SOIL & CROP SCIENCES | RESEARCH ARTICLE

Effect of planting date and genotype on intercepted radiation and radiation use efficiency in chickpea crop (Cicer arietinum L.)

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Abstract: Two field experiments, to assess the effect of planting date on canopy cover, intercepted radiation (IR), and radiation use efficiency of grain yield ($\varepsilon_g$) and biomass production ($\varepsilon_b$) of five chickpea genotypes, were conducted in 2014 & 2015 in NE South Africa. Planting date (1, 14 and 28 May being early, control/normal, and late planting, respectively, based on farmers’ practices) was allocated the main plots and chickpea genotypes (Range 1, Range 3, Range 4, Range 5 and ICCV9901) the sub-plots. Experiment I was well-watered (close to field capacity) throughout the season. Experiment II was watered three times (at planting, flowering and pod formation). The response of $\varepsilon_g$ to planting date varied with genotype in experiment II but was greater in early (1.06 g MJ⁻¹ PAR) compared with control (0.96 g MJ⁻¹ PAR) and late (0.90 g MJ⁻¹ PAR) sowing. $\varepsilon_b$ varied with genotype in experiment I and was subjected to interaction between sowing date and genotype in experiment II. Range 4 and 5 had greater $\varepsilon_b$ (0.97 g MJ⁻¹ PAR) compared to ICCV9901 (0.90 g MJ⁻¹ PAR) and Range 1 & 3 (0.84 g MJ⁻¹ PAR) in experiment I. The study results clearly recommend planting chickpea on the 1st of May in this environment so as to improve radiation capture and its utilization and to increase grain yield.

Subjects: Agriculture & Environmental Sciences; Botany; Plant & Animal Ecology; Soil Sciences

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PUBLIC INTEREST STATEMENT
Chickpea production is being introduced in South Africa. Thus, limited studies have been conducted to help farmers on appropriate agronomic practices needed to grow the crop profitably. Therefore, this study is part of a broad objective to develop sowing (planting date) criteria for chickpea in the region. The work is being conducted in two phases. The first phase involves modeling and field trials to calibrate and validate the model’s performance. This first phase will also evaluate the optimal planting date guidelines that provide better biomass and grain yield in the region. The second phase of the study will determine the likely effect of planting date on chickpea biomass and yield under climate change scenario in North Eastern Region of South Africa. This research paper is part of the findings from the first phase where the effect of planting date and genotype on intercepted radiation and radiation use efficiency in chickpea crop was evaluated.
Keywords: canopy cover; chickpea genotypes; intercepted radiation; kabuli; early and late maturing cultivars

1. Introduction
Chickpea (Cicer arietinum. L) is an important food legume crop that is ranked third amongst legumes after dry bean (Phaseolus vulgaris) and field pea (Pisum sativum) (Mubvuma, 2018). The crop is cultivated in semiarid tropical and subtropical regions of the world (Sadras & Calderini, 2020) and interest in chickpea production is growing in many countries because of its uses as a source of livestock feed, human protein, fuel, and fertilizer (Fikre et al., 2020; Martinelli et al., 2020; Santos et al., 2021; Veisi et al., 2020; Mthulisi & Mcebisi, 2020). However, despite all the advantages, the average chickpea seed yield per hectare is very low and ranges from 0.6 to 2.3 t ha$^{-1}$ in different parts of the world (FAO, 2021).

The low seed yield in chickpea may be a result of several factors such as poor fertilizer management (Macil et al., 2020), pest and disease management, and suboptimal resource capture and their utilization. Whilst fertilizer management (Naderi et al., 2021), irrigation application (Seval et al., 2020) and crop protection methods (Khaliq et al., 2020; Mohammed et al., 2020) have been reported extensively in literature, strategies to optimize the interception of radiation and its utilization in chickpea has not been fully reported to improve crop productivity of the crop (Ogola, 2015). Traditionally, chickpea yield response from radiation interception and its use efficiency has been reported by several workers (Fotiadis et al., 2017; Lusiba et al., 2018; Ogola, 2015), but there are limited studies that integrate the effect of planting date and genotype on the ecophysiological evaluation of aboveground biomass and grain yield production of chickpea (Lake & Sadras, 2017).

Chickpea aboveground biomass production is directly related to the amount of intercepted photosynthetically active radiation and radiation use efficiency ($e$). Lake and Sadras (2017) concluded that the relationship at the biomass level properly captures and synthesizes the optimisation of underlying processes occurring during growth of a chickpea plant. It is clear from the solar driven-growth that any management practice that increases daily incident radiation, fraction of incident radiation intercepted, radiation use efficiency, and the duration of radiation interception will increase crop yield (Lusiba et al., 2018). Although ($e$) is considered to be fairly constant for a given crop species in a given environment (Pradhan et al., 2018), huge variability in radiation use efficiency values under optimal conditions have been reported (Lake & Sadras, 2017) and thus there is need for more comprehensive investigations of the relationship between dry matter accumulation and radiation capture under different management and environmental conditions.

Many studies show that manipulation of field agronomic management practices affects biomass partitioning into grain yield in chickpea (Fotiadis et al., 2017; Lusiba et al., 2018; Raza et al., 2019). Thus, planting early or late in the season may affect radiation capture depending on climate factors such as temperature, rainfall and vapour pressure deficit (VPD) (Richards et al., 2020). In support of this, earlier reports have shown that radiation capture is directly affected by temperature, and that low temperatures may reduce total intercepted radiation in plants (H. Ullah et al., 2019). Therefore manipulation of planting date may not only affect the radiation regime to which a crop grows but the temperature regime as well. Furthermore, early sowing may result in longer growing season and hence a longer duration of radiation interception (Richards et al., 2020) and allow the crop to take advantage of residual moisture in the soil and hence promote a faster and early canopy growth which ensures greater radiation capture. Also, manipulation of sowing date may affect the daily incident radiation, $Q$, indirectly by influencing the radiation regime to which a crop is exposed (Lake & Sadras, 2017).

Therefore there is need for further investigation of the relationship between biomass accumulation and radiation interception and the influence of various management practices such as planting date, genotype and soil moisture content on this relationship. In addition, hardly any study has quantified the novel effect of planting date on radiation capture and its utilization when grown under different soil water content conditions.
We hypothesised that incident radiation, moisture regime and temperature pattern would affect radiation capture and the efficiency of utilization of the captured radiation to produce yield. Thus we designed the study to have two separate experiments, one well-watered, close to field capacity, throughout crop growth and the other one watered only three times (at planting, first flowering and first podding stage). Consequently we investigated the effect of planting date on radiation use and radiation use efficiency of five chickpea genotypes grown under (i) well-watered conditions, and (ii) deficit-irrigation.

2. Materials and method

2.1. Experimental design and site
Field experiments were conducted at the University of Venda’s experimental farm in Thohoyandou (22°58.08’S and 30°26.4’E, and 595 m above sea level), South Africa in 2014 and 2015 winter seasons. The experimental details including climatic and soil characteristics of the study location, experimental design and cultural practices are given below.

Two separate experiments were laid out in a split-plot design, with main plots comprising planting date (1, 14 and 28 May representing early, control/normal and late planting date, respectively), and four desi chickpea genotypes (Range 1, Range 3, Range 4 and Range 5) in 2014, and 4 desi and one kabuli genotype (ICCV99010) in 2015 season were assigned to sub-plots. Range 1 is early maturing and has a bushy canopy structure, Range 3 and ICCV9901 are medium maturing and have erect canopy, and Range 4 and Range 5 are late maturing and display a prostate and an erect canopy structure, respectively. The treatments were replicated three times.

Experiment I was well-watered throughout the season with the aim of keeping the plots close to field capacity, and experiment II was watered three times (at planting, flowering and pod formation). The frequency of irrigation, and the total amount of water applied on each occasion, in experiment I was based on soil moisture content that was measured periodically using a neutron probe. The total amount of water applied (including rainfall) in 2014 was 430 mm in experiment I and 175 mm in experiment two, whilst 435 mm and 235 mm was applied in 2015 in Experiment I & II, respectively.

Sowing was done manually in 12 rows per plot that were 4 metres long and 30 cm apart. In-row spacing was 10 cm and a planting density of 33 plants m\(^{-2}\) (Thangwana & Ogola, 2012) in both experiments and seasons was used. Nitrogen (N) was applied in the form of Limestone Ammonium Nitrate (LAN 28% N) at a rate of 40 N kg ha\(^{-1}\) and phosphorus (P) was applied in the form of Single Superphosphate (SSP 20.3% P), at a rate of 50 kg P ha\(^{-1}\) (Madzivhandila et al., 2012). The experiments were kept free from weeds throughout the season. Five seeds were planted at each planting station and were thinned within 21 days after crop emergence. Net plot area was 14.4 m\(^2\).

2.2. Measurements

2.2.1. Weather records
An automatic weather station that is approximately 100 m from the experiments was used to record relative humidity (%), maximum and minimum air temperatures (°C), and solar radiation (MJ m\(^{-2}\) d\(^{-1}\)), for each day during crop growing season (Table 1).

2.2.2. Biomass and grain yield
Aboveground biomass was measured at 14-day interval starting from 28 days after crop emergence (DAE) until harvest maturity (HM) using destructive sampling method. At each sample collection, all the plants from a quadrant of 0.36 m\(^2\), from inner rows were cut at ground level, chopped, and oven-dried at 80°C for 48 hours before recording sample dry weight (kg m\(^{-2}\)).

For grain yield, all the plants from the two innermost rows of each experimental unit (2.4 m\(^2\)) were harvested (cutting the main stem at ground level) at harvest maturity and pods were manually removed
| Crop development | Stage | Tmax (°C) | Tmin (°C) | Solar radiation (MJ m\(^{-2}\) day\(^{-1}\)) |
|------------------|-------|-----------|-----------|------------------------------------------|
|                  |       | 2014      | 2015      | 2014                                    | 2015                                    |
| **Experiment I** |       |           |           |                                         |                                         |
| Vegetative stage | Early planting | 26.6     | 27.5     | 11.1                                    | 11.1                                    | 14.7                                    | 15.8                                    |
|                  | Normal Planting | 25.9     | 26.9     | 10.9                                    | 10.9                                    | 15.6                                    | 15.4                                    |
|                  | Late Planting  | 25.6     | 26.4     | 10.5                                    | 10.5                                    | 15.9                                    | 16.2                                    |
| Flowering and podding | Early Planting | 30.3     | 31.2     | 10.0                                    | 10.0                                    | 16.4                                    | 16.2                                    |
|                  | Normal Planting | 30.2     | 32.4     | 10.5                                    | 10.5                                    | 16.2                                    | 16.6                                    |
|                  | Late planting  | 33.0     | 33.1     | 11.1                                    | 11.1                                    | 15.8                                    | 17.3                                    |
| **Averages for the entire season** | Early Planting | 28.5     | 29.4     | 10.6                                    | 10.6                                    | 15.6                                    | 16.0                                    |
|                  | Normal Planting | 28.1     | 29.7     | 10.7                                    | 10.7                                    | 15.9                                    | 16.0                                    |
|                  | Late planting  | 29.3     | 29.8     | 10.8                                    | 10.8                                    | 15.9                                    | 16.8                                    |
| **Experiment II** |       |           |           |                                         |                                         |                                         |                                         |
| Vegetative stage | Early planting | 27.5     | 26.9     | 11.1                                    | 10.9                                    | 15.8                                    | 15.5                                    |
|                  | Normal Planting | 26.9     | 26.6     | 10.9                                    | 10.6                                    | 15.4                                    | 15.1                                    |
|                  | Late Planting  | 26.4     | 26.2     | 10.5                                    | 10.3                                    | 16.2                                    | 15.9                                    |

(Continued)
| Flowering and podding |   |   |   |   |   |   |
|-----------------------|---|---|---|---|---|---|
| Early Planting        | 31.2 | 31.6 | 10.0 | 9.9 | 16.2 | 15.9 |
| Normal Planting       | 32.4 | 32.2 | 10.5 | 10.4 | 16.6 | 16.4 |
| Late planting         | 33.1 | 33.8 | 11.1 | 10.9 | 17.3 | 17.1 |
| Averages for the entire season | | | | | | |
| Early Planting        | 29.4 | 29.3 | 10.6 | 10.4 | 16.0 | 15.7 |
| Normal Planting       | 29.7 | 29.4 | 10.7 | 10.5 | 16.0 | 15.8 |
| Late planting         | 29.8 | 30.0 | 10.8 | 10.6 | 16.8 | 16.5 |
from all the harvested plants and weighed using a digital scale, to determine pod weight per plant. The pods were subsequently threshed by hand and the seeds were air-dried, cleaned and weighed to determine grain yield (kg ha⁻¹). Sub-samples of the seeds for each treatment were used to determine 100 seed weight (100-SW). Harvest index was determined at harvest maturity as the ratio of grain yield to total aboveground biomass.

2.2.3. Soil moisture content
Soil moisture content was determined in the form of volumetric soil water content (V₁), wherein both experiments, soil water content was measured at 7 days interval between 28 and 105 days after crop emergence (DAE) in 2014, and 28 and 102 days DAE in 2015. Measurements were conducted using a neutron probe (Model 503DR Hydroprobe, CPN International, and Martinez, California, USA). On each occasion, the neutron probe was lowered into the access tubes that were inserted centrally in each plot at a depth of 1.2 m. Count readings (16 seconds) were taken at soil depth of 30, 60, 90 and 120 cm. Standard counts were taken before and after taking measurements and were used to determine count ratios. V₁ was calculated using the site-specific calibration equations (Thangwana & Ogola, 2016) as shown below:

\[
0.30 \text{m depth} : V_1 = 0.0818x + 0.0268 \\
0.60 \text{m depth} : V_1 = 0.3227x - 0.2733 \\
0.90 - 1.20 \text{m depth} : V_1 = 0.3736x - 0.3297
\]

Where x is the count ratio.

Therefore, water use was estimated as a function of change in storage, irrigation and precipitation. The total amount of water applied in 2014 was 430 mm in experiment I and 230 mm in experiment II, whilst 435 mm and 235 mm were applied in 2015, in Experiment I and II, respectively.

2.2.4. Intercepted radiation and radiation use efficiency
The proportion of intercepted radiation (Fᵢ) by the canopy was approximated based on the method presented by De Felipe et al. (2020) as shown in equation (4).

\[ F_i = 1.0 - T_i \]  

Where Ti is fraction of incident radiation transmitted by the canopy (equation 5):

\[ T_i = 1 - \left( \frac{\text{PAR}_{\text{below canopy}}}{\text{PAR}_{\text{above canopy}}} \right) \]  

The total amount of Photosynthetically Active Radiation (PAR) intercepted (IR) was approximated using equation 5 (De Mattos et al., 2020).

\[ IR = F_i \times Q \]  

Where Q is daily incident radiation.

PAR above and below the canopy was measured mostly at 7-day intervals between 28 and 91 days after emergence (DAE) in both 2014 and 2015. The measurement dates in both years encompassed the vegetative and the reproductive (flowering, podding and physiological maturity) stages of crop growth. The measurements were taken between 11.00 h and 13.00 h (solar noon) on clear, cloudless days using AccuPAR ceptometer (model LP-80, Decagon Devices Ltd., Pullman, USA). When measuring PAR below the canopy, the ceptometer was positioned between the rows in such a manner that it ran perpendicular to the rows. PAR was taken as 50% of the incident solar radiation (De Mattos et al., 2020).

Radiation use efficiency for biomass production (εᵣ) and grain yield (εₒ) was calculated as the ratio of total above ground biomass or grain yield to total intercepted radiation (equations 7 and 8).
\[ \eta_b (\text{gMJ}^{-1}) = \frac{\text{Total aboveground biomass gm}^{-2}}{\text{Total intercepted radiation MJ m}^{-2}} \quad (7) \]
\[ \epsilon_g (\text{gMJ}^{-1}) = \frac{\text{Grain yield gm}^{-2}}{\text{Total intercepted radiation MJ m}^{-2}} \quad (8) \]

2.3. Statistical analysis

Analyses of variance were performed, using the GenStat statistical package 17th edition, to assess the effect of planting date and genotype on proportion of radiation intercepted (Fi), the total amount of intercepted PAR (Ip), soil moisture content and radiation use efficiency of biomass production and grain yield were performed. Significant differences among the treatment means were separated at 0.05 probability level using the Standard error of difference of the means (SED). Linear regression and correlation analysis were used to evaluate the relationship between intercepted radiation and biomass and grain yield, and also the relationship between soil moisture content and radiation use and radiation use efficiency.

3. Results

3.1. Weather data

The maximum temperatures during vegetative growth in experiment I varied with planting date from 25.6°C (late sowing) to 26.6°C (early sowing) in 2014, and 26.4 °C (late sowing) to 27.5 °C (early sowing) in 2015. Similar trend was observed in experiment II (Table 1). In contrast, maximum temperatures during reproductive growth in experiment I were greater in late sowing (33.0°C and 33.1°C) compared with the control (30.2°C and 32.4°C) and early sowing (30.3°C and 31.2°C), respectively, in 2014 and 2015. Similarly in experiment II, maximum temperatures during reproductive stage were greater in late sowing (33.1°C and 33.8°C) compared with the control (30.3°C and 32.2°C) and early sowing (30.4°C and 31.6°C) in 2014 and 2015, respectively (Table 1). However there were some slight variations in temperature during vegetative and reproductive stages between experiment I and II. The minimum temperatures during vegetative growth in experiment I varied with planting date from 10.5°C (late sowing) to 11.1°C (early sowing) in both 2014 and 2015. Similar trend was observed in experiment II (Table 1). In contrast, minimum temperatures during reproductive growth in experiment I were lower in early sowing (10.0°C) compared with the late (11.1°C) and normal sowing (10.5°C). Similarly in experiment II, minimum temperatures during reproductive stage were lower in early sowing (10.0°C and 9.9°C) compared with the control (10.9°C and 10.6 °C) and late sowing (11.1°C and 10.9°C) in 2014 & 2015, respectively (Table 1).

The average incident solar radiation during vegetative growth in experiment I was greater in late sowing (15.9 & 16.2 MJ m⁻² d⁻¹) compared with the control (15.6 & 15.4 MJ m⁻² d⁻¹) and early sowing (14.7 & 15.8 MJ m⁻² d⁻¹), respectively, in 2014 and 2015. Similar trend was observed in experiment II (Table 1). In contrast to vegetative stage, incident solar radiation during reproductive stage was lower in late sowing (15.8 MJ m⁻² d⁻¹) compared with the control (16.2 MJ m⁻² d⁻¹) and early sowing (16.4 MJ m⁻² d⁻¹) in experiment I in 2014 but the converse was the case in 2015 (16.2, 16.6 & 17.3 MJ m⁻² d⁻¹, respectively in early, the control and late sowing) (Table 1). In experiment II, however, incident solar radiation during the reproductive stage was lower in early sowing (14.8 & 15.9 MJ m⁻² d⁻¹) compared with the control (16.7 & 16.4 MJ m⁻² d⁻¹) and late sowing (15.4 & 17.1 MJ m⁻² d⁻¹) in 2014 and 2015, respectively (Table 1).

3.2. Soil water content

Planting date (PD) affected the pattern of soil water content in both experiments over the two seasons (Figure 1). The early sowing recorded lower soil water content (by 4% and 7.2%), respectively compared with the control sowing and the late in the 0–30 cm soil layer, whilst in the 30–60 cm soil layer, early sowing recorded lower soil water content (by 4.8% and 4%), respectively, compared to normal and late sowing in experiment I in both seasons (Figure 1a & c). Similarly, PD affected the pattern of soil water content in the 60–90 cm and 90–120 cm soil layers in experiment I in both seasons (Figure 1e & g). Early sowing recorded lower soil water content (by 8.3% and 11.6%), respectively, compared to normal and late sowing. In the drier experiment with deficit
irrigation, late planting and the control had 4% less soil water content in the 0–30 cm soil layer compared to the early planting (Figure 1b) in both seasons. In contrast, the early planting recorded lower soil water content by 7.5% and 12.9% in the 30–60 cm soil layer, and 5.2% and 6.4% in the 60–90 cm soil layer, respectively, compared to normal and late planting (Figure 1d & f). PD affected soil water content at the 90–120 cm depth (Figure 1h), where the early planting recorded lower soil water content by 3.2% and 2.9%. In general, the drier experiment recorded lower soil water content in the 30–120 cm depths compared with the well-watered experiment (Figure 1a-h).

### 3.3. Aboveground biomass, grain yield and yield components

The effect of planting date (P < 0.001), genotype (P < 0.001) and season (P < 0.001) on aboveground biomass was significant but the interaction between the treatments was not significant in both experiments I & II. Biomass was higher (by 4.3% and 19.8%), respectively, in early sowing (4.83 t ha⁻¹) compared with the control (4.63 t ha⁻¹) and late sowing (4.04 t ha⁻¹) in experiment I (Table 2).
Table 2. Effect of planting date and genotype on aboveground biomass (t ha\(^{-1}\)) and grain yield (t ha\(^{-1}\)) of chickpea crop

| Experiment | Treatment | P (F-ratio) |
|------------|-----------|-------------|
| EPD | NPD | LPD | R1 | R3 | R4 | R5 | ICCV990 2014 |

| Grain Yield (t ha\(^{-1}\)) | | | | | | | |
| Exp I | 1.99\(^a\) | 1.91\(^b\) | 1.33 \(^c\) | 1.62\(^h\) | 1.61\(^h\) | 1.76\(^a\) | 1.74\(^a\) | 1.39 \(^c\) |
| * | ns | ns | ns | ns | | | | |
| Exp II | 1.32\(^d\) | 0.96\(^h\) | 0.81 \(^c\) | 1.07\(^h\) | 1.05\(^h\) | 1.16\(^a\) | 1.15\(^a\) | 0.90 \(^c\) |
| * | ns | ns | ns | ns | | | | |

| Biomass (t ha\(^{-1}\)) | | | | | | | |
| Exp I | 4.83\(^a\) | 4.63\(^b\) | 4.04 \(^c\) | 4.35\(^h\) | 4.24\(^h\) | 4.89\(^a\) | 4.94\(^a\) | 4.01\(^b\) |
| *** | ns | ns | ns | ns | | | | |
| Exp II | 3.70\(^a\) | 2.99\(^b\) | 2.69 \(^c\) | 2.72\(^h\) | 2.82\(^h\) | 3.24\(^a\) | 3.38\(^a\) | 2.48\(^b\) |
| *** | ns | ns | ns | ns | | | | |

| Harvest Index (%) | | | | | | | |
| Exp I | 43\(^a\) | 39\(^h\) | 38 \(^c\) | 39 | 38 | 41 | 40 | 37 |
| 42\(^a\) 34\(^h\) | ** | ns | ns | ns | ns | ns | ns | ns |
| Exp II | 36\(^a\) | 32\(^h\) | 30 \(^c\) | 36 | 36 | 38 | 39 | 35 |
| 34\(^a\) 30\(^h\) | ** | ns | ns | ns | ns | ns | ns | ns |

| S. E. D. (Experiment I) | CV\% | PD | G | S | PD x G | PD x S | G x S | PD x G x S |
|------------------------|------|----|---|---|--------|--------|--------|----------|
| Grain Yield (t ha\(^{-1}\)) | 17.3 | 0.07 | 0.11 | 0.20 | 0.54 | 0.31 | 0.44 | 0.76 |

(Continued)
Table 2. (Continued)

|                          | 25.1 | 0.12 | 0.37 | 0.26 | 0.64 | 0.45 | 0.52 | 0.90 |
|--------------------------|------|------|------|------|------|------|------|------|
| Harvest Index %          | 13.1 | 3.0  | 5.0  | 6.0  | 8    | 11   | 15   | 10   |
| SED (Experiment II)      |      |      |      |      |      |      |      |      |
| Grain Yield (t ha\(^{-1}\)) | 15.5 | 0.14 | 0.07 | 0.12 | 0.28 | 0.20 | 0.23 | 0.41 |
| Above ground biomass     | 18.3 | 0.23 | 0.31 | 0.33 | 0.89 | 0.57 | 0.73 | 0.12 |
| Harvest Index %          | 12.8 | 1.5  | 7.0  | 3.0  | 12   | 16   | 11   | 13   |

EPD, NPD and LPD refer to Early planting date, Normal planting date and Late planting date respectively; PD and G refer to Planting date and Genotype, respectively; R1, R3, R4, R5 are Range 1, Range 3, Range 4, and Range 5 desi varieties. Means in the same row followed by the same letter are not significantly different. Means in the same row followed by the same letter are not significantly different. *, **, and *** were used to show statistical significance at 0.05, 0.01, and 0.001 levels, respectively.
Similarly, early sowing produced greater crop biomass (3.70 t ha$^{-1}$) compared with control (2.99 t ha$^{-1}$) and late (2.69 t ha$^{-1}$) sowing in experiment II (Table 2). Range 4 and 5 had 13.1%, 16.0% and 22.7%, respectively, greater biomass (average of 4.92 t ha$^{-1}$) compared to Range 1 (4.35 t ha$^{-1}$), Range 3 (4.24 t ha$^{-1}$) and ICCV9901 (4.01 t ha$^{-1}$) in experiment I. Similarly, aboveground biomass varied with genotype in experiment II from 2.48 t ha$^{-1}$ (ICCV9901) to 3.38 t ha$^{-1}$ (Range 5) (Table 2).

Grain yield varied with planting date (P < 0.05), genotype (P < 0.001) and season (P < 0.05) in both experiments. Grain yield was higher in early sowing (1.99 t ha$^{-1}$&1.32 t ha$^{-1}$) compared with control (1.91 t ha$^{-1}$&0.96 t ha$^{-1}$) and late sowing (1.33 t ha$^{-1}$&0.81 t ha$^{-1}$) respectively, in experiment I & II (Table 2). ICCV9901 recorded the lowest grain yield in experiment I & II (1.39 t ha$^{-1}$&0.90 t ha$^{-1}$, respectively), and Range 4 and 5 had highest yield in experiment I (average of 1.75 t ha$^{-1}$) and experiment II (1.16 t ha$^{-1}$) (Table 2). Grain yield decreased by 68% (2.81 vs 1.67 t ha$^{-1}$) and 63% (1.34 vs 0.82 t ha$^{-1}$) in experiment I & II, respectively, in 2015 compared with 2014 (Table 2). Chickpea crop planted under irrigated conditions recorded a significantly (p < 0.05) higher grain yield (1.63 & 1.07 t ha$^{-1}$) compared to chickpea planted under dryland conditions (deficit irrigation), which had (1.52 & 1.12 t ha$^{-1}$), respectively, in 2014 & 2015 (Table 2). The interaction between the treatments did not affect grain yield in both experiments (Table 2).

3.4. Proportion of intercepted radiation

The proportion of intercepted radiation (FI) varied with planting date in both experiments but the variation was more pronounced in the well-watered than the drier experiment (Figure 2a & b). Early sowing recorded greater FI compared to the rest of the dates between 49 and 91 DAE in experiment I (Figure 2a) and between 63 and 84 DAE in experiment II (Figure 2b). The proportion of intercepted radiation was lowest in late sowing in both experiments (Figure 2a&b). The maximum FI was recorded in early (92% and 60% in experiment I & II, respectively) compared with the control (60% and 55% in experiment I & II, respectively) and late (51% and 46% in experiment I & II, respectively) sowing (Figure 2a & b).

Also, genotype affected the proportion of IR in both experiments but the variation was greater in experiment I compared to experiment II; Range 4 recorded the highest peak FI in experiment I (65%) and II (60%), and Range 1 (54%) & Range 3 (49%) the lowest peak FI in experiment I and II, respectively (Figure 2c & d).

The main effect of planting date (PD), genotype (G) and year (Y) on total IR was significant in both experiments but in experiment II the effect of PD varied with year (Table 3). Compared to the
Table 3. The response of total intercepted radiation, and radiation use efficiency of grain yield (εg) and biomass production (εb) to planting date and genotype in 2014 and 2015

| Experiment | Treatment  | \( P \) (F-ratio) |
|------------|------------|--------------------|
|            | EPD | NPD | LPD | R1 | R3 | R4 | R5 | PD x G | G x Y | PD x G x Y |
| 2014       |     |     |     |    |    |    |    |        |       |            |
| Exp I      | 7.28a | 5.80b | 50.9 | 5.28a | 573a | 681a | 682a | 564b | 637a | 573b | *** | *** | ns | ns | ns | ns |
| Exp II     | 6.25a | 4.68a | 453b | 50.5 | 513b | 558a | 573a | 529b | 573b | 458b | *** | *** | *** | ns | ns | ns |
| εb (g MJ\(^{-1}\) PAR) | Exp I | 1.37a | 1.29b | 1.13c | 1.13d | 1.26e | 1.29f | 1.19g | 1.44h | 1.31 | 1.21 | *** | ** | ns | ns | ns | ns |
| Exp II     | 1.56a | 1.54c | 1.21d | 1.32e | 1.35f | 1.50g | 1.67h | 1.34i | 1.45 | 1.42 | *** | *** | ns | *** | *** | *** | ns |
| εg (g MJ\(^{-1}\) PAR) | Exp I | 0.99 | 0.89 | 0.84 | 0.84 | 0.83 | 0.94 | 0.99 | 0.90 | 0.97 | 0.84 | ns | *** | ** | ns | ns | ns | ns |
| Exp II     | 1.06a | 0.96b | 0.90b | 0.84b | 0.95b | 0.90b | 0.87a | 0.96 | 0.99 | 0.96 | ** | *** | ns | ns | ns | ns | ns |
| S. E. D. (experiment I) | CV% | PD | G | Y | PD x G | PD x Y | G x Y | PD x G x Y |
| IR         | 5.3 | 30.5 | 39.3 | 24.9 | 68.1 | 43.3 | 55.6 | 96.4 |
| εg         | 20.3 | 0.066 | 0.085 | 0.054 | 0.148 | 0.094 | 0.121 | 1.432 |
| εg         | 25.6 | 0.078 | 0.101 | 0.064 | 0.175 | 0.111 | 0.143 | 0.609 |
| (experiment II) | CV% | PD | G | Y | PD x G | PD x Y | G x Y | PD x G x Y |
| IR         | 11.3 | 21.20 | 27.37 | 17.31 | 47.40 | 29.98 | 38.70 | 67.03 |
| εg         | 8.8 | 0.033 | 0.042 | 0.027 | 0.073 | 0.046 | 0.060 | 0.831 |
| εg         | 22.8 | 0.083 | 0.080 | 0.068 | 0.186 | 0.118 | 0.152 | 0.263 |

EPD, NPD and LPD refer to Early planting date, Normal planting date and Late planting date respectively; PD and G refer to Planting date and Genotype, respectively; R1, R3, R4, R5 are Range 1, Range 3, Range 4, and Range 5 desi varieties.

Means in the same row followed by the same letter are not significantly different. Means in the same row followed by the same letter are not significantly different. *, **, and *** were used to show statistical significance at 0.05, 0.01, and 0.001 levels, respectively.
control, total IR was 25.5% (148 MJ m⁻²) greater in early sowing and 12.2% (71 MJ m⁻²) lower in late sowing in experiment I (Table 3). Similarly, relative to the control, total IR was greater (by 33.5%; 157 MJ m⁻²) in early sowing and lower (by 3.2%; 15 MJ m⁻²) in late sowing in experiment II (Table 3). Also, in experiment II, total IR was subjected to an interaction between planting date and year; with early sowing total IR did not vary from 2014 to 2015 but with the control and late sowing, total IR was lower in 2015 compared to 2014 (Figure 3).

Range 4 and 5 had, on average, 19.9% (113 MJ m⁻²) greater total IR than Range 3 and ICCV9901, and 29.1% (153.5 MJ m⁻²) greater total IR than Range 1 in experiment I (Table 3). Similarly, Range 4 and 5 intercepted 9.7% (49.8 MJ m⁻²) greater total IR compared to the rest of the genotypes in experiment II (Table 3). Also, total IR was greater by 9.7% (62 MJ m⁻²) in 2014 compared to 2015 in experiment I, and by 20% (115 MJ m⁻²) in 2014 compared to 2015 in experiment II (Table 3).

3.5. Radiation use efficiency of biomass production

Radiation use efficiency of biomass production (εb) was significantly affected by the PD (p < 0.001), G (p < 0.01) and the PD x G interaction (p < 0.05) in experiment I but since the main effects of PD and G were more significant than the interactive effects, only the main effects of PD and G are described. Relative to the control, εb was 6.2% (0.08 g MJ⁻¹) greater and 13.2% (0.17 g MJ⁻¹) lower
in early and late sowing, respectively, in experiment I (Table 3). Also, εb varied with genotype from 1.13 g MJ⁻¹ (Range 1) to 1.44 g MJ⁻¹ (ICCV9901) in experiment I (Table 3).

In experiment II in contrast, εb was subjected to the interaction between PD & G (p < 0.001), PD & Y (p < 0.001), and G & Y (p < 0.001) (Table 3). The interaction between PD & G was such that εb varied from 1.09 g MJ⁻¹ (ICCV9901) to 1.39 g MJ⁻¹ (Range 5) in late sowing, and 1.36 g MJ⁻¹ (Range 3) to 1.83 g MJ⁻¹ (Range 5) in early sowing (Figure 4). In addition, there was no significant difference in εb between early sowing and the control (Figure 4). Also, the effect of genotype on εb in experiment II varied with year; Range 5 recorded greater εb in 2014 compared to 2015 while the converse was true for Range 3, and no significant differences in εb between 2014 and 2015 were observed in Range 1, Range 4 and ICCV9901 (Figure 4b). Also, εb was greater in 2014 compared to 2015 in early sowing and the control, while the converse was the case in late planting (Figure 4a).

3.6. Radiation use efficiency of grain yield
Genotype and year affected radiation use efficiency of grain yield (εg) in experiment I (Table 3). Range 4 and 5 recorded the highest εg which was, on average, 7.2% (0.07 g MJ⁻¹) greater than ICCV9901, and 15.6% (0.13 g MJ⁻¹) greater than Range 1 & 3, and εg was 13.4% lower in 2015 compared to 2014 (Table 3). In experiment II in contrast, there were significant main effects of PD & G and a significant PD & G interaction on εg (Table 3). Across genotypes, εg was greater in early sowing compared to the control and late sowing (Table 3). The interactive effect between PD & G was such that no significant difference in εg among the genotypes was observed in the control and late sowings but Range 4 and 5 recorded greater εg compared with the rest of the genotypes in early sowing (Table 3).

Correlation and linear regression between IR and biomass and grain yield, soil water content and radiation use and radiation use efficiency.

Aboveground biomass and IR showed a strong positive correlation in both experiment I and II (Figure 5a & b). Similarly, the linear regression analysis showed that aboveground biomass had a strong relationship with IR. However, there was a slight variation in strength of the relationships amongst the two experiments, with experiment I showing greater correlation and regression slope compared to experiment II (Figure 5a & b). For example, the strength of the correlation and regression slopes as measured by r and R², respectively, in experiment I was 0.8510 and 0.8043 in experiment I, respectively (Figure 5a), and 0.606 and 0.723 in experiment II, respectively.
Figure 5. Regression between aboveground biomass and total intercepted radiation in experiment I (a) and experiment II (b).

In addition, the amount of intercepted radiation showed a strong positive correlation and regression slope with soil moisture content in experiment 1 ($r = 0.8140$, $R^2 = 0.8097$), respectively, whilst experiment II recorded a weak correlation and regression slope ($r = 0.4018$ and $R^2 = 0.4507$) (Figure 6a & b). Increase in soil moisture content resulted in increased intercepted radiation in both experiments.

4. Discussion

4.1. Intercepted radiation

The greater total IR observed in early compared to normal (control) and late sowing was partly due to the greater proportion of intercepted radiation and soil moisture content that was recorded in the early sowing (Figures 1 & 2), and the longer growth period; both days to flowering and physiological maturity were greater in early compared to the control and late planting (Gautam et al., 2019). The greater proportion of intercepted radiation in early sowing was perhaps, in part, due to the observed greater plant height (Bhattacharya, 2018) and canopy size with early sowing. Although we did not measure canopy size directly in this study, it is clear from equation 7, famously known as the Monsi and Saeki (1953) equation, and Figure 2a & b that canopy size was greater in early sowing compared to the control and late sowing Gautam et al., 2019). Moreover, early sowing recorded higher peak values of $F_i$ and also reached

Figure 6. Regression between soil moisture content and total intercepted radiation in experiment I (a) and experiment II (b).
peak values of FL almost 14 days later than the control and late sowing, suggesting that the early sowing recorded greater leaf area duration (Bhattacharya, 2018; Ogola, 2015).

\[ I = I_0 e^{-KL} \]  

Where \( I \) is light flux at any level of the canopy, \( I_0 \) is light flux incident to the top of canopy, \( L \) is LAI, and \( KL \) is the light extinction coefficient.

Our results are comparable to previous reports that IR is a function of incident solar radiation, canopy size and the duration of radiation capture (Bhattacharya, 2018; Fotiadis et al., 2017; Gautam et al., 2019; Lake & Sadras, 2017; Lusiba et al., 2018). However, the early sown chickpea crop in our study was exposed to slightly lower Q compared to the control and late sown crop (Table 1) but this was more than offset by the considerably longer period of growth, hence radiation capture, in early sowing (Gautam et al., 2019). The results clearly show that radiation capture may be improved by a combination of early planting and addition of water through irrigation. This management strategy to improve radiation capture using planting dates has hardly been reported in literature and may be the novel part of this study.

The late maturing genotypes (Range 4 & Range 5) recorded greater total intercepted radiation compared to the early (Range 1) and medium maturing (Range 3) desi genotypes as well as the medium maturing kabuli (ICCV9901) genotype. This variation in total IR was probably due to the variation in period of radiation capture, canopy size and plant height (Bhattacharya, 2018) and hence variation in leaf area duration (LAD). In support of this, the late maturing genotypes reached the peak of radiation interception a week after the early and medium maturing genotypes suggesting a longer LAD in the late genotypes. The effect of management practices on LAD in chickpea has been reported previously at the site of the current study (Ogola, 2015). Earlier, Anwar et al. (2003) attributed the variation in total intercepted radiation amongst chickpea genotypes to a similar genotype variation in days to physiological maturity.

The greater total IR in 2014 compared to 2015 was likely, in part, due to the 18.7% greater incident solar radiation (Table 1) and the 1.6% greater growth duration in 2014 (Gautam et al., 2019) in line with equation 1. Also, total IR was 44% greater in the well-watered compared to the deficit-irrigation experiment as expected. Earlier, Azam et al. (2004; Mekonnen, 2020) reported that irrigation increased radiation interception in chickpea by 80%.

The correlation and regression slope showed that total intercepted radiation had a strong positive effect on aboveground biomass, and this confirmed earlier findings by Gautam et al. (2019), who reported that aboveground biomass is linearly related to total intercepted radiation. The greater correlation strength observed in well-watered experiment 1 compared with the drier experiment that was irrigated three times only was expected and could have been due to the differences in canopy cover, which varied between the experiments (Mubvuma, 2018). Moreover, the strength of the relationship indicated that improvement in above biomass (and associated architecture changes) may result in increased light interception in chickpea plant.

Similarly, greater availability of soil moisture content in early planting compared to normal and late planting resulted in greater canopy cover in early planting compared with the rest and this pattern resulted in more intercepted radiation being recorded in early compared to normal and late planting date. The regression and correlation results clearly show that radiation capture may be improved by a combination of early planting and addition of water through irrigation. Use of this management strategy to improve radiation capture has hardly been reported in literature and may be the novel part of this study.

4.2. Radiation Use efficiency

Radiation use efficiency (\( \varepsilon_b \& \varepsilon_g \)) was greater in the early sowing, and lower in the late sowing, compared with the control, in both experiments. This variation in \( \varepsilon \) with planting date was similar to the observed
variation in cumulative IR (Table 3), and biomass, grain yield and harvest index (Table 2) with planting date. Likewise, Lake and Sadras (2017) attributed the variation in ε with planting date to variation in intercepted radiation across planting dates. Our results suggest that manipulation of planting date may be a useful tool in improving grain yield of chickpea at the site of current study through its effect on cumulative intercepted radiation, the efficiency of utilization of the intercepted radiation to assimilate biomass, and the partitioning of the assimilated biomass into grain yield (Bhattacharya, 2018; Fotiadis et al., 2017; Gautam et al., 2019; Lake & Sadras, 2017; Lusiba et al., 2018) as illustrated in equation 1. Also, the variation in ε with planting date could partly be attributed to the variation in the number of cloudy days that the different sowings were exposed. Albrizio and Steduto (2005) concluded that the percentage of diffuse radiation, which leads to more efficient penetration of radiation into the canopy (Sinclair & Muchow, 1999), is higher on cloudy days. However, we did not determine the number of cloudy days each sowing date was exposed to in the current study and this needs furthermore comprehensive investigation in subsequent studies.

Although early sowing increased both cumulative IR and grain yield, and late sowing decreased cumulative IR and grain yield, relative to the control, no significant differences (p ≤ 0.05) in eg were observed between sowing dates in the well-watered experiment. The non-significant effect of planting date on eg could partly be attributed to the differences in the magnitude of the effect of PD on grain yield and total IR. For example, in experiment I, early sowing increased total IR by 25.5% (Table 3), and grain yield by only 4.2%, while late sowing decreased total IR by 12.2% (Table 3), and grain yield by 30.4%. Similar results were reported by Lake and Sadras (2017) and Gautam et al. (2019) who attributed the results to differences in length of the growing season.

The variation in eg with genotype in both experiment I & II could be attributed partly to similar variation in grain yield (Table 2) and cumulative IR (Table 3) with genotype; this is in agreement with observations from previous studies (e.g., Jha et al., 2012). However, the effect of genotype on eb in experiment I was in contrast to its effect on biomass (Table 2) and cumulative IR (Table 3). Although the late maturing genotypes, Range 4 & 5 had 13.1–22.7% greater biomass (Table 2) and 19.9–29.1% greater cumulative IR (Table 3) than the rest of the genotypes in experiment I, they did not record the highest eb in this study. This suggests that in the well-watered experiment, the greater cumulative IR in the late maturing genotypes (which also had greater plant height and larger crop canopy) did not translate into correspondingly greater biomass probably because part of the IR was at lower canopy levels where irradiance limited photosynthesis (Ogola, 2015).

In experiment II, in contrast, the effect of genotype on eb was influenced by planting date. The late maturing genotypes (Range 4 & 5) generally had greater eb in early and normal sowings. In contrast, late sowing decreased eb of all genotypes but the decrease varied with genotype; from 2.9% (0.04 g MJ⁻¹) in Range 3% to 30.1% (0.49 g MJ⁻¹) in Range 4 and was on average (27.1%; 0.47 g MJ⁻¹) greater in late maturing genotypes. This is consistent with our observations and earlier findings in chickpea (Jha et al., 2012; Andrade et al., 1993) and other crops (Tsimba, 2011) that late sowing leads to a reduction in the length of the growing season. A decrease in the length of the growing season would have greater adverse effect on the late maturing genotypes than the medium and early maturing genotypes.

The wide variation in eb observed across treatments and years suggests the lack of robustness in using the solar-driven productivity in crop growth models. Therefore further and more comprehensive investigations on the relationship between intercepted radiation and biomass across diverse environments are recommended. However, the linear relationship between IR and biomass accumulation (Figure 5) indicates the possibility of using the solar-driven growth engine to analyse the effects of various management practices on chickpea productivity. Also, the results clearly suggest that IR and ε can be manipulated for yield improvement using management strategies such as the choice of planting date within a season (Tsimba, 2011). This does not contradict the conclusions of Sinclair and Muchow (1999) because changing the sowing date essentially changes the environment under which a crop grows, and this affects the time (t) given in equation 1 above.
Although the study was on determining the response of IR and ε to planting date and genotype as factors, it is important to note that there are other several management factors such as planting density, precipitation and fertilizer application which may also affect radiation capture. Effect of precipitation was captured in soil moisture content. However, this study did not evaluate planting density but used optimum planting density of 33 plants m$^{-2}$ as recommended by (Thangwana & Ogola, 2012) in the same study area. Basically, planting density is one of the most important management methods that may affect IR (Tsimba, 2011), because it can also increase canopy cover and the intercepted solar radiation (Sinclair & Muchow, 1999). Thus, one important view would be to increase plant density in this study so as to increase radiation capture (Tsimba, 2011). However, manipulation of planting density has a limit on increasing crop yield as was concluded by Thangwana and Ogola (2012). Similarly, fertilizer rates particularly nitrogen and phosphorus were not evaluated in the study but the study used optimum fertilizer rates as recommended by (Madzivhandila et al., 2012) in the same study area.

5. Conclusion
This study investigated the effect of planting date on radiation use and radiation use efficiency of five chickpea genotypes grown under (i) well-watered conditions, and (ii) deficit-irrigation. In agreement with the study hypothesis, the proportion of intercepted radiation, total intercepted radiation and radiation use efficiency varied with planting date and genotypes but these effects were not consistent across the two experiments. Early sowing and the late maturing genotypes, Range 4 & Range 5, performed better than the rest of the sowing dates, and the early and medium maturing genotypes, respectively. Clearly, manipulation of management practices like sowing time and genotype selection combined with soil moisture management through irrigation may improve radiation capture and utilisation of chickpea.

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