 2011–12) requiring supplementary irrigations during long monsoon breaks (shown by drip/irrigation arrows).

## Materials and methods

An on-station field experiment was laid out at ICAR-Indian Institute of Pulses Research, Kanpur (26°27′N and 80°14′E with an altitude of 152.4 m amsl) consecutively for two years during 2010–12 with an objective of studying the effect of supplemental irrigation along with N and K fertilizers in a long duration pigeonpea during its two most important critical stages, viz. branching (90–100 days) and pod development (200–210 days) combined with different planting configurations. Irrigation scheduling at flowering is not considered as this would result in shedding off of flowers (more so just after harsh winter) and reversing to vegetative growth again (following removal of water stress due to irrigation).

The soil of experimental site was sandy loam (Typic Ustochrept) in texture and neutral in pH with low in N

**Table 1.** Deficient monsoon years showing percentage of deficit from normal between 1982 and 2009

| Year | June | July | August | September | Net less |
|---|---|---|---|---|---|
| 1982 | –16.8 | –23.1 | 8.9 | –32.2 | –14.5 |
| 1986 | 10.8 | –14.2 | –12.7 | –31.2 | –12.7 |
| 1987 | –21.6 | –28.8 | –3.7 | –25.1 | –19.4 |
| 2002 | 9.4 | –54.2 | –1.7 | –12.9 | –19.2 |
| 2004 | –0.8 | –19.9 | –4.3 | –30.0 | –13.8 |
| 2009 | –47.2 | –4.3 | –26.5 | –20.2 | –21.8 |

Source: *The Hindustan Times*, Lucknow, 3 June 2013.

**Table 2.** Representative monthly weather parameters recorded during crop growth period (August 2011 to April 2012)

| | Temperature (°C) | | RH (%) | | | | | |
|---|---|---|---|---|---|---|---|---|
| Month/year | Maximum | Minimum | 8.30 h | 17.30 h | Evaporation (mm/day) | Rainfall (mm) | Rainy days | Sunshine (h) |
| August 2011 | 32.4 | 25.0 | 83.1 | 80.2 | 4.3 | 284.8 | 12 | 4.1 |
| September 2011 | 33.0 | 24.1 | 78.5 | 70.8 | 5.1 | 132.4 | 9 | 5.9 |
| October 2011 | 34.0 | 18.5 | 61.0 | 49.3 | 5.0 | 0.0 | 0 | 7.9 |
| November 2011 | 29.5 | 13.4 | 73.0 | 60.0 | 2.9 | 0.0 | 0 | 5.5 |
| December 2011 | 23.7 | 7.0 | 79.8 | 64.5 | 1.9 | 0.0 | 0 | 4.2 |
| January 2012 | 19.2 | 9.6 | 79.0 | 66.1 | 2.0 | 56.4 | 2 | 5.1 |
| February 2012 | 24.6 | 11.3 | 67.3 | 49.1 | 3.8 | 11.0 | 1 | 7.6 |
| March 2012 | 31.6 | 16.2 | 52.2 | 35.5 | 6.8 | 0.0 | 0 | 7.7 |
| April 2012 | 33.0 | 22.6 | 51.1 | 34.4 | 9.7 | 4.8 | 1 | 8.7 |

(226 kg/ha) and SOC (0.21%), medium in P (19.1 kg/ha), K (167.2 kg/ha) and S (15.0 kg/ha) at the surface depth (0–15 cm). The climate of the location is tropical sub-humid receiving an annual rainfall of 722 mm with mean annual maximum and minimum temperatures of 33°C and 20°C respectively (Table 2). The site was a double cropped irrigated upland with rice–chickpea cropping system before the start of the experiment followed by sowing of long duration pigeonpea 'Narendra Arhar-1' (hereinafter NA-1) during 2010–12 (year of experimentation). Besides resistant to sterility mosaic and tolerant to wilt and Phytophthora blight, this pigeonpea variety matures at around 255–260 days.

The experiment consisted of three planting configurations in main plot and five supplemental irrigation and fertigation schedules in subplot which were laid out in a split plot design with three replications. Three unique planting configurations (maintaining the same plant population at 55,555 plants/ha) included normal planting at 90 × 20 cm (M1), popular paired row system at 60 × 20–120 cm (M2) and wide row planting at 120 × 15 cm (M3), whereas five supplemental irrigation and fertigation schedules (drip-fertigation) included rainfed with basal full NPK dose (farmers' practice, S1), drip irrigation at branching stage (20 mm) with 1/2N + 1.2 K only (S2), drip irrigation at pod development stage (20 mm) with 1/2N + 1/2K only (S3), drip irrigation at both branching and pod development stages (20 + 20 mm) with 1/4N + 1/4K at each stage (S4) and furrow irrigation at both branching and pod development (20 + 20 mm) with basal full NPK dose (improved practice, S5). The aim of these precisely considered five treatments is to explain the effects of key constraints, viz. irrigation (S2, S3 and S4 versus rainfed, i.e. S1) and fertigation (one or two fertigations in S2, S3 or S4 versus no fertigation as in S5).

Sowing of long duration pigeonpea 'NA-1' was carried out during end of July and mid of August during 2010 and 2011 respectively. The entire P (50 kg SSP–$P_2O_5$/ha) along with recommended dose of Zn and S (25 kg $ZnSO_4$/ha) were applied basally in all the plots while N and K were applied according to treatment. Under drip-fertigation treatments, half of N and K along with full P dose were applied only at planting. The remaining halves of N and K doses through urea-N and MOP-K were applied in 5 equal splits through drip-fertigationat branching (S2) and at pod development only (S3) and in 10 equal splits for drip-fertigation at both branch and pod development (S4). The recommended fertilizer dose applied was 20 : 50 : 20 kg N : $P_2O_5$ : $K_2O$/ha in that order. The quantity of irrigation water applied was 20 mm for both furrow irrigation and drip-fertigation at each critical stage coinciding with rainless period during 90–100 and 200–210 days after sowing (DAS). Inbuilt, inline emitters with discharge of 2 litres/h were fixed in 16 mm laterals at the required spacing as mentioned above. Drip irrigation was carried out for 5 times at alternate day basis. Each experimental plot or unit consisted of 8 rows and 36 plants/row by which a total of 288 plants were accommodated (in each plot with relatively large plot size of 51.84 sq. m). Water soluble solid fertilizer of urea (46% N) and MOP (60% $K_2O$) were supplied through venturi in 5 split doses.

The amount of water and/or drip operation time was decided as

Water requirement (litre) = {PE (mm) × Kc × Kp × area ($m^2$)}/IE,

where PE represents evaporation from USWB Class-A open pan evaporimeter (taken as 4 mm/drip irrigation after use of pan coefficient of 0.7 for irrigation scheduling), Kc is crop coefficient (varies with stage, viz. 0.4 to 1.15), Kp is canopy factor (varies with stage, viz. 0.5 to 1.0) and IE is irrigation efficiency (0.9) which were determined following normal procedures[13]. The values can also be estimated from the standard values by adjusting a number of factors such as temperature, humidity, irrigation sequences and soil textures[14] but for more accuracy, it is better to determine the factors locally. The field capacity (FC) and permanent wilting point (PWP) of surface soil (0–15 cm) were determined in the laboratory as 22.05 and 5.19% (w/w) respectively.

Crop was harvested during mid April (i.e. 15 April 2011 and 20 April 2012) in both the years (2011 and 2012). A long duration pigeonpea genotype 'NA-1' was selected owing to its moderately wilt resistance and longer duration favouring greater utility of the drip system beyond the rainy months. Normal practice of crop husbandry was followed for a successful crop raising. Periodic soil moisture samples from 0 to 60 cm soil profile were taken for analysis of soil water content. Other crop parameters related to biometrics, grain yield, yield attributes, crop water use and WUE (along with NPK content and uptake by plant parts) recorded during both the years were pooled for appropriate statistical analysis and interpretation.

In addition to the above on-station study, a field demonstration was also made at farmers' field to evaluate the impact of drip technology on farmers (through feedback) and solving its viability/sustainability issues (for technology transfer). So far the farmers' field condition was concerned, it was typically an undulated alluvial upland, and the crop was grown under rainfed condition. Therefore, to have a greater visibility of the technology, the study on drip-fertigation in long duration pigeonpea was carried out at district level involving two representative KVKs (Krishi Vigyan Kendra) at Chitrakoot and Chandauli in Uttar Pradesh, India. These KVKs are regarded as hub of all extension activities at the district level as the farmers have a direct access to the technology because of proximity to the villages and acting as a source of seed/other inputs. These KVK machineries were used with the fund support from ICAR (Indian Council of Agricultural Research as the Apex body). Three selected treatments of the experiment were simultaneously tried at farmers' field during 2011–12 involving KVK at district level. Three treatments included namely, growing of pigeonpea under rainfed condition (S1), applying furrow irrigation at branch and pod development (similar to S5 in on-station study) and application of drip-fertigation at branching and pod development (similar to S4). The same pigeonpea variety 'NA-1' was also grown exactly following the same methodology described as in the above using only 90 × 20 cm spacing. Here the source of irrigation was bore well which was used for supplementary drip-fertigation. Other cultivation practices/agro-techniques were common to all the treatments. The technology index was calculated as[15]

Technology index = (Pi – Di) × 100/Pi,

where Pi is the potential yield of *i*th crop and Di is the demonstration yield of *i*th crop. A potential average yield of 3000 kg/ha (reference yield) was considered for fairly a good estimation of technology gaps under the above condition. The reference yield is taken from the average potential yield of long duration varieties cultivated in the seed chain and that has actually been realized under field condition so far.

## Results and discussion

### *Yield formation and its attributes*

Maintenance of adequate plant population is the prerequisite for realization of optimum yield[2] as a minimum of 5–8 plants/$m^2$ holds good in case of long duration pigeonpea for occupying the allocated space over time and duration. In the present study although different planting patterns could not influence crop performance (due to maintenance of 55,500 plants per hectare in all these treatments), relatively higher yield (3296 kg/ha) was realized with 90 × 20 cm row spacing (higher by 93–135 kg/ha over other row spacings). Among irrigation treatments, the significant finding of the present study was that the pigeonpea crop could give a grain yield of 2858 kg/ha under rainfed situation which was very near the potential yield realized under the optimum management condition. This was mainly attributed to maintenance of adequate or optimum plant population in case of pulses as a whole and pigeonpea in particular. Further improvement in yield from this base level (constrained by supplementary irrigation) was also possible by precision techniques applied through drip-fertigation. In the present case, a single supplementary irrigation (20 mm water through 5 splits) by drip-fertigation with half of N + K fertilizers at branching stage could result in realization of additional grain yield to the tune of 19.6% (with two years' mean grain yield of 3419 kg/ha) in comparison to plots where pigeonpea was grown under rainfed condition (Figure 2 and Table 3). In addition, the plots where

**Table 3.** Effect of drip-fertigations on grain yield, its attributes and harvest index*

| Treatment | Grain yield (kg/ha) | Stalk yield (t/ha) | Pods/plant | Seeds/pod | 100 seed wt. (g) | HI (%)** |
|---|---|---|---|---|---|---|
| Planting configurations | | | | | | |
| 90 × 20 cm | 3296 | 7.20 | 281 | 3.60 | 10.3 | 31.6 |
| 60–120 × 20 cm | 3161 | 7.15 | 272 | 3.55 | 10.1 | 30.8 |
| 120 × 15 cm | 3203 | 7.04 | 287 | 3.58 | 10.1 | 31.4 |
| SEm (±) | 46.2 | 0.08 | 7.7 | 0.21 | 0.06 | 0.26 |
| CD (0.05) | NS | NS | NS | NS | NS | NS |
| Drip fertigation schedules | | | | | | |
| Rainfed | 2858 | 6.83 | 256.0 | 3.49 | 9.9 | 29.6 |
| Drip$^{Br}$ | 3419 | 7.36 | 305.9 | 3.57 | 10.5 | 31.9 |
| Drip$^{pod}$ | 3092 | 6.84 | 283.6 | 3.58 | 9.9 | 31.3 |
| Drip$^{Br+pod}$ | 3468 | 7.48 | 298.4 | 3.64 | 10.3 | 32.0 |
| Irrigation$^{Br+pod}$ | 3262 | 7.15 | 257.0 | 3.60 | 10.2 | 31.5 |
| SEm (±) | 77.6 | 0.15 | 13.9 | 0.34 | 0.10 | 0.45 |
| CD (0.05) | 225 | 0.43 | 40.2 | NS | 0.3 | 1.30 |

*Pooled data for these attributes; Treatments as described in material and methods, **Harvest index; Interaction of factors not significant.


**Figure 2.** Comparison between a rainfed plot vis-à-vis drip-fertigation (branch) plot.

drip-fertigation was applied at both critical stages (branch and pod formation) of the crop (3468 kg/ha) out-yielded significantly over improved practice (furrow irrigation with a mean grain yield of 3262 kg/ha) during the second year (9.4%) and in pooled data (6.3%). Here, the argument against application of two supplementary irrigations corroborates many underlying facts[12]. In fact, there is a need for second irrigation especially when rainfall does not likely to coincide with the time when maximum pods set in and the plants go to absolute reproductive stage requiring water in the seed filling stage (as happened in the present study, Table 2 and Figure 1). Moreover, once the portable drip system is in place and water is available (for a critical life saving irrigation), it will be economical to apply it (along with fertilizers) at later critical stage (pod development) to boost up productivity further. Thus, significantly higher grain yield was recorded in all the irrigation plots over that in rainfed control plots which focuses the potential role of life saving supplementary irrigation in pigeonpea. The study also substantiated the timing of such irrigation as application of fertigation at only pod formation could not yield the desired results (Table 3).

It is observed that when a deep rooted dicot plant (pigeonpea in the present case) survives with adequate soil water availability after planting through (a relatively well distributed initial) rainfall during early in rainy season, the possibility of its survival and ability to yield formation even under subsequent water stress condition (experienced later in the season) is much higher over the plants grown with water stress as a starter. In the former case, the crop establishes well and performs better even after withdrawal of rainfall/irrigation during late branching and pod development stages. That was the reason which explained superior performance of rainfed crop in the present study. Nevertheless, crop performance was immensely improved when the scarcity of soil water during branching and pod development stages was compensated with a need based supplementary irrigation(s). Here again the role of drip-fertigation at these stages is evident (Table 3 and Figure 1) resulting in better survival of plants in later stages with enhanced growth and development. The inference drawn from such a strategic irrigation (and fertigation) is the pertinent role of water (and nutrient) availability at critical stages for bridging the yield gap between potential and actual yield realized with the set of given agro-ecology. Here the function of fertigation (N&K) at critical stages was also evident from the difference in grain yield(s) obtained with drip at both branch and pod development (or drip at branch alone) vis-a-vis furrow irrigated plots (Table 3). As a result, significantly higher harvest index (32%) was analysed with drip-fertigation at both branching and pod development over that in rainfed control (29.6%) which reiterated the fact that drip fertigation both at branching and pod development had a positive effect on crop growth, development and consequently on grain yield (as it was enhanced over both rainfed and irrigated control). Therefore, it is inferred that drip-fertigation has a beneficial effect on the performance of long duration pigeonpea which is evident in the existing Eastern Indo-Gangetic Plain Zone (EGPZ) where average crop productivity stabilizes at around 800 kg/ha mostly because of rainfed situation beyond mid October[1].

As in other pulses, pigeonpea is cultivated in marginal soil with poor fertility status which is more often subjected to vagaries of the nature. There is a misconception in farming community in EGPZ that pigeonpea does not require any irrigation. However, it is scientifically confirmed that the crop can be profitably raised with one or two need based life saving irrigations applied according to crop need during its specific critical stages (in the entire crop growth period of 260 days) for realizing the best achievable yield in a given set of condition (Figure 2 and Table 3). Moreover, once the plant is fully established (up to 3 months), it grows on its own utilizing the resources available *in situ* (being a deep-rooted dicot plant). Further, there is a requirement for initial boost to have a minimum threshold biomass to bear adequate reproductive flushes (2 or more flushes depending on spells of cold winter) later in the growing season by a supplementary irrigation especially at branching (90–100 days) along with the second irrigation, if required at pod development stage for adequate and normal seed setting[2]. Many a time severe limitations in soil moisture at the root zone experienced during its critical growth stages could jeopardise its subsequent (crop) growth and biomass production (and yield formation). Further restrictions imposed as a result of climatic aberrations in terms of deficiency in rainfall[8] and its diminished frequency/distribution especially at pod development are also not conducive for realization of its potential yield[6,7]. Hence the need for supplementary irrigation arises.

Yield attributes such as pods/plant, 100-seed weight and harvest index showed similar trend with that of grain yield (Table 3). Therefore, drip-fertigation (supplementary irrigation with a water saving strategy as a component of precision agriculture) had in fact contributed towards higher productivity performance of long duration pigeonpea in EGPZ. It also influenced biomass partitioning in plants as significantly higher (2.4%) harvest index was obtained in plots where drip-fertigation was given at both branching and pod development over that in rainfed control plots. It was also confirmed from the findings that higher soil water availability (Figure 3 *c* and *d*), especially during critical stages of the crop following supplementary irrigation, had a bearing on enhanced seed index and increased output (grain yield).

In planting configurations case, similar grain and straw yields were realized with normal, paired row and wide row planting (Table 3) although slightly higher yields were obtained at 90 × 20 cm row spacing. This confirmed the inherent elasticity in long duration pigeonpea as envisaged even with diversified planting configurations. Therefore, optimum plant population has a key role towards productivity enhancement as yield per unit area is a function of number of plants, pods per plant, seeds per pod and seed weight (yield traits). In the present study also, these basic yield attributes, viz. pods/plant (and pod dry weight), seeds/pod and 100 seed weight were not influenced due to different planting patterns leading to confirmation of the finding that planting configurations or plant rectangularity had less influence especially in pulses. However, plant population had the influence[1,2].

## *Dynamics of crop growth and development*

Some of the periodic crop growth attributes, viz. plant height, branches per plant, dry matter accumulation and leaf area indices measured during different crop growth stages revealed that similar to grain yield, both plant height and vegetative branches were not influenced by different planting configurations. However, there were appreciable differences on dry matter accumulation pattern in the crop (Figure 4). The crop planted even at 120 × 15 cm row spacing showed higher plasticity to cover the inter-row spaces in comparison to other planting configurations[16]. Thus, the highest dry matter accumulation (DMA) was analysed at the row spacing of 120 × 15 cm at the end of grand growth stage (at around 200 days after sowing) during both years. Similarly, leaf area and maximum leaf area index ($LAI_{max}$) were also enhanced at paired row planting during the 1st year (because of inter-row crop competition) and wide row planting during the 2nd year (Figure 5). With minor exception, this trend continued till harvest with paired row planting during both the experimental years.

Contrary to the effect of planting pattern on growth dynamics, periodic plant height and branches per plant were significantly influenced by different drip-fertigation schedules. Supplementary irrigation enabled better dry matter accumulation in plants in comparison to rainfed control plots (Figure 4). As a result, DMA was consistently higher with drip-fertigation at branching or branching and pod development and in furrow irrigation in comparison to rainfed control. Similar was the case for leaf area and $LAI_{max}$ (Figure 5) as both leaf area and $LAI_{max}$ were highest (5.37) at 160 DAS (during 1st year) due to favourable soil moisture balance following irrigation after the rainfall events. Thus, the crop under all the irrigation schedules maintained a consistent growth and higher LAI (up to 200 DAS) over the control plots till final blooming and pod development stage. Similarly with little deviation, the crop attained a low LAI of 3.94 at 130 DAS during the 2nd year because of pertinent

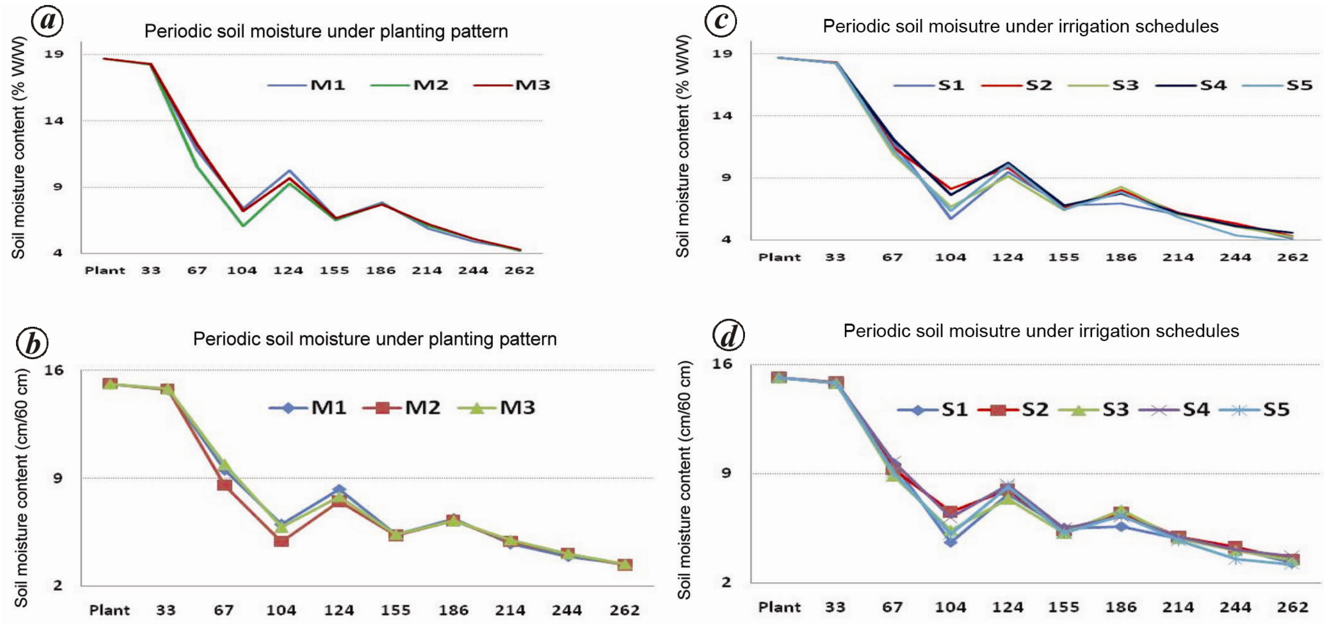


**Figure 3.** Trend in periodic (day) soil moisture (% w/w in surface soil and cm/60 cm soil profile) under different planting configurations and drip-fertigation schedules. M1, M2 and M3 are planting configurations and S1, S2, S3, S4 and S5 are drip-fertigation schedules as described in materials and methods.

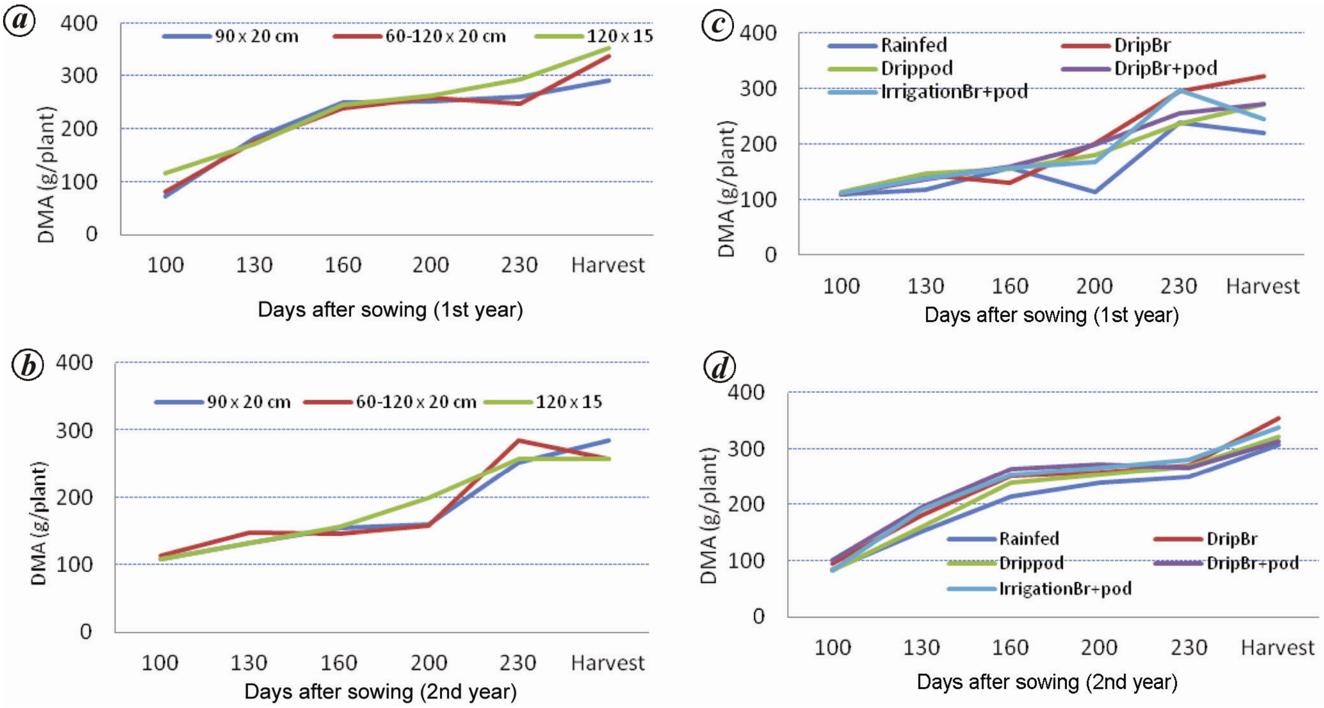


**Figure 4.** Trend in periodic dry matter accumulation (DMA) in different treatments (***a***, ***b***, planting configurations and ***c***, ***d***, drip-fertigation schedules) during both the years.

moisture stress experienced during 2011–12 due to deficit rainfall (Tables 1 and 2). Thereafter it declined because of early reproductive flush. One observation needed to be considered here. Irrespective of planting time (during July or August) the crop was set for maturity by mid April, i.e. before the hot sunny weather prevailed. A peculiar phenomenon was also observed when the same crop got little rain towards April end, it triggered to grow vegetatively (like a ratoon crop) with the dry pod bearing inflorescence remained hooked to main stem imparting an appearance of a peacock's tail. In addition to beneficial crop growth due to drip-fertigation, a more representative plant attribute, viz. weed smothering efficiency was also observed to be higher especially under this treatment

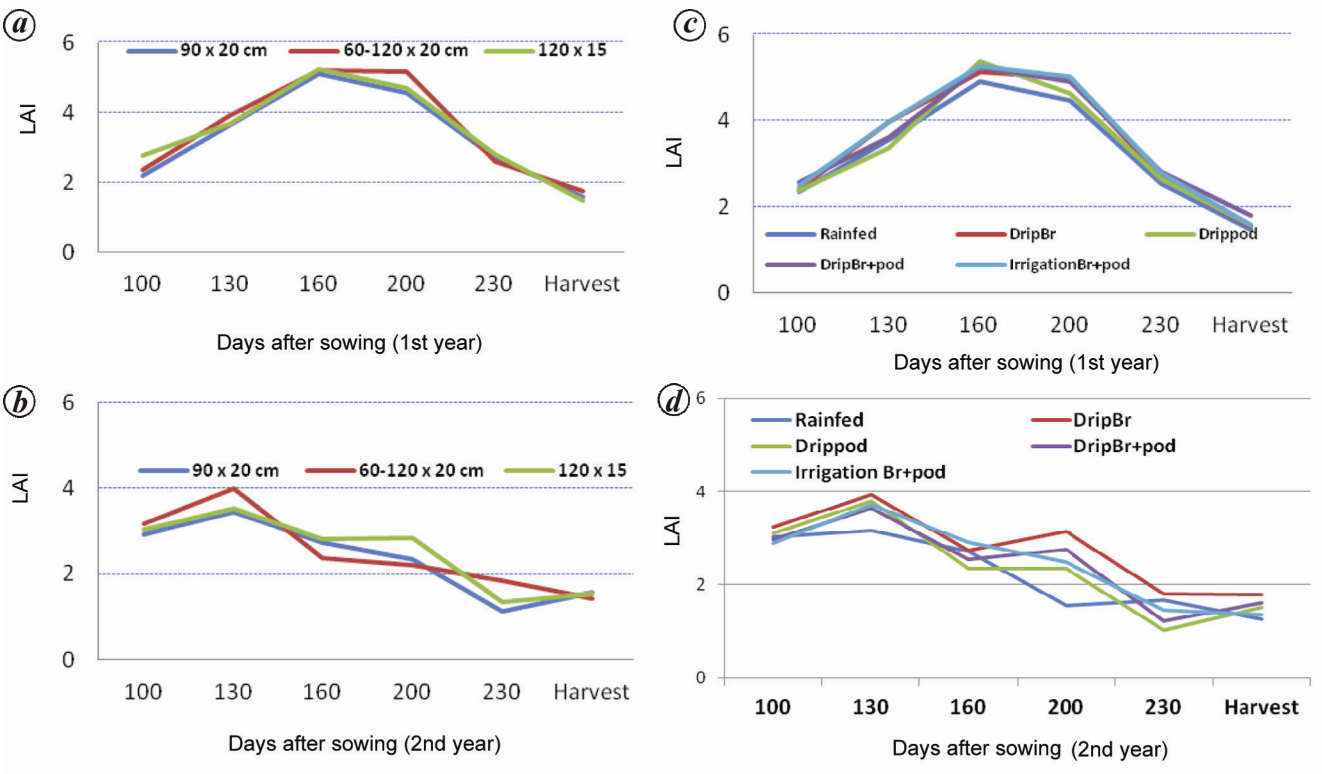


**Figure 5.** Trend in periodic leaf area index (LAI) in different treatments during both the years: ***a***, ***b***, planting configurations; ***c***, ***d***, drip-fertigation schedules.

(data not included). It is postulated that due to better utilization efficiency for both nutrient and moisture, plant bears higher growth, leaf area and yield which fairly well competes with weeds as their growth was reduced by about 50% with the drip method of irrigation compared to furrow method[17]. Significant reduction in weed biomass (by 50%) was also observed in drip irrigated plots as compared to surface irrigated plots[18].

## *Soil moisture, seasonal water use and its efficiency*

Optimum yield formation in crops is also attributed to underground soil/root condition that remains mostly unexplored and unanalysed as in most agricultural crops (albeit up to a threshold depth of 15–30 cm only). Soil moisture at key stages could infer the condition underground depicting the level and extent of moisture availability (and stress) the crop is subjected to. In the present study on soil moisture profile carried out at different crop growth stages of long duration kharif planted pigeonpea, it indicated that the moisture content in soil decreased following withdrawal of monsoon from planting to 90–100 days (at branching), the time for first drip/furrow irrigation event. Then it again shot up following irrigation (as per treatment) and again decreased as rainfall completely terminated beyond October (Figure 3 and Table 2). This trend further continued till irrigation applied at around 200 days after planting (February last week) coinciding with development of pod. After this, a decreasing trend in soil moisture was recorded till harvest of crop (mid-April) in which the least rainfall events occurred during this period.

Study on soil moisture dynamics as influenced by diverse planting configurations revealed that percentage stored moisture content in soil profile was similar irrespective of row spacing. So was the case of crop water use over the profile depth (Figure 3). It is in fact attributed to compensatory contribution of both evaporation and transpiration components of evapo-transpiration (ET)/total water use. The contribution of evaporation component was more in case of 120 cm row spacing (wider gaps between the rows) while that of transpiration component was higher for 90 cm row spacing (gaps being close). On supplementary irrigation case, higher moisture content in surface soil was recorded in drip at both critical stages (followed by drip at branching and furrow irrigation) in comparison to drip at pod development and un-irrigated (rainfed) control. So was the case for profile soil moisture use measured in terms of depth of water (Figure 5). It was pertinent enough to prove that in case of drip-fertigation at branching, initial good vigour of the well established plants tolerated better the relative water stress experienced at pod development stage; and the plants came up with normal reproductive growth and higher seed setting during later stages in the growing season[7]. Similarly, higher soil moisture was also observed in drip-fertigated plots at both branching and pod development in both surface soil and across the depth of profile because of two supplementary irrigation events (1st irrigation at branching and 2nd at pod development). Therefore, split irrigation had resulted in better moisture availability (and its storage) in soil and was more apparent in case of drip-fertigation given at both stages (although crop response to irrigation was more pertinent when soil moisture content was less and the crop was under water deficit/stress). Contrary to soil moisture dynamics in the current experiment (where drip was applied once or twice at critical stages only), soil moisture remained at or near to the field capacity under most of drip irrigation experiments involving vegetables[19] or dwarf fruit crops (as the same was operational throughout the growth period) whereas, in conventional furrow irrigation, the soil moisture status curve travelled from above or near field capacity to 50% moisture depletion conditions[12,20]. This fluctuation in soil moisture dynamics especially in case of conventional furrow irrigation affects crop–soil–water balance and ultimately productivity.

Consumptive water use (crop water use or ET) calculated for normal, paired row and wide row planting patterns was almost similar (51.7, 52.0 and 51.9 cm respectively, Table 4), indicating more or less similar water use efficiencies (WUE, 63.8, 60.7 and 61.8 kg/ha-cm respectively, as in case of similar productivity per unit area). To the contrary, the highest water use was measured under furrow irrigation (54.2 cm) with the lowest water use as usual (with no irrigation[17]) in rainfed control (49.1 cm, Table 4). Consequently, WUE was maximum in case of drip-fertigation at branch (66.9 kg/ha-cm) followed by that at both branching and pod development (65.1 kg/ha-cm), and the minimum efficiency being under rainfed control (58.2 kg/ha-cm, Table 4). More confirmatory analysis made from profile soil moisture content throughout crop growth stages of long duration kharif planted pigeonpea also confirmed the above finding. Higher WUE with low water use again establishes additional advantage of drip-fertigation (either at branching or branching + pod development stages as in the present case) which further explores the possibility of water allocation to more areas and/or crops. Therefore, higher WUE in drip irrigation and low efficiency with furrow irrigation further suggest that drip system of irrigation provides ample scope to opt for alternatives to utilize scarce water resources effectively, efficiently and also for enhanced crop productivity[12].

### *Nutrient availability in soil and plant system*

Nutrient availability in both soil and plant system depicts the nature of crop and residual status in soil so as to fit in a cropping system(s) relevant on a long-term prospective as sustainability of a cropping system(s) is solely a combination of diverse crops with different nutrient mining capacities. In the present study, soil nutrient status after two years of continuous cropping of long duration pigeonpea revealed similar nutrient stocks in respect of NPK and SOC (soil organic carbon) with minor exceptions under all the planting configurations that maintained a constant plant population (Tables 4 and 5). On the contrary, better crop growth (with higher leaf fall) and yield formation in case of drip-fertigation at branch or branch + pod development resulted in relatively higher N, P, K and SOC residual status under these treatments compared to both rainfed control plots and drip-fertigation applied at later stage, i.e. pod development only (Tables 4 and 5). In the above case, optimum fertilization even in case of pulses has resulted in maintaining a relatively higher nutrient stock in soils for the next crop in succession[21]. This is contrary to the perception that the soils in the Indo-Gangetic plains in India where intensive agriculture practices are followed with liberal uses of fertilizers and manures have reported showing declining trend of nutrient status and SOC content[21,22]. Yet to add as an advantage with pulses, growing of pigeonpea in comparison to maize increases SOC content[23] which may be attributed to significant biomass and nitrogen additions through leaf fall, N fixation, root and crop residues.

Besides soil availability, nutrient accumulation in plant parts also determines the extent of mining from soil which acts as an indicator for residual availability of soil nutrient for supply considerations (nutrient recommendations). In the present study, nutrient removal by crop under different planting configurations indicated that relatively higher grain yield in case of 90 × 20 cm row spacing resulted in significantly higher N, P and S uptake in seed compared to other planting configurations (Table 6). Similarly higher straw K, S and Zn uptake were evident in case of 90 × 20 cm row spacing. However, higher nutrient uptake either in seed or straw did not increase total (seed + straw) N, P and Zn uptake by any of planting configurations although higher K and S uptake in straw resulted in higher total K and S uptake in 90 × 20 cm row spacing (on par with paired row in respect of total S uptake). Therefore, relatively lower nutrient uptake in both seed and total plant along with similar grain yields under paired row planting vis-à-vis other row spacings may be cited as one of the reasons for making it relatively more efficient (economic and popular) planting pattern (in case of drip technology) over others[2].

To the contrary, higher grain yield in case of application of drip-fertigation schedules at branch or branch + pod development stages resulted in significantly higher N, P, K, S and Zn uptake in both seed and straw over those plots, viz. no-irrigation (control) and drip-fertigation given at only pod development stage (Table 6). In addition, higher nutrient uptake in seed and straw

**Table 4.** Net return, seasonal crop water use, agronomic efficiency and SOC as influenced by treatments*

| Treatment | Net return (Rs 000/ha) | Profit/ day (Rs) | Productivity/ day (kg) | Seasonal water use (cm) | WUE (kg/ha-cm) | Agronomic efficiency (kg grain/kg NPK) | SOC (%) 0–15 cm | SOC (%) 15–30 cm |
|---|---|---|---|---|---|---|---|---|
| Planting configurations | | | | | | | | |
| 90 × 20 cm | 71.78 | 283 | 13.0 | 51.7 | 63.8 | 15.5 | 0.30 | 0.21 |
| 60–120 × 20 cm | 71.31 | 281 | 12.4 | 52.0 | 60.7 | 14.0 | 0.29 | 0.22 |
| 120 × 15 cm | 70.63 | 278 | 12.6 | 51.9 | 61.8 | 14.5 | 0.28 | 0.20 |
| SEm (±) | 1.54 | 5.9 | 0.06 | | 1.0 | 0.5 | | |
| CD (0.05) | NS | NS | NS | - | NS | NS | – | – |
| Drip-fertigation schedules | | | | | | | | |
| Rainfed | 66.40 | 262 | 11.2 | 49.1 | 58.2 | 10.6 | 0.27 | 0.18 |
| Drip$^{Br}$ | 74.91 | 295 | 13.5 | 51.1 | 66.9 | 16.9 | 0.31 | 0.23 |
| Drip$^{pod}$ | 64.36 | 253 | 12.2 | 51.4 | 60.1 | 13.2 | 0.28 | 0.19 |
| Drip$^{Br+pod}$ | 76.05 | 300 | 13.7 | 53.4 | 65.1 | 17.4 | 0.32 | 0.25 |
| Irrigation$^{Br+pod}$ | 74.49 | 294 | 12.8 | 54.2 | 60.2 | 15.0 | 0.29 | 0.22 |
| SEm (±) | 2.42 | 9.4 | 0.30 | | 1.5 | 0.9 | – | – |
| CD (0.05) | 7.01 | 27.4 | 0.88 | – | 4.4 | 2.6 | 0.21** | 0.17** |

*Pooled Treatments as described in material methods; WUE, water use efficiency; SOC, soil organic carbon; **Initial status of soil at the start of the trial, 1$ = Rs 56.59; Interaction of factors not significant.

**Table 5.** Depth-wise soil available NPKS status (kg/ha) at final harvest of pigeonpea (after two years of cropping)

| Treatment (cm) | N 0–15 | N 15–30 | P 0–15 | P 15–30 | K 0–15 | K 15–30 | S 0–15 | S 15–30 |
|---|---|---|---|---|---|---|---|---|
| Planting configurations | | | | | | | | |
| 90 × 20 cm | 244.3 | 183.9 | 13.9 | 8.1 | 164.6 | 148.9 | 15.6 | 11.8 |
| 60–120 × 20 cm | 260.5 | 211.0 | 12.2 | 8.8 | 169.6 | 153.6 | 16.3 | 12.2 |
| 120 × 15 cm | 216.4 | 169.3 | 11.2 | 8.4 | 176.7 | 149.2 | 16.1 | 12.1 |
| Mean | 240.4 | 188.1 | 12.4 | 8.4 | 170.3 | 150.6 | 16.0 | 12.0 |
| Drip–fertigation schedules | | | | | | | | |
| Rainfed | 239.9 | 178.6 | 12.3 | 8.2 | 174.0 | 147.2 | 13.9 | 10.7 |
| Drip$^{Br}$ | 243.1 | 192.0 | 12.7 | 8.3 | 174.3 | 151.3 | 16.3 | 12.6 |
| Drip$^{pod}$ | 230.0 | 188.2 | 12.6 | 8.0 | 167.3 | 151.7 | 15.9 | 11.8 |
| Drip$^{Br+pod}$ | 250.9 | 193.4 | 13.2 | 8.5 | 177.7 | 153.5 | 17.6 | 12.9 |
| Irrigation$^{Br+pod}$ | 238.1 | 188.2 | 11.4 | 9.1 | 158.2 | 149.1 | 16.5 | 12.2 |
| Initial status | 225.8 | 188.2 | 12.1 | 8.8 | 167.2 | 141.2 | 15.0 | 13.8 |

led to significantly higher total (seed + straw) N, P, K, S and Zn uptake by the above drip-fertigation treatments compared to rainfed (control) and drip-fertigation at pod development alone. Irrigation given twice at above stages by normal furrow method did not raise nutrient uptake as that of above efficient drip-fertigation treatments. Thus, the above nutrient uptake pattern proves the fact that macro-irrigation is more efficient over conventional method of irrigation as the former has higher nutrient uptake (Table 6), productivity/day, agronomic efficiency and SOC (Table 4) over the latter[1,2].

## *Economics of interventions*

Sustainability of a sound agriculture practice and its adoption is largely a function of its favourable cost benefit analysis. In practice, micro-irrigation technologies should be feasible and viable to make these popular among clientele, i.e. farmers. The major hindrance for its rapid and elevated adoption is its higher prohibitive initial cost (similar to tapping of non-conventional energy sources) although the same can be recovered in a span of 8–10 years keeping in view the shelf-life of the system. In the present study based on an assumption of minimum 5 years life span of the system with no subsidy involved, higher net monetary returns were obtained with drip-fertigation at branching and branching + pod development. An additional net return of INR 9650/ha was realized following drip-fertigation technology applied at both critical stages in comparison to rainfed control (Table 4). Consequently, higher per day profit (INR 300) and crop productivity (13.7 kg) were calculated under this treatment. In addition to water economy, a supplementary net

**Table 6.** Effect of treatments on NPKSZn uptake in pigeonpea (pooled data)

| | N uptake (kg/ha) | | | P uptake (kg/ha) | | | K uptake (kg/ha) | | | S uptake (kg/ha) | | | Zn uptake (g/ha) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Treatment | Seed | Straw | Total | Seed | Straw | Total | Seed | Straw | Total | Seed | Straw | Total | Seed | Straw | Total |
| Planting configurations | | | | | | | | | | | | | | | |
| 90 × 20 cm | 122 | 127 | 249 | 26.2 | 21.1 | 47.2 | 27.3 | 86.8 | 114.1 | 17.6 | 46.5 | 64.2 | 89 | 186 | 275 |
| 60–120 × 20 cm | 110 | 126 | 236 | 23.1 | 23.1 | 46.2 | 27.5 | 77.6 | 105.1 | 16.6 | 47.3 | 63.9 | 88 | 143 | 231 |
| 120 × 15 cm | 114 | 127 | 241 | 25.8 | 21.8 | 47.6 | 25.9 | 78.7 | 104.6 | 16.5 | 41.3 | 57.8 | 81 | 172 | 253 |
| SEm (±) | 2.1 | 1.8 | 3.3 | 0.5 | 0.3 | 0.7 | 0.5 | 1.9 | 1.9 | 0.2 | 1.1 | 1.3 | 4.3 | 7.5 | 6.9 |
| CD (0.05) | 8.3 | NS | NS | 1.4 | 1.5 | NS | NS | 7.3 | 7.4 | 0.9 | 4.4 | 4.9 | NS | 29.4 | NS |
| Drip-fertigation schedules | | | | | | | | | | | | | | | |
| Rainfed | 101 | 126 | 227 | 21.7 | 20.3 | 42.0 | 25.1 | 74.4 | 99.5 | 14.3 | 37.7 | 52 | 65 | 149 | 214 |
| $Drip^{Br}$ | 124 | 136 | 261 | 26.1 | 23.2 | 49.3 | 26.9 | 82.7 | 109.6 | 18.4 | 44.7 | 63.1 | 102 | 250 | 352 |
| $Drip^{pod}$ | 107 | 112 | 219 | 25.6 | 20.5 | 46.1 | 25.2 | 80.7 | 105.9 | 15.4 | 50.2 | 65.6 | 71 | 161 | 232 |
| $Drip^{Br+pod}$ | 129 | 133 | 263 | 27.1 | 25.0 | 52.0 | 29.7 | 84.3 | 114 | 19.2 | 52 | 71.2 | 118 | 163 | 281 |
| $Irrigation^{Br+pod}$ | 115 | 127 | 243 | 24.6 | 21.1 | 45.7 | 27.4 | 83.0 | 110.4 | 17.2 | 40.7 | 57.9 | 74 | 111 | 185 |
| SEm (±) | 3.2 | 2.6 | 2.9 | 0.7 | 0.5 | 1.0 | 0.8 | 1.7 | 2.2 | 0.6 | 1.0 | 1.3 | 6.3 | 6.6 | 10.1 |
| CD (0.05) | 9.2 | 7.6 | 14.4 | 2.1 | 1.3 | 3.0 | 2.2 | 5.0 | 6.5 | 1.7 | 3.0 | 3.8 | 18.3 | 19.1 | 29.4 |

Interaction of factors not significant.

**Table 7.** On-farm demonstration on drip-fertigation technology at KVKs in Uttar Pradesh, India

| Treatment | Chitrakoot | | | Chandauli | | |
|---|---|---|---|---|---|---|
| | Grain yield (kg/ha) | Increase over rainfed (%) | Technology index* | Grain yield (kg/ha) | Increase over rainfed (%) | Technology index* |
| Rainfed | 1710 | – | 43.0 | 1370 | – | 54.3 |
| Irrigation$^{Br+pod}$ improved practice | 1980 | 15.8 | 34.0 | 1645 | 20.1 | 45.2 |
| Precision technology (Drip$^{Br+pod}$) | 2625 | 53.5 | 12.5 | 1900 | 38.7 | 36.7 |
| Remarks | 32.6% increase over improved practice with better TI | | | 15.5% increase over improved practice with better TI | | |

*Technology index is based on potential yield of 3000 kg/ha (PY). It is calculated in percentage based on deficit in yield from PY divided by PY.

return of INR 1560/ha was obtained with drip-fertigation when compared to normal furrow irrigation (improved practice). These results further confirmed our hypothesis that depending on water stress, drip irrigation and fertigation were helpful in up-scaling grain yield, economics with rationality in fertilizer and water use[1,2,24].

It was well-established from the present study that moderate water use under drip-fertigation at branching + pod development produced optimum/potential grain yield (3468 kg/ha) and WUE (65.1 kg/ha-cm) complemented with higher net profit (INR 76,050) and agronomic efficiency (Table 4). Higher net return and benefit cost ratio were also reported with drip-fertigation at Coimbatore, India[24]. Contrarily, economics of planting configurations or pattern showed a more or less similar net return under different row configurations because of the similar plant population was maintained in all the treatments. The same was the status for agronomic efficiency, profit/day and productivity/day (Table 4) for the planting patterns evaluated. However, paired row system is better equipped with higher economy and efficiency as it involves less costs (both in terms of lay out and labour/cost requirements) following pairing of rows and inserting a (drip-) lateral between a paired row. Suitability of these is known from the additional possibility of intercropping (beyond the paired row) under such a modified plant row arrangement.

## *Technology transfer*

The experimental findings were further subjected to confirmation through an on-farm trial (farmers' field) for a possible technology transfer. It was undertaken as a case study with an objective of extending the benefits of drip-technology in pulses to farmers (Table 7). Similar to experimental outcome, drip-fertigation at both branching and pod development with half of N&K doses applied was doable and remunerative for realizing higher grain yield in pigeonpea. The outcome of the farmers' field trial revealed that enhancement in grain yield to a staggering 32.6% and 15.5% was obtained with the above fertigation treatment (precision technology) imposed at both the locations over the improved farmers' practice. This was further confirmed from the lower values of technology index, i.e. reducing the gap between potential and actual pigeonpea grain yield realized under the field condition (Table 7). This evidently established the possible application of precision irrigation technology (drip-fertigation) towards realizing productivity potential of the pulses (long duration pigeonpea in this case). This in turn would explore the possibilities for up-scaling both farm output and income further[15].

Besides trial on famers' field, the feedback about the drip technology and its management indicated farmers' acceptance since most of them in the eastern IGP region owned a tube well for fulfilling their domestic requirements (for crop/animal raising and house-hold use). In the presence of adequate financial support from the Governments in providing necessary infrastructural set up for establishing drip technology, the farmers are now more eagerly taking up the technology. Moreover, technology advances in drip technology available right now using reinforced pipes or laterals with embedded drippers are more convenient and easy to use. This enables *in situ* installation of the system more user friendly with less drudgery. Today farmers are adopting more scientific way of lifting the water by solar operated pumps (also supported by Government) or gravity operated high volume tanks installed at an elevation for smooth and steady discharge of water through drip-laterals. This helps them to reduce the loss of energy, time and expenditures involved, making it possible for a quick and sustainable transfer of technology.

From this two-year study, it is inferred that depending on deficit in monsoon rain, drip-fertigation at both branching and pod development or at branching alone with half of N&K dose could be highly beneficial for up-scaling grain yield, better water and nutrient use efficiency and more returns under NEPZ of Indian subtropics. Although paired row planting ($60 \times 20$–120 cm) was comparable to other planting row configurations in terms of crop growth, development and yield, it was economically advantageous for adoption of fertigation along with drip-technology compared to cost ineffective normal planting.

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