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# Optimizing land configuration and weed management practices for enhanced productivity of pigeon pea

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## Abstract

A field investigation was conducted at Tamil Nadu Agricultural University, Coimbatore, to evaluate the effects of various land configurations and weed management practices on the productivity of pigeon pea. The study aimed to identify the most effective land configuration and weed management strategy to optimize pigeon pea growth and yield. The experiment comprised 15 treatment combinations arranged in a split-plot design with three replications. It included 3 land configurations ($L_1$- flatbed, $L_2$- ridges and furrows, $L_3$- broad bed furrow (BBF)]. 5 weed management practices were tested: [$W_1$- weedy check, $W_2$- two-hand weeding at 20 and 40 days after sowing (DAS), $W_3$- pre-emergence pendimethalin at 0.75 kg active ingredient $ha^{-1}$ followed by hand weeding at 30 DAS, $W_4$- pre-emergence pendimethalin at 0.75 kg active ingredient. $ha^{-1}$ followed by early post-emergence imazethapyr at 60 g active ingredient $ha^{-1}$, $W_5$- pendimethalin at 0.75 kg active ingredient $ha^{-1}$ followed by power weeder at 30 DAS followed by post-emergence quizalofop ethyl at 50 g active ingredient $ha^{-1}$). The results indicated that, in comparison to ridge and furrow ($L_2$) and flatbed ($L_1$) layouts, the BBF ($L_3$) configuration significantly reduced weed biomass and density. This configuration achieved superior weed control efficiency (WCE) and weed control index (WCI), resulting in enhanced crop growth and yield. Among the weed management practices, $W_5$ (pendimethalin at 0.75 kg active ingredient $ha^{-1}$ followed by power weeder at 30 DAS and post-emergence quizalofop ethyl at 50 g active ingredient $ha^{-1}$) proved the most effective. It significantly reduced weed population and biomass while promoting robust crop growth. In conclusion, pigeon pea grown under the BBF ($L_3$) configuration, combined with the integrated weed management (IWM) strategy of $W_5$, recorded the highest crop growth and yield. This combination effectively improves pigeon pea productivity by integrating appropriate land configurations with efficient weed management practices.

## Keywords

chemical control; hand weeding; land configuration; pigeon pea; power weeder

## Introduction

Pulses are an excellent source of protein, energy, fiber, essential vitamins and minerals (1). Among these, pigeon pea (*Cajanus cajan* L.), commonly known as arhar, tur, or red gram, is one of the oldest cultivated crops. Belonging to the Leguminosae family, it is the fourth most important legume crop globally and ranks second in importance in India. Pigeon pea thrives in tropical and subtropical regions (2). In India, pigeon pea is cultivated over an area of 4.9 million hectares, with an annual production of 4.22 million tonnes and a productivity of 861 kg ha$^{-1}$ (3). In addition to its agricultural importance, pigeon pea is crucial for ecological sustainability and has the potential to significantly enhance global food security and nutritional health (4).

Pigeon pea seeds contain up to 22% protein and 67% carbohydrates (5). They are a rich source of essential amino acids, including lysine, tyrosine, cysteine and arginine. However, they also contain certain antinutritional factors such as tannins, cyanogenic glycosides, hemagglutinin, and alkaloids, influencing their nutritional value. Proper processing is essential to mitigate the effects of these antinutrients (6).

In India, weeds pose a significant biological constraint, reducing crop productivity by as much as 34% (7). Weed further compromises crop health and productivity by competing with crops for essential natural and applied resources and serving as a host for pests and diseases (8). This competition diminishes both the quantity and quality of agricultural output (9). Weed infestation poses significant challenges for pigeon pea cultivation since the crop's slow early growth permits weeds to vigorously fight for space, nutrients, and light (10). The critical period for weed competition spans from planting to 60 DAS, during which weed management is crucial to ensure optimal crop performance (11). It has been observed that unchecked weed growth can significantly reduce pigeon pea yield, ranging from 32% to 68% (12).

Implementing effective weed management practices is crucial to minimize yield losses and enhance crop growth (13, 14). Rising labor costs and shortages have prompted farmers to increasingly rely on herbicides for weed control (14). Although manual weeding is a prevalent method, it is labor-intensive, time-consuming, and expensive. High labor expenditures render hand weeding economically impractical in areas with elevated labor expenses (15).

This has highlighted the need for alternative weed management strategies that are both efficient and cost-effective. Chemical weed control using selective herbicides has emerged as a promising solution. Selective herbicides offer systematic weed control by targeting specific weed species while minimizing harm to crops when applied appropriately (16). They enable farmers to manage weeds over large areas more quickly and efficiently than manual methods, significantly reducing labor costs and the time required for weed control (17). Research indicates that using pre-emergence herbicides combined with post-emergence measures can substantially decrease weed pressure, improving crop yields (18). Additionally, IWM approaches, which combine chemical methods with cultural practices such as crop rotation and cover cropping, enhance weed control effectiveness while supporting soil health and promoting sustainable farming practices (19).

Besides weed management, the productivity of pigeon pea is profoundly affected by land configuration, which influences water drainage, soil erosion, and nutrient availability, all of which are essential for crop growth (20). Modifying land configuration is among the most effective strategies to conserve soil moisture and enhance its availability to crops throughout the growing season (20, 21).

Among the common land configurations-flatbed, ridges and furrows and BBF systems-ridges and furrows, as well as BBF methods, have proven highly effective. These configurations control surface runoff, minimize soil erosion and improve water infiltration, providing better-growing conditions for pigeon peas (22). While flatbed systems are cost-effective and facilitate easy irrigation, they often suffer from poor drainage, leading to waterlogging, which can adversely affect root development and overall plant growth (23). Land configurations like ridges and furrows or BBFs aim to optimize water retention within the soil profile during the crop-growing season, ensuring better moisture availability (20).

This study focuses on optimizing land configuration and implementing effective weed management practices to address the dual challenges of moisture stress and weed infestation. The objective is to enhance pigeon pea yield, improve resource use efficiency and support the livelihoods of farmers.

## Materials and Methods

### *Experimental site and soil status*

The field experiments were conducted at the E1 block of the Cotton Department Farm, Tamil Nadu Agricultural University, Coimbatore, during the summer seasons (February - June 2024). The experimental field was located within the Northwestern agroclimatic zone of Tamil Nadu, at 11.02°N latitude and 76.93°E longitude. The soil in this region is red sandy loam, characterized by low available nitrogen, medium available phosphorus, and high potassium content. The soil pH is 8.63, and the organic matter content is 0.65 g kg$^{-1}$.

### *Experimental design*

The study used a split-plot design with three replications comprising 15 treatment combinations. The main plots included three land configurations, while the subplots included five weed management practices. Treatments were randomly assigned to each replication.

The main plot treatments comprised three land configurations: $L_1$ - flat bed method, $L_2$ - ridges and furrows, and $L_3$ - BBF. The subplot treatments included five weed management practices: $W_1$ - weedy check, $W_2$ - hand weeding twice at 20 and 40 DAS, $W_3$ - pendimethalin at 0.75 kg active ingredient ha$^{-1}$ at 3 DAS, followed by one hand weeding at 30 DAS, $W_4$ - pendimethalin at 0.75 kg active ingredient ha$^{-1}$ at 3 DAS, followed by imazethapyr at 60 g active ingredient ha$^{-1}$ at 20 DAS and $W_5$ - pendimethalin at 0.75 kg active ingredient ha$^{-1}$ at 3 DAS, plus power weeding at 30 DAS and quizalofop ethyl at 50 g active ingredient ha$^{-1}$ as IWM.

Pigeon pea variety "CO (Rg)-7" was sown on February 1st, at a seed rate of 15 kg ha$^{-1}$, with a plant spacing of 60 cm × 30 cm. Before sowing, farmyard manure (FYM) was applied at 5 t $ha^{-1}$, and the crop was fertilized with a basal dose of 12.5-25-12.5 kg $ha^{-1}$ of N-$P_2O_5$-$K_2O$, using urea, single super phosphate (SSP) and muriate of potash (MOP), respectively.

### *Observations*

Weed parameters were recorded at 20, 40, and 60 DAS, following the application of all herbicidal and weed management treatments (manual weeding, power weeding). Plant parameters were observed at 30, 60, and 90 DAS from the representative samples, which had been tagged earlier in each plot. Observations included plant height, number of leaves per plant, number of branches per plant, dry matter accumulation, yield attributes such as pods per plant, number of seeds per pod, 1000 seed weight, and seed and stalk yield (t $ha^{-1}$). All measurements were expressed in standard units.

### *Weed observations*

Various weed management indices were calculated to analyze and interpret the results, as described below.

### *Weed density (No. $m^{-2}$)*

Weeds were counted from a one-square-meter area at 20, 30, and 60 DAS. At each sampling stage, the weeds were categorized into sedges and broad-leaved weeds (BLW) and expressed as number per square meter ($m^2$). The original data values were then transformed into square root values and subjected to statistical analysis. Each plot was recorded using a quadrat of size 0.25 × 0.25 m.

### *Weed dry weight (g $m^{-2}$)*

Weeds present within the quadrant area were uprooted and transferred on brown covers. After air drying, the weeds were further dried in a hot air oven at 65-70 °C until constant weights were obtained. The weed dry weight (WDW) was then expressed in g $m^{-2}$.

### *Weed control efficiency (%)*

Weed control efficiency was calculated based on dry weight basis by adopting the formula given in Eqn. 1.(24).

$$\text{WCE} = \frac{\text{Dry matter of weeds in weedy check} - \text{Dry matter of weeds in treated plot}}{\text{Dry matter of weeds in weedy check}} \times 100 \quad \text{.......(Eqn. 1)}$$

### *Weed control index (%)*

The weed control index was calculated by considering the reduction in weed population in the treated plot compared to the weed population in the unweeded check plot (Eqn. 2). It is expressed as a percentage.

$$\text{WCE} = \frac{WP_C - WP_T}{WP_C} \times 100 \quad \text{.......(Eqn. 2)}$$

Where, $WP_C$ = weed population /area in control plot, $WP_T$ = weed population /area in the treated plot

### *Statistical analysis*

All data were subjected to analysis of variance (ANOVA) following standard procedures, and the data were analyzed using 'R' software. When the 'F' ratio was significant, the critical difference (CD) value was calculated at p = 0.05 to compare the treatment means.

## Results

### *Weed parameters*

### Effect on weed density

The analysis of weed density (WD) showed that land configuration and weed management practices significantly affected WD (Table 1). Significant differences were observed between the main plot and subplot treatments, although no interaction effects were detected. The lowest WD at all growth stages was observed in pigeon pea planted using the BBF ($L_3$) land configuration, while the highest WD was recorded in plots with the flatbed ($L_1$) configuration.

Among the weed management strategies, $W_5$-pendimethalin at 0.75 kg active ingredient $ha^{-1}$ at 3 DAS + power weeding at 30 DAS + quizalofop ethyl at 50 g active ingredient $ha^{-1}$ as PoE showed the greatest reduction in WD at all stages of growth. All weed management strategies significantly reduced WD compared to the weedy check (untreated control-$W_1$).

### Effect on weed dry weight

The impact of land configuration and weed management practices on WDW, as shown in Table 1, revealed significant differences among the main plot and subplot treatments, with no noticeable interaction effect. At 20, 40, and 60 DAS, the BBF recorded the lower WDW in all stages. Among the weed management practices, the IWM ($W_5$) treatment resulted in the most significant reduction in WDW across all growth stages. The power weeder effectively controlled the weeds, leading to a reduction in WDW in W5. In contrast, the highest WDW was observed in the untreated control (weedy check) plot.

### Effect on weed control efficiency and weed control index

Table 2 presents the effects of various land configurations and weed management practices on WCE and the WCI. At 40 and 60 DAS, the broad bed ($L_3$) combined with the IWM approach ($W_5$) achieved the highest WCE (79.13%, 72.06%) and WCI (76.19%, 81.28%). In comparison, the flatbed ($L_1$) with the $W_4$ treatment (pendimethalin at 0.75 kg active ingredient $ha^{-1}$ at 3 DAS and imazethapyr at 60 g active ingredient $ha^{-1}$ at 20 DAS) recorded the lowest WCE and WCI. The superior weed management indices observed in the BBF ($L_3$) with IWM ($W_5$) were attributed to a reduced weed infestation.

### *Plant parameters*

### Effect on plant height

The effects of various land configurations and weed management practices on the plant height of pigeon peas were significant in both the main plot and subplot, as presented in Table 3. However, no interaction effect on plant height was observed. The BBF method resulted in a significantly greater plant height (122.93 cm) than the flatbed method

**Table 1.** Effect of land configuration and weed management practices on total weed density and weed dry weight in pigeon pea during summer, 2024.

| Treatment | Total weed density (No.m$^{-2}$) | | | Total weed dry weight (g m$^{-2}$) | | |
|---|---|---|---|---|---|---|
| | 20 DAS | 40 DAS | 60 DAS | 20 DAS | 40 DAS | 60 DAS |
| **Land configuration** | | | | | | |
| $L_1$ | 7.33 (55.02) | 8.53 (74.73) | 9.71 (74.50) | 4.19 (17.41) | 6.98 (50.41) | 8.89 (82.70) |
| $L_2$ | 6.79 (46.81) | 7.55 (59.90) | 8.69 (60.26) | 3.70 (13.40) | 6.10 (38.66) | 7.77 (65.40) |
| $L_3$ | 6.39 (41.46) | 6.87 (50.39) | 8.02 (52.57) | 3.48 (11.90) | 5.60 (33.03) | 6.93 (51.90) |
| SE | 0.119 | 0.127 | 0.222 | 0.046 | 0.091 | 0.135 |
| CD (p=0.05) | 0.330 | 0.351 | 0.617 | 0.126 | 0.251 | 0.374 |
| **Integrated weed management** | | | | | | |
| $W_1$ | 8.83 (77.99) | 10.87 (117.97) | 11.85 (112.23) | 4.50 (19.95) | 8.69 (75.49) | 11.54 (133.38) |
| $W_2$ | 7.11 (50.29) | 7.32 (53.80) | 7.88 (50.32) | 3.98 (15.36) | 6.36 (40.60) | 6.75 (46.90) |
| $W_3$ | 6.09 (36.95) | 6.46 (41.94) | 8.21 (46.68) | 3.42 (11.31) | 5.14 (26.27) | 6.86 (47.06) |
| $W_4$ | 6.59 (43.15) | 7.86 (61.83) | 9.31 (63.27) | 3.91 (14.99) | 6.30 (39.62) | 8.59 (74.37) |
| $W_5$ | 5.55 (30.43) | 5.73 (32.84) | 6.78 (39.72) | 3.14 (9.56) | 4.66 (21.52) | 5.58 (31.65) |
| SE | 0.198 | 0.152 | 0.212 | 0.133 | 0.170 | 0.298 |
| CD (p=0.05) | 0.409 | 0.314 | 0.438 | 0.274 | 0.351 | 0.616 |
| **Land configuration × Integrated weed management** | | | | | | |
| S E | 0.329 | 0.268 | 0.397 | 0.210 | 0.279 | 0.482 |
| CD (p=0.05) | NS | NS | NS | NS | NS | NS |
| **Integrated weed management × Land configuration** | | | | | | |
| SE | 0.343 | 0.264 | 0.367 | 0.230 | 0.295 | 0.517 |
| CD (p=0.05) | NS | NS | NS | NS | NS | NS |

**$L_1$**- flatbed, **$L_2$**-ridges and furrows, **$L_3$**-broad bed furrow, **$W_1$**- weedy check, **$W_2$**- hand weeding twice at 20 and 40 days after sowing (DAS), $W_3$- pendimethalin at 0.75 kg active ingredient ha$^{-1}$ at 3 DAS and one hand weeding at 30 DAS, **$W_4$**- pendimethalin at 0.75 kg active ingredient ha$^{-1}$ at 3 DAS and imazethapyr at 60 g active ingredient ha$^{-1}$ at 20 DAS and **$W_5$**- pendimethalin at 0.75 kg active ingredient ha$^{-1}$ at 3 DAS + power weeding at 30 DAS + quizalofop ethyl at 50 g active ingredient ha$^{-1}$.

**Table 2.** Effect of land configuration and weed management practices on weed control efficiency (%) and weed control index (%) in pigeon pea during summer, 2024.

| Treat-ments | Weed control efficiency (%) | | Weed control index (%) | |
|---|---|---|---|---|
| | 40 DAS | 60 DAS | 40 DAS | 60 DAS |
| $L_1W_1$ | - | - | - | - |
| $L_1W_2$ | 48.63 | 44.73 | 38.89 | 50.32 |
| $L_1W_3$ | 57.45 | 47.35 | 61.77 | 64.75 |
| $L_1W_4$ | 42.56 | 33.61 | 46.13 | 37.41 |
| $L_1W_5$ | 69.11 | 56.69 | 69.49 | 70.01 |
| $L_2W_1$ | - | - | - | - |
| $L_2W_2$ | 61.81 | 61.42 | 49.98 | 74.86 |
| $L_2W_3$ | 68.61 | 61.69 | 65.35 | 64.51 |
| $L_2W_4$ | 53.65 | 47.07 | 50.90 | 48.94 |
| $L_2W_5$ | 72.80 | 65.79 | 69.77 | 78.95 |
| $L_3W_1$ | - | - | - | - |
| $L_3W_2$ | 63.27 | 60.00 | 52.03 | 71.66 |
| $L_3W_3$ | 72.50 | 67.30 | 69.75 | 64.93 |
| $L_3W_4$ | 53.47 | 50.70 | 45.49 | 47.46 |
| $L_3W_5$ | 79.78 | 72.06 | 76.19 | 81.28 |

**$L_1$**- flatbed, **$L_2$**-ridges and furrows, **$L_3$**-broad bed furrow, **$W_1$**- weedy check, **$W_2$**-hand weeding twice at 20 and 40 days after sowing (DAS), **$W_3$**-pendimethalin at 0.75 kg active ingredient ha$^{-1}$ at 3 DAS and one hand weeding at 30 DAS, **$W_4$**- pendimethalin at 0.75 kg active ingredient ha$^{-1}$ at 3 DAS and imazethapyr at 60 g active ingredient ha$^{-1}$ at 20 DAS and **$W_5$**- pendimethalin at 0.75 kg active ingredient ha$^{-1}$ at 3 DAS + power weeding at 30 DAS + quizalofop ethyl at 50 g active ingredient ha$^{-1}$.

(111.96 cm).

Among the weed management practices, the IWM approach ($W_5$) produced the highest plant height (124.25 cm), which was statistically on par with $W_3$ (pendimethalin at 0.75 kg active ingredient ha$^{-1}$ at 3 DAS and one-hand weeding at 30 DAS). In contrast, the weedy check recorded the lowest plant height (111.62 cm).

## Effect of number of leaves per plant

Significant differences were observed in the number of leaves per plant across different land configurations and weed management practices (Table 3). The BBF ($L_3$) method resulted in a significantly higher number of leaves per plant (123.35) compared to the flatbed method ($L_1$), which recorded the lowest number of leaves per plant (96.02). Among the weed management practices, the IWM ($W_5$) treatment produced the highest number of leaves per plant (118.80), while the weedy check ($W_1$) treatment recorded the lowest number of leaves, which was statistically comparable to $W_4$ (pendimethalin at 0.75 kg active ingredient ha$^{-1}$ at 3 DAS and imazethapyr at 60 g active ingredient ha$^{-1}$ at 20 DAS).

## Effect of number of branches per plant

The data on branches per plant (Table 3) showed significant differences among the treatments. The highest number of branches per plant (9.52) was found in crops sown using the BBF method, which was significantly supe-

**Table 3**. Effect of land configuration and weed management practices on growth parameters of pigeon pea during summer, 2024.

| Treatment | Plant height (cm) | Number of leaves plant$^{-1}$ | Number of branches plant$^{-1}$ | Root length (cm) | Dry matter production (Kg ha$^{-1}$) |
|---|---|---|---|---|---|
| | At harvest | At harvest | At harvest | At harvest | At harvest |
| **Land configuration** | | | | | |
| $L_1$ | 111.96 | 96.02 | 7.7 | 56.60 | 3488 |
| $L_2$ | 118.50 | 108.89 | 8.7 | 63.31 | 3845 |
| $L_3$ | 122.93 | 123.35 | 9.5 | 71.71 | 4115 |
| SE | 1.903 | 2.49 | 0.23 | 1.67 | 52.6 |
| CD (p=0.05) | 5.284 | 6.97 | 0.64 | 4.57 | 146.0 |
| **Integrated weed management** | | | | | |
| $W_1$ | 111.62 | 101.81 | 8.1 | 59.41 | 3455 |
| $W_2$ | 118.36 | 108.06 | 8.3 | 64.47 | 3596 |
| $W_3$ | 121.54 | 112.75 | 9.0 | 65.61 | 4161 |
| $W_4$ | 117.35 | 105.69 | 8.6 | 63.10 | 3472 |
| $W_5$ | 124.25 | 118.80 | 9.2 | 66.79 | 4396 |
| SE | 3.359 | 3.80 | 0.29 | 1.99 | 112.7 |
| CD (p=0.05) | 6.932 | 7.85 | 0.61 | 4.10 | 232.6 |
| **Land configuration × Integrated weed management** | | | | | |
| SE | 5.47 | 6.39 | 0.51 | 3.50 | 182.4 |
| CD (p=0.05) | NS | NS | NS | NS | 387.2 |
| **Integrated weed management × Land configuration** | | | | | |
| SE | 5.82 | 6.585 | 0.51 | 3.44 | 195.2 |
| CD (p=0.05) | NS | NS | NS | NS | 402.9 |

**$L_1$** - flatbed, **$L_2$** -ridges and furrows, **$L_3$** -broad bed furrow, **$W_1$**- weedy check, **$W_2$**-hand weeding twice at 20 and 40 days after sowing (DAS), **$W_3$**-pendimethalin at 0.75 kg active ingredient ha$^{-1}$ at 3 DAS and one hand weeding at 30 DAS, **$W_4$**- pendimethalin at 0.75 kg active ingredient ha$^{-1}$ at 3 DAS and imazethapyr at 60 g active ingredient ha$^{-1}$ at 20 DAS and **$W_5$**- pendimethalin at 0.75 kg active ingredient ha$^{-1}$ at 3 DAS + power weeding at 30 DAS + quizalofop ethyl at 50 g active ingredient ha$^{-1}$.

rior to the flat bed method (7.72). Among the weed management practices, the IWM ($W_5$) treatment was statistically on par with $W_3$ (pendimethalin at 0.75 kg active ingredient ha$^{-1}$ at 3 DAS and one-hand weeding at 30 DAS), with both resulting in a higher number of branches per plant (9.2 and 9.0). In contrast, the lowest number of branches were observed in the weedy check $W_1$ treatment (8.1) and the $W_2$ (hand weeding twice at 20 and 40 DAS) (8.3) treatments.

### Effect on root length

Table 3 shows a significant difference in the main plot and subplot. The BBF ($L_3$) method recorded significantly greater root length than the ($L_1$) flatbed method, which can be attributed to enhanced crop growth. Among the weed management practices, the IWM ($W_5$) treatment resulted in the longest root length, which was statistically comparable to $W_3$ (pendimethalin at 0.75 kg active ingredient ha$^{-1}$ at 3 DAS and one-hand weeding at 30 DAS) and $W_2$ (hand weeding twice at 20 and 40 DAS). In contrast, the weedy check treatment recorded the shortest root length.

### Effect on dry matter production

Table 3 demonstrates significant differences in the main plot, subplot and interaction effect. The BBF method achieved higher dry matter production (DMP) (4114.5 kg ha$^{-1}$), while the flatbed method recorded lower DMP (3487.81 kg ha$^{-1}$). Among the weed management practices, IWM ($W_5$) resulted in the highest DMP, which was statistically on par with $W_3$ (pendimethalin at 0.75 kg active ingredient ha$^{-1}$ at 3 DAS and one-hand weeding at 30 DAS). In contrast, the weedy check ($W_1$) showed lower DMP, which was statistically similar to $W_2$ (hand weeding twice at 20 and 40 DAS) and W3 (pendimethalin at 0.75 kg active ingredient ha$^{-1}$ at 3 DAS and one hand weeding at 30 DAS).

## *Effect of land configuration on yield and yield attributes*

### Effect on number of pods per plant

The data on the number of pods per plant in pigeon pea, as shown in Table 4, indicated significant differences among all treatments related to land configuration practices. The results showed that the BBF method recorded the highest number of pods per plant (70 pods plant$^{-1}$), which was significantly greater than the flatbed method (58 pods plant$^{-1}$). Regarding weed management, the IWM ($W_5$) treatment resulted in the highest number of pods per plant (68), while the weedy check treatment recorded the lowest (59 pods plant$^{-1}$).

### Effect on number of seeds per pods

Table 4 presents the effects of land configuration practices on the number of seeds per pod in pigeon pea. The BBF configuration resulted in the highest number of filled seeds per pod (4.34), which was statistically superior to the flatbed method (4.05 filled seeds pod$^{-1}$). Although weed management practices had significant effects, all treatments were statistically on par with one another.

### Effect on test weight

No significant differences were found among the different land configurations and weed management practices re-

**Table 4.** Effect of land configuration and weed management practices on yield and yield attributes of pigeon pea during summer, 2024.

| Treatment | No. of pods plant$^{-1}$ | No. of seeds pod$^{-1}$ | 100 seed weight (g) | Grain yield (kg ha$^{-1}$) | Stalk yield (kg ha$^{-1}$) | Harvest index (%) |
|---|---|---|---|---|---|---|
| **Land configuration** | | | | | | |
| $L_1$ | 58 | 4.0 | 8.1 | 962 | 2526 | 27.5 |
| $L_2$ | 64 | 4.2 | 8.3 | 1100 | 2745 | 28.5 |
| $L_3$ | 70 | 4.3 | 8.4 | 1216 | 2898 | 29.4 |
| SE | 1.52 | 0.10 | 0.2 | 15.028 | 37.63 | 0.44 |
| CD (p=0.05) | 4.22 | 0.28 | NS | 41.72 | 104.42 | 1.21 |
| **Integrated weed management** | | | | | | |
| $W_1$ | 59 | 4.1 | 7.9 | 901 | 2481 | 26.1 |
| $W_2$ | 64 | 4.2 | 8.3 | 1033 | 2563 | 28.7 |
| $W_3$ | 67 | 4.3 | 8.4 | 1224 | 2937 | 29.3 |
| $W_4$ | 62 | 4.2 | 8.2 | 991 | 2553 | 28.5 |
| $W_5$ | 68 | 4.3 | 8.5 | 1314 | 3081 | 29.8 |
| SE | 1.96 | 0.13 | 0.30 | 32.472 | 80.48 | 0.82 |
| CD (p=0.05) | 4.04 | 0.26 | NS | 67.023 | 166.11 | 1.69 |
| **Land configuration × Integrated weed management** | | | | | | |
| SE | 3.39 | 0.22 | 0.50 | 52.503 | 130.23 | 1.42 |
| CD (p=0.05) | NS | NS | NS | 111.428 | NS | NS |
| **Integrated weed management × Land configuration** | | | | | | |
| SE | 3.39 | 0.22 | 0.52 | 56.244 | 139.39 | 1.34 |
| CD (p=0.05) | NS | NS | NS | 116.087 | NS | NS |

$\mathbf{L_1}$ - flatbed, $\mathbf{L_2}$ -ridges and furrows, $\mathbf{L_3}$ -broad bed furrow, $\mathbf{W_1}$ - weedy check, $\mathbf{W_2}$ -hand weeding twice at 20 and 40 days after sowing (DAS), $\mathbf{W_3}$ -pendimethalin at 0.75 kg active ingredient ha$^{-1}$ at 3 DAS and one hand weeding at 30 DAS, $\mathbf{W_4}$ - pendimethalin at 0.75 kg active ingredient ha$^{-1}$ at 3 DAS and imazethapyr at 60 g active ingredient ha$^{-1}$ at 20 DAS and $\mathbf{W_5}$- pendimethalin at 0.75 kg active ingredient ha$^{-1}$ at 3 DAS + power weeding at 30 DAS + quizalofop ethyl at 50 g active ingredient ha$^{-1}$.

garding seed weight. However, the BBF method achieved the highest seed weight at 8.38 g, while the flatbed method resulted in the lowest seed weight at 8.13 g. Among the weed management practices, the IWM ($W_5$) treatment resulted in the highest seed weight at 8.5 g, while the lowest weedy check recorded the lowest seed weight at 7.92 g.

### Effect on seed yield and stalk yield

The study presented in Table 4 examines the impact of various land configurations and weed management practices on the seed and stalk yields of pigeon pea. The results indicated significant differences in seed yield based on the main plot, subplot, and their interaction. However, no interaction effect was observed for stalk yield. The BBF method produced the highest seed yield at 1424.19 kg ha$^{-1}$, which was significantly higher than the lowest yield observed in the flatbed method (1064.95 kg ha$^{-1}$). Among the weed management practices, the IWM strategy ($W_5$) resulted in the highest grain yield, which was statistically comparable to the $W_3$ treatment (pendimethalin at 0.75 kg active ingredient ha$^{-1}$ at 3 DAS followed by one hand weeding at 30 DAS). The weedy check treatment recorded the lowest grain yield at 1078.38 kg ha$^{-1}$. In terms of interaction effects, the combination of BBF with IWM ($W_5$) resulted in the highest grain yield, which was statistically on par with BBF with W3 treatment (pendimethalin at 0.75 kg active ingredient ha$^{-1}$ at 3 DAS and one hand-weeding at 30 DAS).

In terms of stalk yield, the BBF method produced the highest yield at 3509.64 kg ha$^{-1}$, while the flatbed method recorded the lowest yield at 3146.32 kg ha$^{-1}$. Among the weed management practices, IWM ($W_5$) resulted in the highest stalk yield at 3538.66 kg ha$^{-1}$, which was statistically comparable to the $W_3$ treatment, yielding 3382.97 kg ha$^{-1}$. In contrast, the weedy check treatment recorded the lowest stalk yield at 3142.54 kg ha$^{-1}$.

### Harvest index

The harvest index, which reflects the ratio of economic yield to total biological yield, did not show significant differences among the treatments (Table 4). No significant differences were observed among the main plot, subplot, or their interaction effects for different land configurations and weed management practices. The highest harvest index was recorded in the BBF treatment (29.42%), which was similar to the ridges and furrows treatment (28.50%), while the lowest was observed in the flatbed treatment (27.52%). All weed management strategies, except the weedy check (26.07%), showed comparable results.

## Discussion

### *Effect on weed density and weed dry weight*

The results indicate that land configuration and weed management practices significantly impact WD and dry weight (Fig. 1 and 2). The superior performance of BBF ($L_3$) can be articulated by the more vigorous growth of the crop plants, which suppresses weeds due to reduced space for weed growth and enhanced nutrient and moisture availability for the crop compared to other land configurations (23). Similar findings were observed in urd bean with BBF plant-

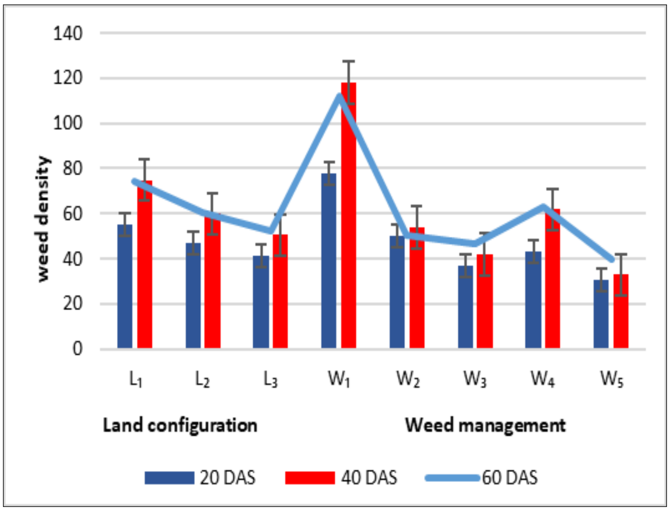


**Fig. 1.** Effect of land configuration and weed management practices on weed density at 20, 40, and 60 DAS (No. m$^{-2}$).

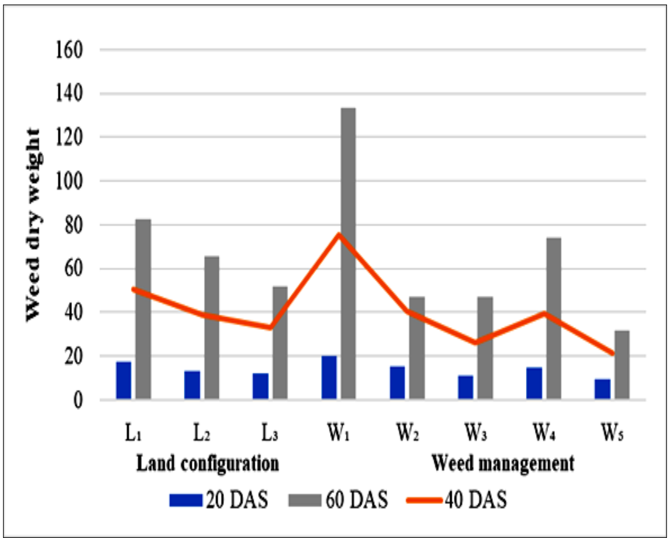


**Fig. 2.** Effect of land configuration and weed management practices on weed dry weight at 20, 40, and 60 DAS (g m$^{-2}$).

ing decreasing the WD and weed dry matter (25). Among weed management from experimental results, IWM ($W_5$) treatment achieved the most significant reduction in WDW at every growth stage. The power weeder effectively controlled weeds due to this WDW was reduced in IWM ($W_5$). Similar results were obtained in the weed management of pigeon pea and black gram (23, 26).

### *Weed control index and weed control efficiency*

Significant variations in WCE and WCI were observed (Fig. 3 and 4). In the experimental field, superior weed management indices were recorded in the BBF ($L_3$) with the IWM, ($W_5$) treatment, which was attributed to reduced weed infestation. A study also reported that using a power weeder at 20 and 40 DAS, followed by hand weeding, resulted in higher WCE (26). Moreover, it was found that higher WCE was achieved with an integrated approach of pendimethalin at 1000 g ha$^{-1}$ as a pre-emergence treatment, followed by inter-cultivation and hand weeding at 30 and 60 DAS (27). These results align with findings from previous studies on pigeon pea (23, 28, 29).

### *Effect on growth parameters*

Studies have shown that structured land configurations, such as BBF and ridges and furrows, contribute to increased plant height, a greater number of leaves, and higher DMP. These findings align with the present study, emphasizing the importance of adopting suitable land configuration practices to optimize vegetative growth and biomass accumulation in pigeon peas (22, 23, 30). The enhanced plant height observed with BBF planting highlights the effectiveness of this land configuration in promoting more vigorous crop growth (31, 32).

Among the various weed management practices, the IWM treatment resulted in greater plant height and a higher number of branches, further underscoring the critical role of effective weed control in enhancing crop growth and development (22, 23).

### *Effect on yield and yield attributes*

The effect of land configuration and weed management significantly influenced grain yield, given in Fig. 5. The increase in the number of pods per plant under the BBF system can be attributed to the improved crop growth, which likely led to more efficient nutrient translocation to reproductive parts, thereby enhancing yield-attributing

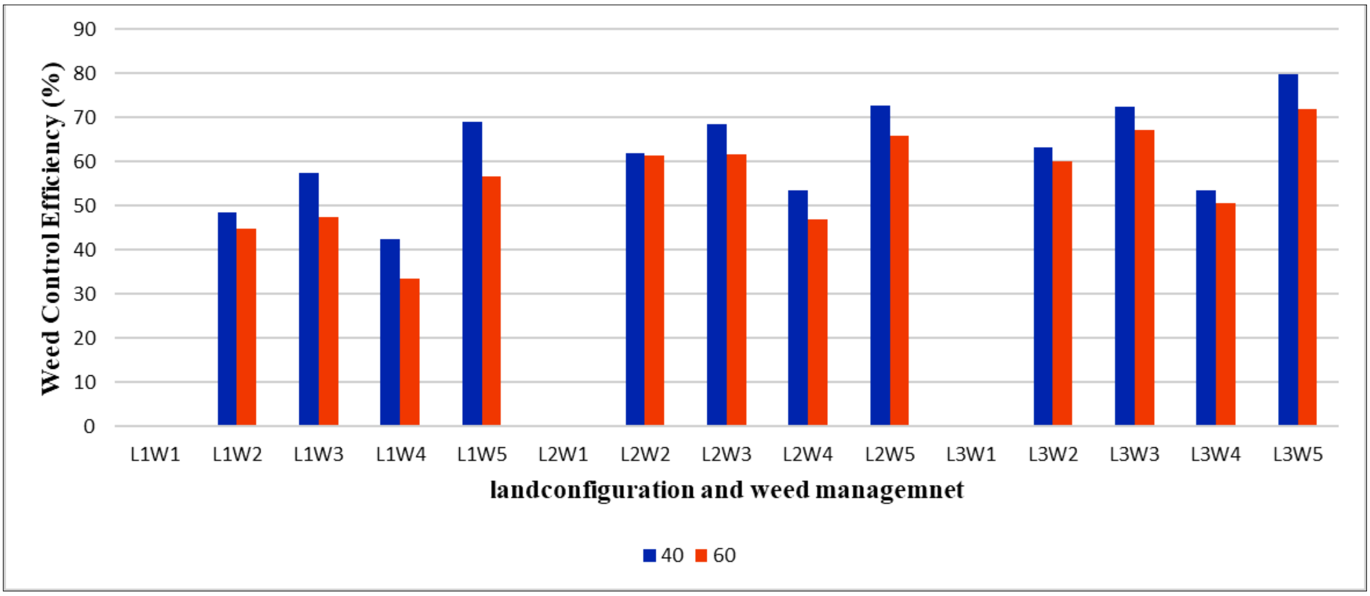


**Fig. 3.** Effect of land configuration and weed management practices on weed control efficiency at 40 and 60 DAS (%).

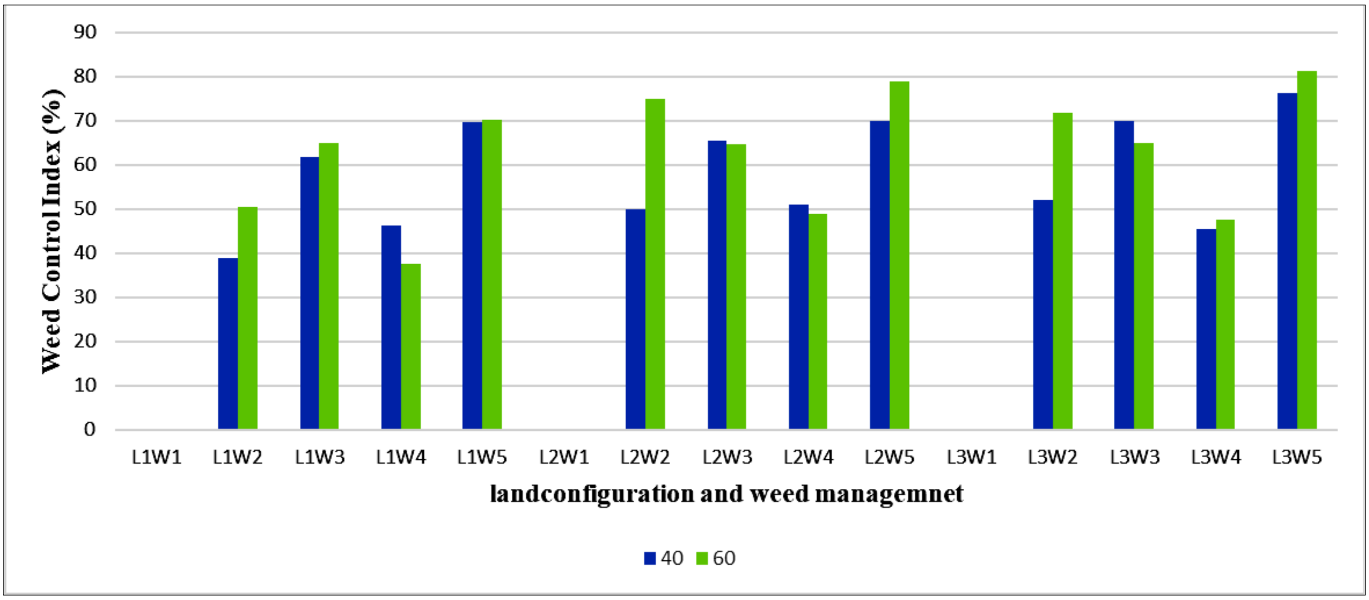


**Fig. 4.** Effect of land configuration and weed management practices on weed control index at 40 and 60 DAS (%).

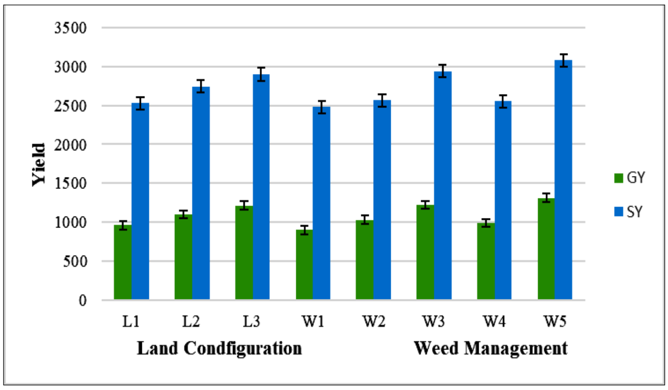


**Fig. 5.** Effect of land configuration and weed management practices on grain yield and stalk yield (Kg ha$^{-1}$).

characteristics. These findings match another report stating that raised bed planting significantly increased yield attributes, including the number of pods per plant and seed yield, compared to flatbed planting (23). This result also aligns with the outcomes of several other investigations (21, 22, 31). An investigation reported that the BBF method improves soil structure by promoting aeration and reducing compaction, enhancing water infiltration and retention (30). Similarly, it was also observed that the BBF system improved yield attributes, including the number of pods and seeds per plant in pigeon pea, compared to flatbed planting (32).

Among weed management practices, effective weed control during critical growth stages resulted in improved nutrient uptake, enhanced source-to-sink translocation, increased dry matter accumulation, and superior yield attributes (26, 27). Integrated Weed Management proved to be more cost-effective than other treatments, emerging as a key factor for achieving higher economic returns. In contrast, the weedy check recorded the lowest net returns and benefit-cost ratio (BCR), primarily due to significantly reduced seed and stalk yields caused by unchecked weed infestation (27, 33, 34).

## Correlation analysis

The correlation matrix presented in Fig. 6 demonstrates a strong positive correlation between WD and WDW at 20, 40, and 60 DAS, indicating that higher early weed densities are directly associated with increased weed biomass. Conversely, WCE and WCI exhibit a strong negative correlation with weed density and dry weight. This suggests that an effective IWM strategy reduces weed density and biomass significantly, reflecting its success in minimizing weed competition over time.

Pre-emergence herbicides, such as pendimethalin, effectively controlled early-stage broadleaf weeds. Additionally, power weeding and post-emergence herbicides

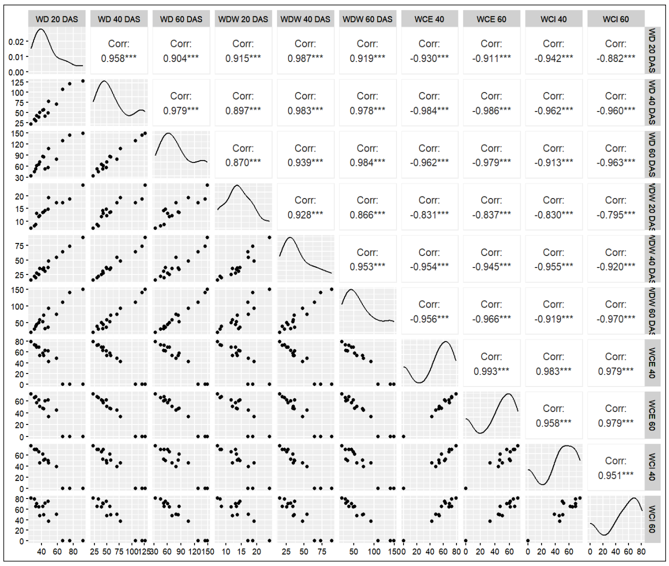


**Fig. 6**. Correlation analysis on weed management practices.

like quizalofop ethyl further managed the remaining weeds at various growth stages. This integrated approach effectively curtailed weed growth during critical stages, leading to a marked decrease in weed density and biomass.

The correlation matrix in Fig. 7 highlights significant relationships among key agronomic traits influencing pigeon pea productivity. Grain yield exhibits strong correlations with plant height (0.985), seed count (0.993), and pod number (0.967), indicating that taller plants with a greater number of seeds and pods achieve higher yields. Similarly,

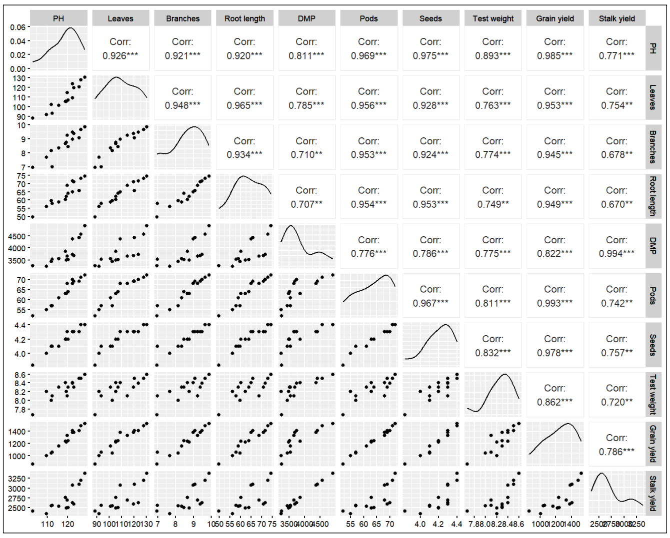


**Fig. 7.** Correlation analysis on plant parameters.

DMP is strongly correlated with plant height (0.811) and pod number (0.776), suggesting their contribution to biomass accumulation. Stalk yield is closely linked to DMP (0.994), underscoring the role of dry matter in boosting stalk production. Test weight shows a moderate correlation with grain yield (0.862), emphasizing the importance of seed weight in overall yield.

These correlations underscore the pivotal role of plant height, seed count, pod number, and dry matter in determining grain and stalk yields, providing valuable insights for optimizing pigeon pea production.

## Conclusion

The BBF ($L_3$) method of pigeon pea sowing emerged as the most productive and profitable land configuration, significantly outperforming the flatbed and ridges-and-furrows systems in reducing weed density and dry weight. Among the weed management practices, the integrated approach combines the application of pendimethalin at 0.75 kg active ingredient $ha^{-1}$ at 3 DAS, followed by power weeding at 30 DAS and a post-emergence application of quizalofop ethyl at 50 g active ingredient $ha^{-1}$ ($W_5$) proved to be the most effective. This strategy consistently minimized weed infestation, resulting in the highest WCE and WCI, which, in turn, enhanced crop growth parameters and yield attributes. The pre-emergence application of pendimethalin effectively targeted broadleaf weeds during the early stages of crop growth. Midway through the growing season, power weeding controlled a wide range of weeds, including grasses and sedges. In the later stages, the post-emergence herbicide quizalofop ethyl was specifically applied to manage grassy weeds. This comprehensive, stage-specific weed management strategy ensured effective control throughout the crop cycle, significantly reducing competition and fostering better crop growth and yield. Adopting the BBF land configuration and the IWM strategy ($W_5$) can substantially enhance pigeon pea productivity. This approach boosts yield and promotes sustainable farming practices by minimizing weed pressure and optimizing resource use efficiency. The higher yields achieved through this method encourage farmers to adopt IWM strategies. Policymakers can support the broader adoption of these practices through training programs and subsidies, thereby advancing sustainable agricultural development and strengthening food security.

## Authors' contributions

AB performed the field work, collection of data and contributed to data analysis and interpretation and also drafted the manuscript. VN supervised the research, provided resources, technical support, assisted the manuscript outline and edited the manuscript. SR, NS and AK were involved in the manuscript correction and supervised the process. All the authors read and approved the final manuscript.

## Compliance with ethical standards

**Conflict of interest**: Authors do not have any conflict of interests to declare.

**Ethical issues**: None.

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