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Research Article

Effect of Static Magnetic Treatment to Seeds on Soil-Plant-Water Relations in Chickpea (*Cicer arietinum* L.)

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ABSTRACT

The soil moisture stress at pod filling and seed development stage in chickpea (*Cicer arietinum* L.) crop is one of the major constraints to its production. This 'terminal drought stress' is significantly important as the crop is largely grown as rainfed in post-rainy season in arid and semi-arid regions. Field experiment was conducted at the research farm of I.A.R.I., New Delhi to monitor the effect of static magnetic field (SMF) treatment to seeds on soil-plant-water relations in chickpea with special emphasis on terminal stress period, when soil moisture reduced to <15% by volume. Seeds exposed to the SMF of 100 mT for 1 h (treated) resulted in better root growth, which enabled the crop to utilize the residual soil water. The active growth period (78-118 DAS) was the most susceptible to soil water stress, where the treated crop extracted 60% greater moisture. The soil water stress to the crop was evident through its hyperspectral reflectance. The water band index in near infrared and canopy-air-temperature difference in thermal infrared region of spectra were related to the leaf water potential. Growth, and water and radiation use efficiencies in chickpea were better in SMF treated plants. Results conclude that seed treatment by SMF may promote better root growth and water uptake, which have practical implications in chickpea production in arid and semi-arid regions of India.

Key words: Soil water, Static magnetic field, Chickpea, Terminal drought stress

Introduction

Chickpea (*Cicer arietinum* L.) is the largest produced food legume in south Asia, and the premier pulse crop of Indian sub-continent. India is the largest chickpea growing country, accounting 73% share in Asia (Saha *et al*., 2013). In rainfed situation, soil moisture stress (often termed as 'terminal drought stress') occurring at the pod filling stage and the increasing severity towards end of season have been seen as the major constraint to its production. Although drought-tolerant varieties have been developed, lack of understanding of drought manifestation mechanisms and using only yield as an empirical selection criterion, the water stress continues to be the most important abiotic stress in chickpea (Saxena, 2003).

Scarcity of roots in the deep soil layers restricts the full utilization of soil water by the crops (Serraj and Sinclair, 2002). Experiments conducted at various parts of the world suggest that improvement of root traits might be a promising approach in strengthening the drought avoidance by chickpea under moderate to extreme terminal drought conditions, indicating that the cultivar with more effective root systems may avoid the terminal drought stress and able to produce satisfactory yield.

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Laboratory experiments under controlled conditions at IARI, New Delhi established that root growth could be significantly enhanced through static magnetic field (SMF) treatment of pre-sowing seeds (Vashisth and Nagarajan, 2008; Vashisth *et al*., 2013). However, whether this preliminary increase in root growth will lead to improved water uptake by the crop in actual field condition is still unanswered. An evaluation of enhanced root growth (by SMF treatment) in field chickpea will help in evolving strategies to optimize the yield and water use efficiency of this crop under terminal drought stress. A study was thus planned to identify and characterize the terminal drought stress in *desi* types of chickpea and their water uptake and use efficiencies as influenced by seed treatment through SMF.

Materials and Methods

Study area and treatments

A field experiment on chickpea was conducted during winter season (October-April) of 2008-09 at the experimental farm, IARI, New Delhi (28°35' N, 77°12' E and 228.16 m above mean sea level). The climate is semi-arid with dry hot summer and cold winters. During the experimental period, 4.2 and 6.5 mm rains occurred on 89 and 113 days after sowing (DAS), respectively and no other day received rains. The soil of experimental site is classified as sandy clay loam (typic Haplustept) and is non-calcareous and slightly alkaline in reaction.

The experiment was laid out in a randomized block design with magnetic field treatment to *desi* type and non-treated was kept as control. Individual plot size was 6 m x 3.5 m. Phosphate fertilizer in the form of di-ammonium phosphate @ 50 kg ha^{-1} was applied just before ploughing. Sowing was done manually on 24th October, 2008, with seed rate of 6 kg ha^{-1} and row-to-row spacing of 50 cm. A limited amount of irrigation water (2 cm) was applied on 12 DAS and thereafter, no irrigation was given. However on 123 DAS, a light irrigation was given to avoid irreversible damage if any, due to water stress at maturity.

Observations

The observations were made just before flowering and at 50% of flowering, initiation of pods, 50% pod appearance and at maturity (just before harvest). Soil moisture was monitored at weekly interval.

Soil moisture was monitored by neutron moisture meter (CPN 503, International INC. USA.) at weekly intervals for each 30 cm layer increments (0-30, 30-60, 60-90 and 90-120 cm depth). The crop water use was computed using soil water balance equation. Root water uptake during 78-118 DAS was computed from the depletion of soil moisture during the same period for 0-30 cm soil, assuming no drainage as the soil was dry. Water use efficiency (WUE) of the crop was calculated as the ratio of biomass or yield produced (g m^{-2}) and the amount of water used (cm).

Six root samples for each treatment were collected by a root auger of 8 cm diameter in all above-mentioned stages except maturity. Roots were collected for each 15 cm layer down to 45 cm depth. Roots were carefully processed and total root length, length and weight density were determined by using WinRHIZO (Regent Instruments, Inc., 2001) in the root analyzer.

Ground held spectroradiometer (ASD Field Spec™ 3) [25° field of view, 350 to 2500 nm range] was used for monitoring the hyperspectral reflectance of the crop. Results were produced at every 1 nm reading (ASD ViewSpecPro software). Following broadband and hyperspectral indices were calculated:

(i) $\mathrm{NDVI} = \dfrac{(NIR - RED)}{(NIR + RED)}$ (Rouse *et al.,* 1973)

(ii) $\mathrm{WBI} = \dfrac{R_{970}}{R_{900}}$ (Penuelas *et al*., 1993)

where NDVI and WBI refer to normalized difference vegetation index and water band index, respectively; NIR and RED represents reflectance at near infrared and red region of the spectrum;

R_{970}, R_{900} refers as reflectance at 970 and 900 nm, respectively.

A hand-held infrared thermometer (AG-42, Teletemp Crop. USA) with 8^0 FOV was used to measure the canopy-air-temperature difference (CATD). The data for each plot were the mean of 2 readings, taken from 3rd row of each plot, at an angle of approximately 45^0 to the horizontal, in a range of directions such that it shoots plant canopy. Stress degree days were computed by progressively adding the CATD values.

Leaf water potential (ø) was measured following Scholander *et al.* (1964). For plant biomass, two plants were randomly selected in each plot and cut at the ground level. The leaves were separated and their area was determined by leaf area meter (LICOR-100). The leaf area index (LAI) was calculated as:

LAI= [Leaf area per plant (cm^2) × Number of plants per m^2]/10000

The leaves, stem, and pods were oven-dried (60-65^{0}C for 48 h) and the dry weights were recorded.

Incoming and outgoing PAR values were recorded at two heights, top and bottom of the plant throughout the season using line quantum sensor (LICOR-3000). The measurements were taken on clear sunny days between 11:30 and 12:00 h local standard time. These data were further used to derive radiation use efficiency (RUE) using APAR (Absorbed PAR):

(i) APAR = [Incident radiation on the top of the canopy–reflected radiation by the top of the canopy–incident radiation at the bottom (transmitted) + reflected from the ground]

(ii) RUE (g MJ^{-1}) of the crop was expressed as the slope of the curve of biomass accumulated at various stages and cumulative APAR at the respective stages.

Statistical analysis like analysis of variance (ANOVA), computation of correlation coefficients, regression relations was carried out using MS Excel and SPSS packages (Version 10.0). Treatment difference was expressed with least significant difference at 5% probability level. The required graphs were drawn using MS Excel/Power Point software packages.

Results and Discussion

Soil moisture

The soil moisture (% v/v) variation was evident mostly in the surface layer (0-30 cm), and was negligible beyond 90 cm depth. Initially (0-19 DAS), soil moisture depletion was similar among the treatments (Fig. 1). In next 60 days (19-78 DAS), most of the water depletion occurred due to upward flux (no rain or irrigation during the period). The depletion was greater at 0-30, followed by 30-60 cm, and the change was limited in 60-90 and 90-120 cm layers. Treatments differences were significant during 78-118 DAS, in which significantly higher soil water depletion was recorded at 30-60 cm layer. Considering the entire profile, 1.80 and 1.82 cm water were depleted under treated crop, while the depletion was 1.10 and 1.13 cm for the untreated crops during same period. During 118-150 DAS, treated plants apparently utilized higher soil moisture at 0-30 cm layers. However, for other depths, water depletion was similar among the treatments. As the crop was irrigated once in the beginning, the soil moisture depleted continuously and reached to deficit at this critical stage of pod filling and seed development. This period of water deficit (terminal drought stress) could reduce the seed yield drastically (Saxena, 1984; Siddique *et al.*, 2000; Gaur *et al.*, 2008), which is observed in this study also. However, soil moisture profile data distinctly acquaints the positive effect of magnetic field treatment in augmenting root growth helping the crop to extract more moisture (discussed later).

The cumulative water depletion over the crop growth period showed a clear distinction between treated and untreated crops (data not presented). Water depletion was steadily higher under treated crop with the highest cumulative depletion (6.02 cm) from 0-30 cm soil layer against 5.34 cm in case of non-treated crop. For 30-60 and 60-90 cm layers, the corresponding values were 4.98 and 3.92 cm under treated and 4.45 and 2.93 cm in non-treated crop.

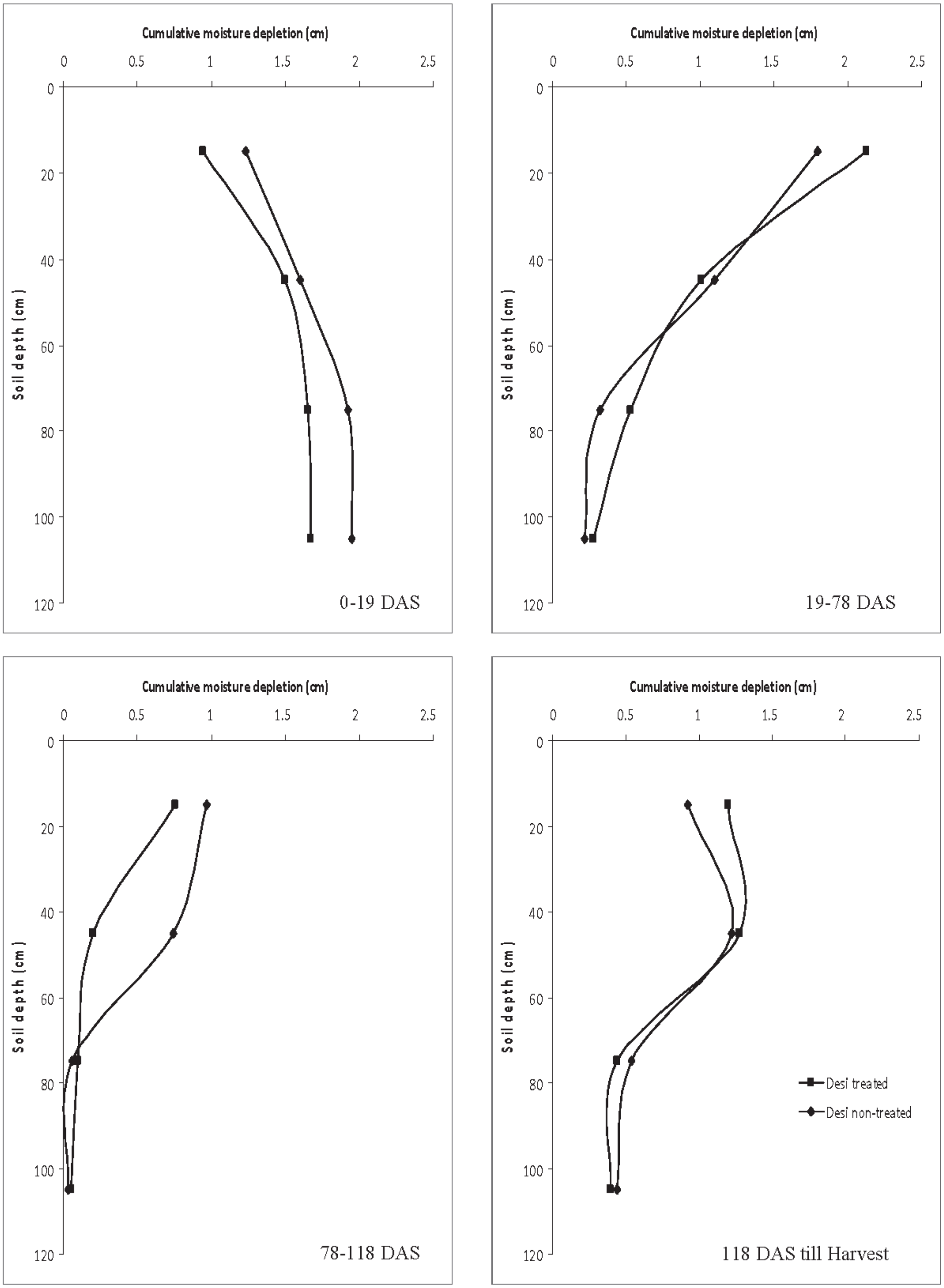


Fig. 1. Soil moisture depletion during different growth intervals in chickpea

Root morphological characteristics and water uptake

Root length and weight densities were at par between the treatments till 105 DAS, but the effect of SMF treatment is clearly visible on 118 DAS (Fig. 2). In 0-15 cm layer, the root length density (RLD) showed significantly higher value in treated (0.88 cm cm^{-3}) on 118 DAS, as compared to 0.53 cm cm^{-3} in non-treated plants. Similar trends were observed at 15-30 cm depth, although the treatment difference narrowed down. Root weight density (RWD) at 0-30 cm layer did not change appreciably and the treatment effect was visible only on 118 DAS (Fig. 3); the RWD in treated plants was 0.0041 g cm^{-3} which was significantly higher that the non-treated plants (0.0029 g cm^{-3}). Other root growth parameters like surface area and root volume showed higher values in treated chickpea crop, but no difference in average diameter of roots in either treated or non-treated plants was recorded (data not presented).

Maximum root growing period occurred between 78 and 118 DAS and the increased root growth might possibly lead to higher water uptake by the crop. Rainfall was negligible (4.2 and 6.5 mm on 89 and 113 DAS) and no irrigation was applied during this period. Greater soil water was extracted by treated (17.12 mm) than the non-treated (9.32 mm) plant. Root water uptake during 78-118 DAS (Y, cm) was positively and significantly correlated (r=0.71, $p=0.05$) to root length density (0-30 cm) on 118 DAS and their regression yielded the following relationship (Fig. 4a):

$$Y = 0.825X + 0.4313 \ (R^2=0.50)$$

The specific water uptake rate (cm^3 cm^{-1} day^{-1}) in 0-30 cm soil depth showed significantly

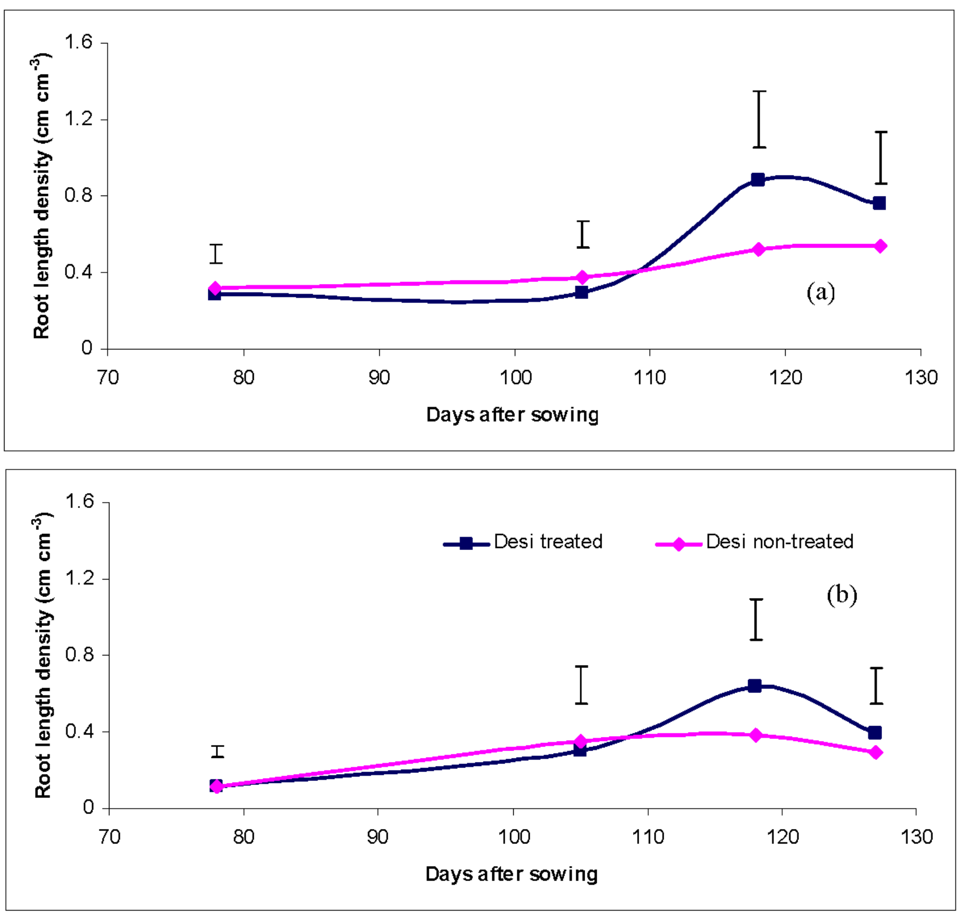


Fig. 2. Root length density of chickpea *desi* type in (a) 0-15 and (b) 15-30 cm soil as affected by magnetic field treatment (vertical bars represent LSD at 0.05% between treatments)

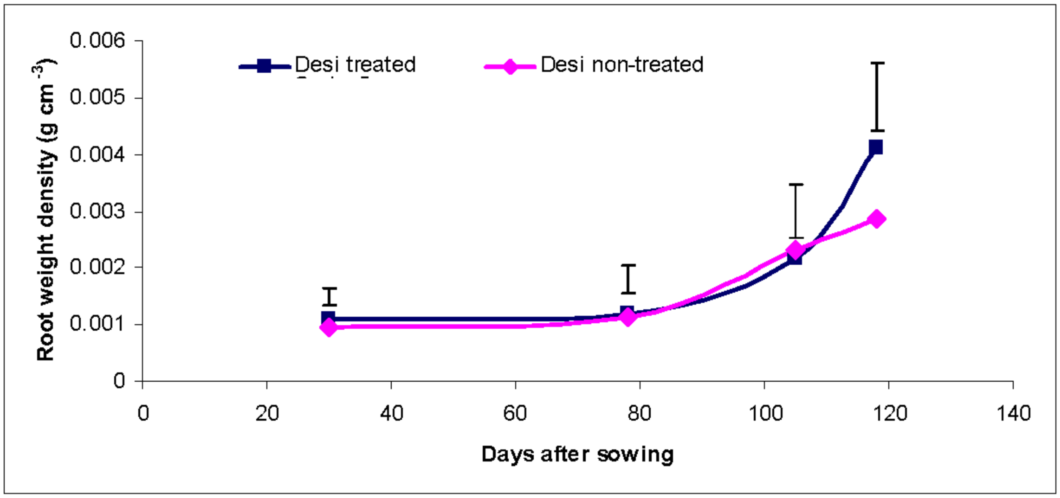
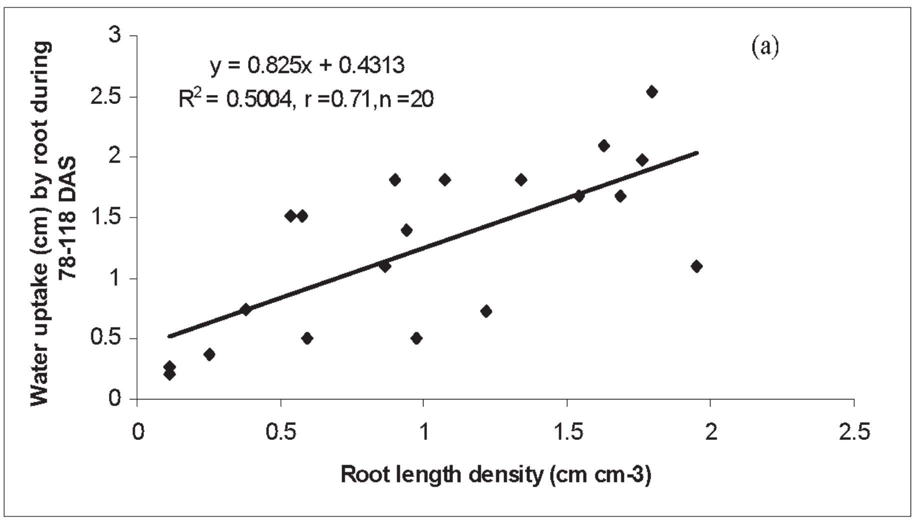


Fig. 3. Root weight density of chickpea (0-30 cm soil depth) as affected by magnetic field force



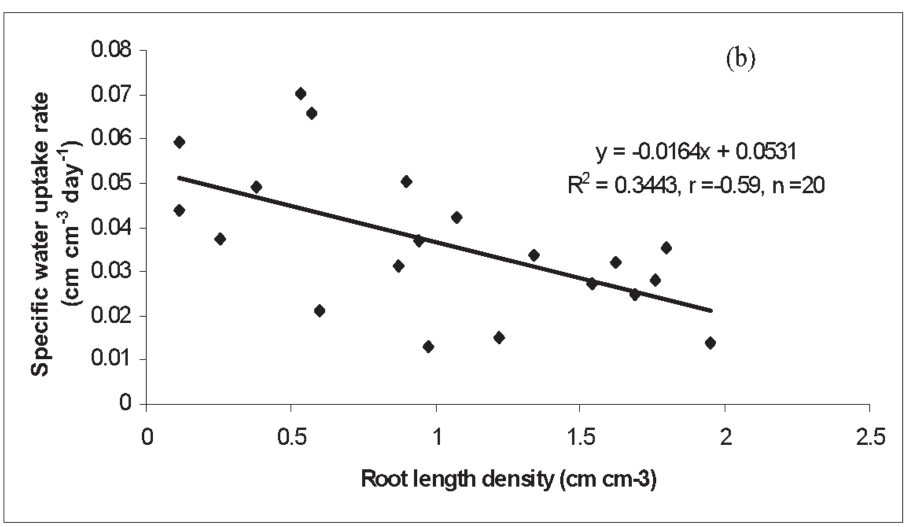


Fig. 4. Relationship between root length density in 0-30 cm soil on 118 DAS with water uptake (a) and specific water uptake rate (b) by roots of chickpea during 78-118 DAS

negative correlation with root length density (r=-0.59, *p=0.05*) and their regression yielded the relationship as (Fig. 4b):

$$Y = -0.016X + 0.0531 \ (R^2=0.34)$$

Results imply that the magnetic field treatment to seeds was most successfully translated in improving root length, which is likely to facilitate the crop in greater uptake of water, especially during 78-118 DAS. Thus the role of SMF in augmenting the root growth and water uptake in adverse situation, when the moisture from soil was fast depleting and a terminal drought like condition developed is well explained. The higher water uptake in treated crop was well correlated with its higher RLD, giving rise to its minimum specific water uptake rate. Specific water uptake rate was negatively related with root density indicating that higher root density was obtained in the upper soil layers in which the roots being older and growing under relatively lower moisture condition could be less active in water uptake function (Mishra, 1980).

Effect of deep root systems in extracting more water from soil has been documented in other crops like sorghum (Jordan *et al*., 1983; Sinclair, 1994), rice (Fukai and Cooper, 1995; Kamoshita *et al*, 2002), legumes (Saxena and Johansen, 1990; Turner *et al*., 2001) etc. The study demonstrates an improved root growth system from seeds pre-exposed to SMF. This is essential for higher water uptake and may result in higher grain yield under terminal drought stress (Soltani *et al.,* 2000). The better root growth has led to higher biomass and yield, improving water and radiation use efficiencies. Large root surface area in treated plants could best be used for dryland chickpea production in semi-arid climates (Benjamin and Nielsen, 2006) in view of the increasing trend of weather aberrations evidenced by reduced rainfall in winter months.

Plant water status

Leaf water potential (LWP) generally decreased as the crop advanced and attained the minimum value near maturity (Fig. 5). On 44 DAS, LWP was recorded as -0.25 and -0.21 MPa for treated and non-treated crop, respectively. But on 105 DAS, treated plant recorded higher LWP (-1.24 MPa) compared to -1.61 MPa in non-treated plants.

The canopy temperature (CT) has been demonstrated as an important parameter for water stress in plants. Results revealed that the difference between the treatments were the most distinguishable during 89-125 DAS (Fig. 6a). The canopy temperature was initially low on 89 DAS (21-22 °C), due to both non-limiting soil water (>18-20%, v/v) and low air temperature (maximum day temperature of 23.3 °C coinciding with the time of observation. On 105 DAS, it

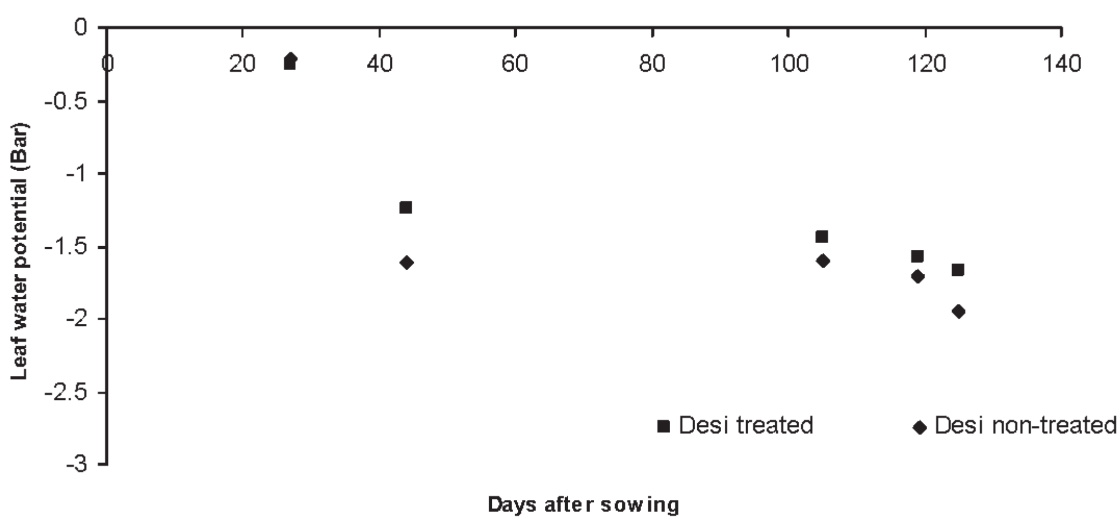


Fig. 5. Leaf water potential of treated and non-treated *desi* chickpea

recorded 28-30°C owing to higher air temperature (25.2 °C) and lower soil moisture level (15-16%, v/v). Thereafter, CT increased and recorded to a very high value of 32-35°C on 145 DAS, 5 days prior to harvest. Although no significant difference was recorded initially, canopy-air-temperature difference (CATD) started decreasing and recorded significantly lower value (-0.63 °C) in treated plants on 105 DAS (Fig. 6b). In contrast, non-treated plants recorded positive value (0.43 °C). The CATD increased thereafter and on 118 DAS also, treated plants showed significant difference. A small change in CATD happened due to light irrigation to the crop on 123 DAS, followed by steep increase at harvest. Results indicated that the treated plants could maintain a cooler canopy even when soil moisture became limiting, possibly due to its ability to utilize soil moisture from deeper layers through increased root growth.

Stress-degree-days progressively increased in each treatment with increase in crop growth, but a consistent difference was observed in the rate of increase (Fig. 6c). Significantly higher difference between treated and non-treated plants was obtained at later stages of crop growth (118, 125 and 145 DAS). The SDD profile showed a distinctly lower cumulative CATD values in treated plants, indicating that magnetic treatment to seeds enabled the plants to endure the moisture stress in soil, as attributed by its increased root growth.

Spectral reflectance of crop

The primary maximum reflectance obtained between 750 and 1350 nm (Fig. 7). The spectral reflectance (peaks and valleys) on 76 DAS was low indicating presence of soil background effect. The SMF effect was clearly distinguishable on 118 DAS. The reflectance by treated plant at NIR region reached maxima (36-50%), while the absorbance at visible red region was the lowest (8-9%). Treatment effect persisted till 128 DAS; reflectance in NIR was ranging between 30-40% for both treated and non-treated crops, although the curves were distinctly separated throughout the NIR region. Higher reflectance in near infrared (NIR) region (750-1300 nm) was diagnostic to the higher growth rate in treated chickpea.

The NDVI reached to its peak during 105-118 DAS, as expected, keeping in view of the peak vegetative growth occurring during similar period (Fig. 8), and differentiated treated and non-treated chickpea on 118 DAS. Water band index (WBI) decreased to 0.94-0.96 on 105 DAS from its initially higher values (~1, due to low canopy ground coverage on 76 DAS) as leaf water content increased along with advancement of crop growth. Beyond 105 DAS, the WBI values increased, reaching to a maximum (0.95-0.98) on 118 DAS. Significant difference was observed between treatments on this day when treated plants recorded 0.95 values as against 0.97 in non-treated plants.

In our study, the soil moisture is marginal and progressively depleting; plants with better root growth improved the water uptake, and therefore, increased its water content. The initially higher values of WBI could be due to effect of soil which was dry and not covered by the canopy, while the subsequent lower values were indicative of better plant water status. A sharp rise of WBI on 118 DAS implied the effect of terminal drought (water) stress to plants, when the soil was at its sub-optimal moisture content, 10% (v/v) at surface and 15-20% (v/v) at sub-surface on 110 DAS. Our data suggested that the maximum water stress reached on 118 DAS in which significant difference were observed between treated and non-treated plants. This signified a better water content in the treated crops.

Better soil moisture availability at initial crop growth period correlated well with lower LWP values. Effect of magnetic treatment was significant on 105 DAS, which was also supported by spectral and thermal indices obtained during similar periods. Overall, lower values of LWP in non-treated plants indicated that it could not maintain the leaf water status similar to treated plants. This was also indicated by the CATD, and a negative correlation between LWP and CATD (data not presented) imply that this thermal index

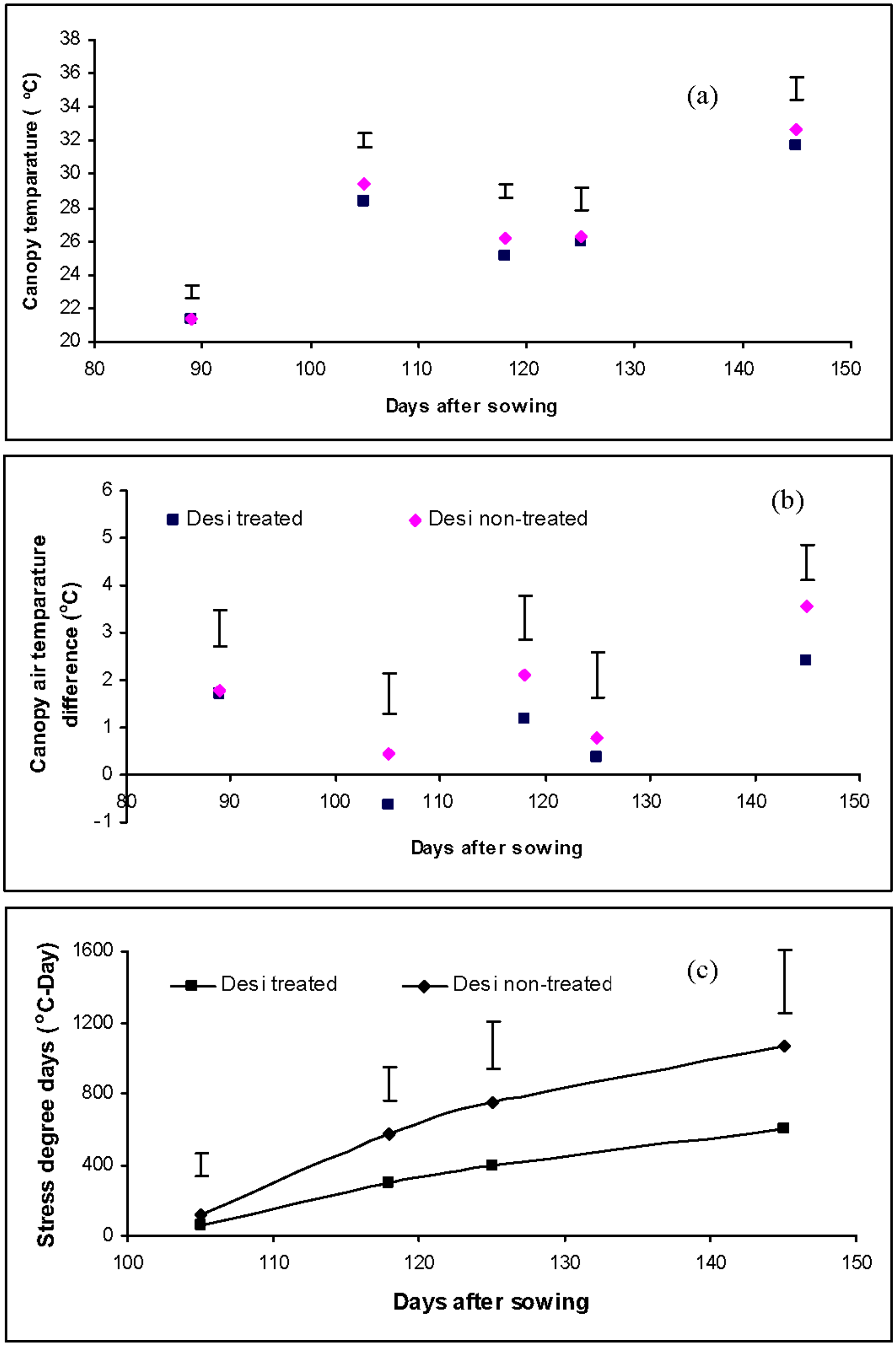


Fig. 6. Canopy temperature (a), canopy-air-temperature difference (b) and stress degree days (c) in chickpea as affected by magnetic treatment to seeds

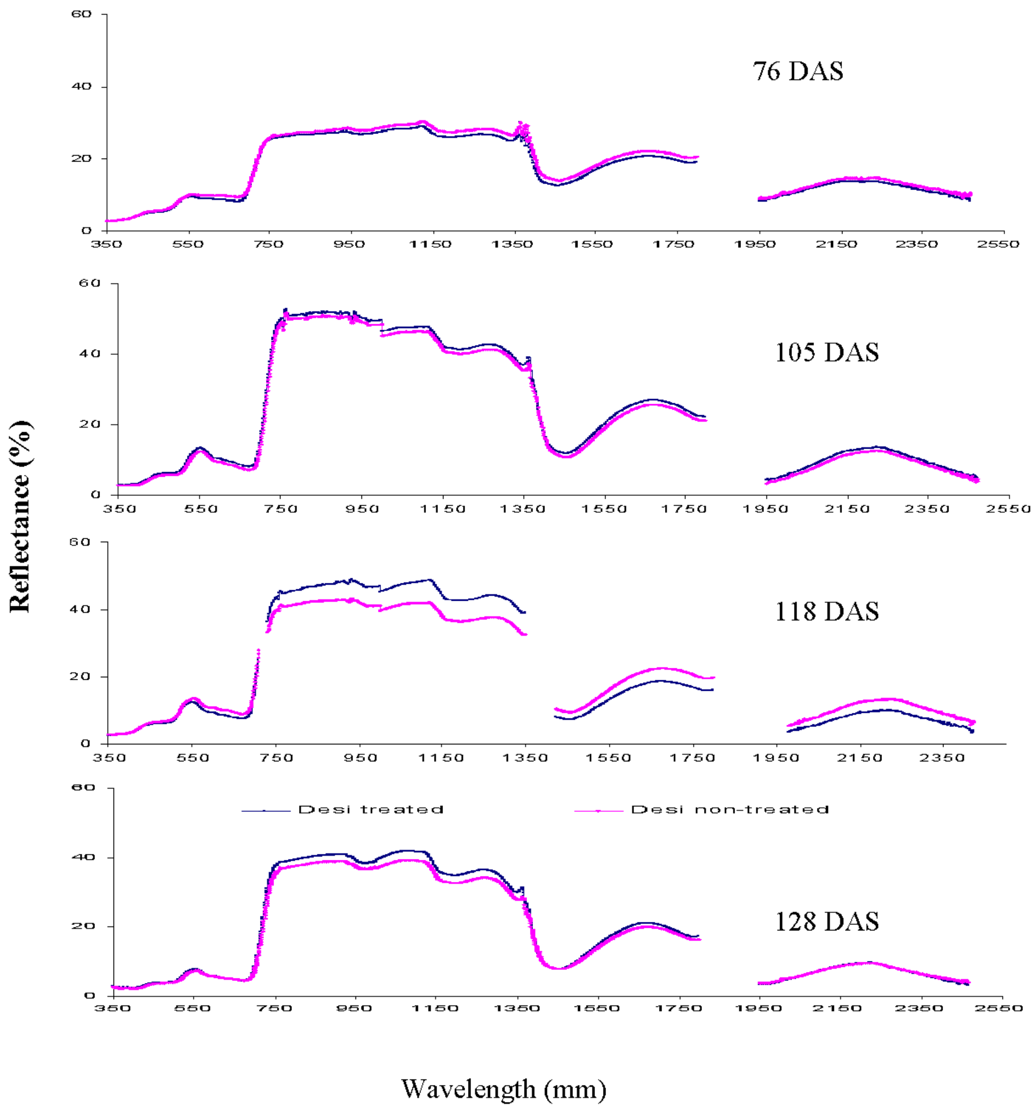


Fig. 7. Spectral reflectance curve of chickpea on different crop growth days

can successfully indicate the limiting soil water status and the stress to the crop. Moreover, lower LAI corresponding to lower NDVI values (an exponential relation) also indicated that the water stress, which led to limited growth, can also be identified in chickpea by using the vegetation index.

Plant growth parameters, water and radiation use efficiency

Crop growth rate was initially low but increased rapidly beyond 105 DAS and the rate was higher in treated plants. The growth reached to its maxima at 124 DAS (15.63 in treated and 14.24 g m^{-2} day^{-1} in non-treated) and thereafter decreased. The decrease was sharper for non-treated than treated plants due to lower biomass production under water stress condition. As chickpea is a bushy, spreading type crop of very low heights, the leaf area index (LAI) was low compared to many other winter crops like wheat, mustard etc. The peak LAI was recorded on 118 DAS (data not shown). The treated plants showed significantly higher LAI (1.77) than non-treated (1.35) plants. It is to be noted that the effect of magnetic treatment was significant on 124 DAS coinciding with the period of occurrence of minimum soil water content. Specific leaf area

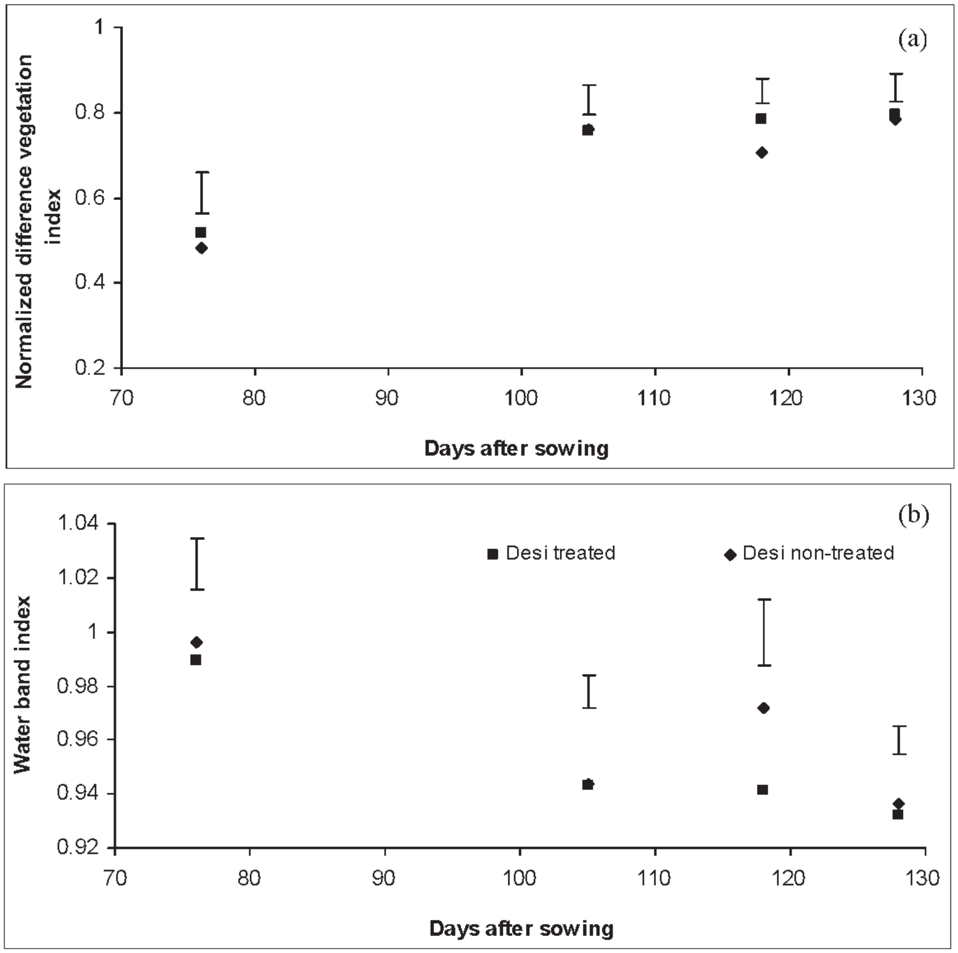


Fig. 8. Spectral indices of chickpea on 76, 105, 118 and 128 DAS: (a) normalized difference vegetation index and (b) water band index

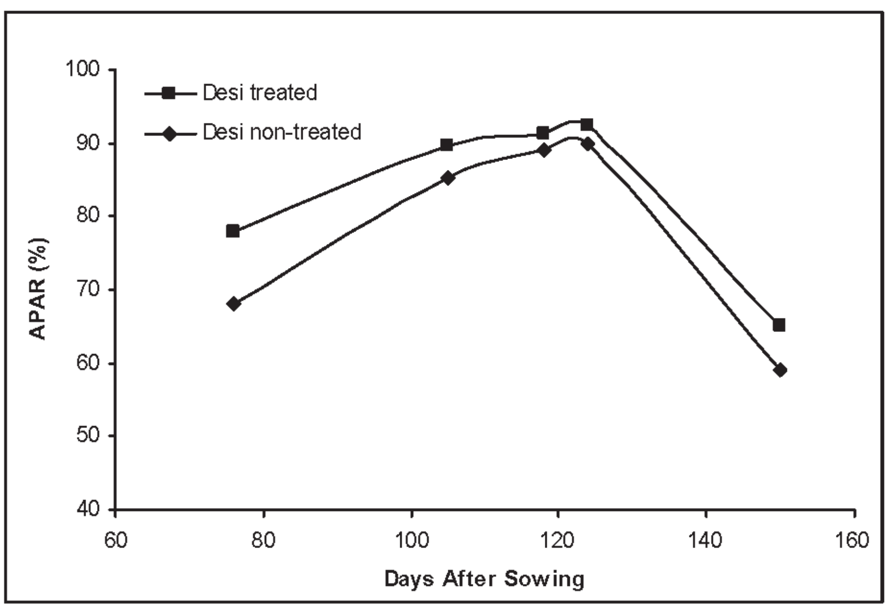


Fig. 9. The Absorbed photosynthetically active radiation (APAR) profile of treated and non-treated chickpea crop

did not show any apparent trend and was similar for all the treatments (data not shown).

Absorbed photosynthetically active radiation (APAR) was initially lower corresponding to a low canopy development, but the treated crops recorded higher APAR (Fig. 9). The APAR gradually reached to peaks on 124 DAS, keeping a continuous difference between treated and non-treated types. The APAR profile declined sharply afterwards, though the difference between treated and non-treated plants was clearly discernible.

Treated plants had higher seed number (1358 m^{-2}) and the highest seed yield (255.1 g m^{-2}). Number of pod bearing seeds was also significantly higher in treated plants (679.15 m^{-2}). But pod abortion due to terminal drought was affected in nearly the same proportion in both the treatments. The crop water use was non-significant between treatments, though treated plants used marginally higher soil water. The water use efficiency (yield) was computed as 17.1 (treated) and 16.2 (non-treated) g m^{-2} cm^{-1}. From crop biomass (harvest) point of view, the values of WUE were recorded at 37.7 and 31.5 g m^{-2} cm^{-1} in treated and non-treated crop, respectively. Radiation use efficiency was significantly higher in treated plant (0.73 g MJ^{-1}) compared to non-treated (0.58 g MJ^{-1}). The improved root growth substantially increased the water uptake by the crop, thereby increasing the biomass in treated chickpea. Treated plants also developed significantly higher number of pods and seeds, which led to higher seed yield. Due to better yield and biomass, water and radiation use efficiencies were also higher.

Conclusions

The significant increase in plant growth parameters and greatly improved root characteristics in the plants from magnetically treated seeds were observed. This has practical importance in chickpea which is a rainfed crop and generally grows under receding stored soil moisture. Magnetic treatment was able to ameliorate the effect of stress to some extent which may be attributed to maintenance of better plant water status by osmotic adjustment and greater root growth than the control.

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