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# IMPACT OF PLANT DENSITY ON PRODUCTIVITY OF SOME PANICUM CULTIVARS AT DESERT SOILS

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**ABSTRACT:** In light of increasing water scarcity and the urgent need for sustainable forage production in arid regions, two field experiments were conducted at the Agricultural Experimental Station of the Desert Research Center (D.R.C.), El-Kharga Oasis, New Valley Governorate, Egypt (27°47.7′N, 30°24.7′E) during the 2021 and 2022 seasons. The study aimed to evaluate the impact of planting density on the growth and productivity of panicum cultivars under the arid conditions of the New Valley. Significant differences were observed among cultivars in both seasons. The cultivar Arowana consistently outperformed the others across all measured traits, followed by Mombasa. Plant density had a significant effect on all parameters. The spacing of 60 cm between rows and 50 cm between plants proved most effective, particularly in 2021, when Arowana produced the tallest plants 134.2 cm, the highest number of tillers per plant 22.03, the greatest net photosynthetic rate 21.81 µmol $CO_2$ $m^{-2}$ $s^{-1}$, and the maximum green and dry forage yields averaging 3,271 and 1,498 kg $fed^{-1}$ per cut, respectively. Moreover, the Arowana exhibited the highest water use efficiency, at 2.97 kg fresh weight per $m^3$ of water. In contrast, the widest spacing, 80 × 30 cm, gave the lowest values for most traits, except for leaf fiber content, which showed the opposite trend. Overall, optimizing planting density, particularly at 60 × 50 cm, markedly enhances panicum growth, yield, and water use efficiency under desert conditions, supporting sustainable livestock feed production and improving agricultural resilience in arid regions.

**Key words:** Panicum, cultivars, plant density, photosynthetic rate, forage yield, and arid areas.

## INTRODUCTION

Meeting the increasing demand for food and livestock feed remains a significant global challenge, particularly in arid and semi-arid regions, where climate change, land degradation, and water scarcity significantly constrain agricultural productivity (Mohammed *et al.*, 2022). As highlighted by Li *et al.* (2025), the sustainable restoration of degraded lands through the cultivation of forage crops, legumes, and perennial grasses represents an essential strategy to enhance agricultural resilience and strengthen food security. Among these crops, Panicum spp. has attracted considerable attention due to its adaptability to harsh environmental conditions, including high temperatures, drought, salinity, and low soil fertility (Hare *et al.*, 2014; Silveira et al., 2010). Its high biomass yield, nutritional value, and efficient water use make it a promising forage crop for arid and desert ecosystems.

Optimizing cultivar selection and planting density, as emphasized by Casal *et al.* (2017) and Kaneko *et al.* (2019), is crucial to maximizing growth, yield, and forage quality under stressful environmental conditions. In Egypt, particularly in newly reclaimed and desert areas like the New Valley Governorate, the scarcity of green fodder poses a major constraint due to the predominance of sandy soils, limited rainfall, and low nutrient availability (Khalifa & Metwally 2020). Similarly, Ahmed and El-Mahdy (2017) and Abd El-Aziz *et al.* (2022) reported that introducing drought-tolerant and fast-growing species, such as panicum, offers a sustainable solution to mitigate the growing feed deficit in such regions. According to Al-Shareef and Al-Dakheel (2021) and Kebede *et al.* (2023), these perennial grasses develop deep root systems and produce substantial biomass with minimal irrigation, making them ideal for climate-smart forage production systems.

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Globally, feed shortages have emerged as one of the most critical constraints to livestock production (Smith *et al.*, 2021). In Egypt, this problem is particularly acute, as the green fodder deficit exceeds 70% during the summer months, which drastically reduces livestock productivity and resilience (FAO, 2022; El-Sayed & Abdalla, 2020). To bridge this feed gap, expanding panicum cultivation through both horizontal expansion and intensified management practices (vertical productivity) has become an urgent necessity under desert conditions. As reported by Aliscioni *et al.* (2003), panicum is characterized by its high protein content (16–22%), long persistence (up to ten years), and remarkable tolerance to salinity levels approaching 10,000 ppm. Fernandes *et al.* (2014) and Muir *et al.* (2001) found that cultivars such as *Tanzania* and *Mombasa* exhibit superior yield performance, strong regrowth ability, and high palatability. Nevertheless, planting density plays a crucial role in determining productivity, influencing light interception, tiller development, and canopy structure (Souza 2019; Humphreys 2020). Therefore, as emphasized by Dele *et al.* (2013) and Michael *et al.* (2021), identifying the most suitable combination of cultivar and spacing is fundamental to maximizing forage yield, improving fodder quality, and enhancing resource-use efficiency in arid environments.

Based on these considerations, the present study was conducted to evaluate the performance of three Panicum cultivars under different planting densities in the hyper-arid conditions of the New Valley Governorate, Egypt, with the aim of identifying optimal strategies for maximizing forage yield, improving quality, and enhancing water use efficiency under limited-water desert conditions.

## MATERIALS AND METHODS

### Experimental site description

Two field experiments were conducted at the Agricultural Experimental Station of the Desert Research Center (DRC), located in El-Kharga Oasis, New Valley Governorate, Egypt (latitude 27°47.7′ N, longitude 30°24.7′ E) during the 2021 and 2022 growing seasons. The site is characterized by a hyper-arid climate, high temperature fluctuations, low relative humidity, and the absence of rainfall throughout the growing period. The physicochemical properties of the soil were analyzed according to the procedures described by Jackson (1973), while the chemical characteristics of the irrigation water were analyzed following the methods outlined by Page *et al.* (1982). Both soil and water analyses were performed at the Central Laboratory of the Desert Research Center (DRC), Cairo, Egypt, and the results are presented in Tables 1 and 2.

**Table 1: Physical and chemical properties of the experimental soil.**

| Season | Particles (%) | | | Texture | EC (ppm) | pH | P (ppm) | Available ions (meq/L) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Sand | Silt | Clay | | | | | N | K | Ca | Mg | $CO_3^{=}$ | $HCO_3^-$ | $Cl^-$ | $SO_4^{--}$ |
| 2021 | 77.3 | 15.4 | 7.3 | sand | 951 | 8.2 | 0.54 | 0.67 | 1.35 | 1.10 | 0.89 | 4.32 | 7.15 | 104.6 | 0.82 |
| 2022 | 78.5 | 14.9 | 6.6 | | 936 | 8.1 | 0.65 | 0.84 | 1.44 | 1.23 | 0.78 | 4.13 | 6.87 | 95.9 | 0.71 |

**Table 2: Analysis of irrigation water.**

| Season | pH | E.C. dS/m | S.A.R | Soluble cations (meq/L) | | | | Soluble anions (meq/L) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | $Ca^{++}$ | $Mg^{++}$ | $Na^+$ | $K^+$ | $CO_3^{=}$ | $HCO_3^-$ | $SO4^{=}$ | $Cl^-$ |
| 2021 | 7.84 | 1.17 | 6.86 | 13.68 | 2.74 | 4.82 | 0.41 | - | 7.43 | 4.75 | 9.47 |
| 2022 | 7.79 | 1.12 | 6.14 | 15.32 | 2.93 | 4.51 | 0.45 | - | 5.61 | 7.36 | 10.24 |

## Treatments and experimental design

The experiment comprised 12 treatments, resulting from the combination of two factors:

1. **Cultivars:** Three panicum cultivars, namely Mombasa, Tanzania, and Arowana, were initially germinated in foam trays within a greenhouse from March 1st to March 5th and maintained for a period of 45 days. After this pre-germination stage, the seedlings were transplanted into the field. The panicum cultivars used in this study were obtained from a major agricultural company specialized in importing and distributing forage crop seeds in Egypt.
2. **Planting densities:** Four planting densities were evaluated, defined by the combination of row spacing and intra-row plant spacing: (1) 80 × 30 cm, (2) 70 × 40 cm, (3) 60 × 50 cm, and (4) 50 × 60 cm.

The field experiment was arranged in a split-plot design with three replicates. Each experimental plot measured 3.5 m × 3 m (10.5 $m^2$). The main plots were assigned to the different cultivars, while the subplots were allocated to the various planting densities.

## Field management

The Panicum cultivars were transplanted in mid-May during both experimental seasons. Prior to planting, soil preparation included the incorporation of 10 $m^3$ of chicken manure per feddan, followed by a basal application of 100 kg calcium superphosphate (15.5% $P_2O_5$, equivalent to 15.5 kg $P_2O_5$ per feddan). After each cutting, a top-dressing of 50 kg ammonium sulfate (20.5% N, equivalent to 10.25 kg N), 10 kg potassium sulfate (48% $K_2O$, equivalent to 4.8 kg $K_2O$), and 50 kg superphosphate (15.5% $P_2O_5$, equivalent to 7.75 kg $P_2O_5$) per feddan was applied approximately five days later. The total fertilizer input during the growing season amounted to approximately 61.5 kg N, 62 kg $P_2O_5$, and 29 kg $K_2O$ per feddan. Irrigation was carried out using groundwater through a drip irrigation system, ensuring uniform water distribution across all plots. The average daily irrigation rate was approximately 12 $m^3$ of water per feddan, corresponding to an annual irrigation amount of about 4380 $m^3$ per feddan. All other standard agronomic practices were applied consistently to maintain optimal plant growth and forage productivity. The total number of cuttings obtained during the year was 8, with two cuttings occurring in the winter months (December, January and February) and five cuttings during the rest of the year, from March to the end of November.

## Sampling and assessments

From each experimental plot, five randomly selected guarded plants were evaluated to determine plant height (cm), number of tillers per plant, leaf area index (LAI), root length (cm), net photosynthetic rate (µmol $CO_2$ $m^{-2}$ $s^{-1}$), green fodder yield (kg/fed/cutting), dry fodder yield (kg/fed/cutting), leaf protein content (%) and leaf fiber content (g/kg) at harvest. The average green and dry fodder yield per cutting (kg/fed) was calculated by dividing the total yield of each cutting by the cultivated area. The mean yield per cutting was then obtained by averaging the data from eight consecutive cuttings per year under similar management practices. For each cutting, representative samples were collected to determine the above-mentioned parameters, and the overall mean was computed for analysis.

Root length (cm) of plants was determined in the field after the last cutting of each season (one year) by carefully excavating the soil around three representative clumps from each plot. The roots were gently separated and washed with water to remove adhering soil particles. The main root length was then measured from the crown to the tip using a graduated ruler. The Leaf Area Index (LAI) was estimated following the method described by Watson (1952). It was calculated as the ratio of the total leaf area of the plant to the area it occupies on the ground. The net photosynthetic rate (NPR) was measured on the fully expanded upper leaf, located third from the top, using a portable photosynthesis system (*LI-6400, LI-COR, Lincoln, NE, USA*). Measurements were taken on clear sunny days between 10:00 and 11:00 a.m. to minimize diurnal variation. The instrument was adjusted to maintain a photosynthetic photon flux density (PPFD) of approximately 1000 µmol $m^{-2} s^{-1}$, a reference $CO_2$ concentration of 400 µmol $mol^{-1}$, and a leaf temperature around 25 ± 2 °C under ambient relative humidity. Three readings per plot were recorded and averaged to represent the photosynthetic rate for each treatment. The protein content of leaves was determined using the modified micro-Kjeldahl technique as outlined in AOAC (2005). Additionally, the total nitrogen content in leaves was measured. The crude protein content percentage was determined by multiplying the total nitrogen percentage by 6.25, while the determination of fiber was carried out using the Official Methods of Analysis (AOAC 1990).

## Statistical methods

The data from each season were statistically analyzed using the analysis of variance procedures outlined by Gomez and Gomez in 1984, with the MSTAT-C software program (MSTATC, 1992). The means were compared using the least significant difference (LSD) test under a significance level of $p < 0.05$. Pearson's correlation coefficient and principal component analysis (PCA) were used to investigate the relationship between the characteristics examined across experimental variables. An analysis of variance (ANOVA), a Pearson's correlation coefficient plot, and principal component analysis (PCA) were performed using the computer software programs SPSS version 25 and OriginPro 2021 version 4.9.0.193.

# RESULTS AND DISCUSSION

## Effect of cultivars

Table 3 illustrates the effect of different Panicum cultivars on forage productivity under desert soil conditions in the New Valley during the 2021 and 2022 growing seasons. Significant differences were observed among all tested cultivars in both seasons. The results indicated that the cultivar Arowana consistently outperformed the other cultivars across all measured traits, followed by Mombasa, which showed intermediate performance.

**Table 3: Effect of some cultivars on the productivity of Panicum during the 2021 and 2022 growing seasons in desert areas under New Valley conditions.**

| **Char.** / **Cultivars** | **Plant height** cm | **Number of tillers per** plant | **Leaf area index** (LAI) | **Root length** cm | **NPR** µmol $CO_2$ $m^{-2}$ $s^{-1}$ | **Average Green fodder yield** kg/fed. /cutting | **Average Dry fodder yield** kg/fed. /cutting | **Leaves protein** % | **Leaves fiber** g $kg^{-1}$ | **WUE** kg $_{f.w.}$ $m^{-3}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| **2021 season** | | | | | | | | | | |
| **Mombasa** | 128.3 | 18.40 | 3.14 | 52.9 | 19.26 | 2974 | 1367 | 16.12 | 176.3 | 2.81 |
| **Tanzania** | 121.4 | 16.77 | 2.89 | 48.30 | 17.16 | 2843 | 1134 | 14.41 | 191.4 | 2.68 |
| **Arowana** | 133.0 | 21.54 | 3.63 | 55.1 | 22.10 | 3201 | 1458 | 17.36 | 162.1 | 3.01 |
| **LSD at 5%** | **2.10** | **1.21** | **0.22** | **1.70** | **0.94** | **76.0** | **65.0** | **0.77** | **6.70** | **0.11** |
| **2022 season** | | | | | | | | | | |
| **Mombasa** | 127.6 | 17.41 | 3.06 | 51.40 | 18.88 | 2954 | 1313 | 16.02 | 175.3 | 2.78 |
| **Tanzania** | 121.0 | 15.48 | 2.74 | 47.20 | 17.04 | 2794 | 1098 | 14.17 | 189.7 | 2.61 |
| **Arowana** | 132.2 | 20.87 | 3.48 | 53.90 | 21.79 | 3156 | 1407 | 17.04 | 160.8 | 2.97 |
| **LSD at 5%** | **2.30** | **1.04** | **0.28** | **1.90** | **0.81** | **87.0** | **59.0** | **0.84** | **8.20** | **0.15** |

**NPR:** Net photosynthetic rate, **WUE** kg $_{f.w.}$ $m^{-3}$**;** water use efficiency (kg fresh weight per $m^3$ of water)

In the first season, the cultivar Arowana exhibited superior performance across all measured growth and productivity parameters, achieving a plant height of 133.0 cm, 21.54 tillers per plant, a leaf area index (LAI) of 3.63, root length of 55.1 cm, and a net photosynthetic rate (NPR) of 22.10 µmol $CO_2$ $m^{-2}$ $s^{-1}$. Additionally, it produced the highest forage yields, with green fodder yield of 3201 kg/fed./cutting and dry fodder yield of 1458 kg/fed./cutting, accompanied by a leaf protein content of 17.36% and the lowest leaf fiber percentage of 16.21%. Moreover, Arowana recorded the highest water use efficiency (WUE), reaching 3.01 kg fresh weight $m^{-3}$ of water. The observed differences in productivity among cultivars may be attributed to variations in their morphological and physiological traits, including root system size and distribution, photosynthetic efficiency, leaf characteristics, chlorophyll content, and the degree of adaptation to environmental stresses that can limit plant growth and productivity. These findings are consistent with previous studies, which reported similar variations in growth and productivity among *Panicum* cultivars (Silveira *et al.*, 2010; Hare *et al.*, 2014; Carnevalli *et al.*, 2016; Santos *et al.*, 2019; Michael *et al.*, 2021; Mohammed & Ibraheem, 2022).

## Effect of planting densities: PD

In both growing seasons, planting density had a significant effect on multiple growth and productivity parameters of panicum, including plant height, number of tillers per plant, leaf area index (LAI), root length, net photosynthetic rate (NAR), green and dry fodder yield per cutting, leaf protein content, leaf fiber content, and WUE (Table 4). The highest values for most traits were achieved when plants were spaced 60 cm apart between rows and 50 cm apart within rows, except for leaf fiber content, which was highest under the 80 × 30 cm spacing in both seasons. Conversely, the lowest values for most traits were observed in plots planted at 80 × 30 cm, except for leaf fiber.

**Table 4: Effect of some plant densities on the productivity of Panicum during the 2021 and 2022 growing seasons in desert areas under New Valley conditions.**

| **Char.** / **PD** | **Plant height** cm | **Number of tillers per**plant | **Leaf area index** (LAI) | **Root length** cm | **NPR** µmol $CO_2$ $m^{-2}$ $s^{-1}$ | **Average Green fodder yield** kg/fed /cutting | **Average Dry fodder yield** kg/fed /cutting | **Leaves protein** % | **Leaves fiber** g $kg^{-1}$ | **WUE** kg f.w. $m^{-3}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| **2021 season** | | | | | | | | | | |
| **80 x 30 cm** | 124.3 | 15.32 | 2.61 | 41.1 | 17.75 | 2485 | 1109 | 14.30 | 193.6 | 2.34 |
| **70 x 40 cm** | 127.8 | 17.26 | 2.96 | 45.9 | 19.68 | 2763 | 1274 | 14.92 | 176.5 | 2.60 |
| **60 x 50 cm** | 135.4 | 22.51 | 3.75 | 57.8 | 21.72 | 3340 | 1537 | 16.85 | 159.0 | 3.14 |
| **50 x 60 cm** | 132.5 | 20.14 | 3.39 | 54.3 | 20.41 | 3105 | 1368 | 15.63 | 164.8 | 2.92 |
| **LSD at 5%** | **2.0** | **1.47** | **0.32** | **1.4** | **0.60** | **136** | **83** | **0.48** | **3.6** | **0.13** |
| **2022 season** | | | | | | | | | | |
| **80 x 30 cm** | 123.7 | 15.08 | 2.55 | 40.9 | 17.46 | 2474 | 1082 | 14.03 | 191.8 | 2.33 |
| **70 x 40 cm** | 127.1 | 16.73 | 2.83 | 45.4 | 19.06 | 2702 | 1253 | 14.70 | 175.7 | 2.54 |
| **60 x 50 cm** | 132.9 | 21.74 | 3.61 | 56.2 | 21.06 | 3311 | 1476 | 16.35 | 158.7 | 3.12 |
| **50 x 60 cm** | 130.5 | 19.86 | 3.22 | 53.5 | 19.86 | 3080 | 1325 | 15.11 | 163.2 | 2.90 |
| **LSD at 5%** | **1.8** | **1.34** | **0.24** | **1.7** | **0.73** | **154** | **66** | **0.37** | **4.1** | **0.12** |

**PD:** Plant densities (Distance between the rows x Distance between the plants), **NPR:** Net photosynthetic rate, **WUE:** water use efficiency (kg fresh weight per $m^3$ water).

Compared with the 80 × 30 cm control, the 60 × 50 cm treatment increased plant height by 8.93% and 7.44%, tillers per plant by 46.93% and 44.09%, LAI by 43.62% and 41.56%, root length by 40.63% and 37.41%, NAR by 22.33% and 20.62%, green fodder yield by 34.40% and

33.79%, dry fodder yield by 38.59% and 36.41%, leaf protein content by 17.83% and 16.54% and WUE by 34.18 and 33.91 in the first and second seasons, respectively. In contrast, leaf fiber content decreased by 21.76% and 20.86% in the first and second seasons, respectively, under the 60 × 50 cm spacing. These findings are in agreement with previous reports on Panicum and other forage grasses, which have highlighted the critical role of planting density in optimizing growth, yield, and quality parameters (Casal *et al.*, 2017; Kaneko *et al.*, 2019; Kay *et al.*, 2021).

## Effect of the interaction between cultivars and plant densities

The data presented in Tables 5a and 5b clearly indicate that all measured parameters of Panicum were significantly affected by the interaction between cultivars and plant densities during both growing seasons. The best performance was achieved by the Arowana cultivar, grown at a spacing of 60 cm between rows and 50 cm between plants, resulting in optimal values for most growth and yield attributes in both seasons. The superior performance of the Arowana cultivar at the 60 × 50 cm spacing could be attributed to a more uniform plant distribution, which enhanced light interception, air movement, and root development. This configuration likely reduced intra-specific competition for essential growth resources such as water, nutrients, and light. As a result, plants exhibited greater photosynthetic efficiency and produced higher yields of green and dry forage. Furthermore, the moderate plant density under this spacing might have helped to maintain adequate soil moisture levels and alleviate stress effects associated with the hyper-arid conditions of El-Kharga Oasis. These findings are consistent with those of Casal *et al.* (2017) & Souza (2019) & Kebede *et al.* (2023), who reported that appropriate plant density enhances canopy architecture, resource use efficiency, and overall productivity of forage grasses, especially under stress-prone environments. Similarly, Muir *et al.* (2001) & Fernandes *et al.* (2014) observed that panicum cultivars exhibit variable yield responses depending on plant population and environmental factors, highlighting the importance of optimizing spacing for sustainable forage production in arid regions.

**Table 5a: Effect of the interaction between cultivars and plant density on productivity of Panicum during the 2021 growing season at desert areas under New Valley conditions.**

| Cultivars x PD / Char. | | **Plant height** cm | **Number of tillers per** plant | **Leaf area index** (LAI) | **Root length** cm | **NPR μmol $CO_2$** $m^{-2}$ $s^{-1}$ | **Average Green fodder yield** kg/fed. /cutting | **Average Dry fodder yield** kg/fed. /cutting | **Leaves protein** % | **Leaves fiber** g $kg^{-1}$ | **WUE** kg f.w. $m^{-3}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **2021 season** | | | | | | | | | | | |
| Mombasa | 80x30 cm | 126.3 | 16.86 | 2.88 | 47.3 | 18.56 | 2730 | 1238 | 15.21 | 185.0 | 2.58 |
| | 70x40 cm | 128.1 | 17.83 | 3.05 | 49.4 | 19.47 | 2869 | 1321 | 15.52 | 176.4 | 2.71 |
| | 60x50 cm | 131.9 | 20.46 | 3.45 | 55.4 | 20.39 | 3157 | 1452 | 16.49 | 167.8 | 2.96 |
| | 50x60 cm | 130.4 | 19.27 | 3.27 | 53.6 | 19.84 | 3040 | 1368 | 15.88 | 170.6 | 2.87 |
| Tanzania | 80x30 cm | 122.9 | 16.05 | 2.75 | 45.0 | 17.51 | 2664 | 1122 | 14.36 | 192.5 | 2.51 |
| | 70x40 cm | 124.6 | 17.02 | 2.93 | 47.1 | 18.42 | 2803 | 1204 | 14.67 | 184.0 | 2.64 |
| | 60x50 cm | 126.6 | 18.61 | 3.17 | 51.8 | 18.58 | 3000 | 1293 | 15.45 | 176.6 | 2.91 |
| | 50x60 cm | 127.0 | 18.46 | 3.14 | 50.3 | 18.79 | 2974 | 1251 | 15.02 | 178.1 | 2.80 |
| Arowana | 80x30 cm | 128.7 | 18.43 | 3.12 | 48.4 | 19.98 | 2843 | 1284 | 15.83 | 177.9 | 2.68 |
| | 70x40 cm | 130.4 | 19.40 | 3.30 | 50.5 | 20.89 | 2982 | 1366 | 16.14 | 169.3 | 2.81 |
| | 60x50 cm | 134.2 | 22.03 | 3.69 | 56.5 | 21.81 | 3271 | 1498 | 17.11 | 160.7 | 2.97 |
| | 50x60 cm | 132.8 | 20.84 | 3.51 | 54.7 | 21.26 | 3153 | 1413 | 16.50 | 163.5 | 2.05 |
| **LSD at 5%** | | **1.3** | **0.79** | **0.11** | **1.4** | **0.14** | **23** | **19** | **0.25** | **1.2** | **0.05** |

PD: Plant densities (Distance between the rows x Distance between the plants), NPR: Net photosynthetic rate, **WUE** kg f.w. $m^{-3}$**:** water use efficiency (kg fresh weight per $m^3$ water).

**Table 5b: Effect of the interaction between cultivars and plant density on productivity of Panicum during the 2022 growing season at desert areas under New Valley conditions.**

| Char. / Cultivars x PD | | Plant height cm | Number of tillers per plant | Leaf area index (LAI) | Root length cm | NPR µmol $CO_2$ $m^{-2}$ $s^{-1}$ | Average Green fodder yield kg/fed /cutting | Average Dry fodder yield kg/fed /cutting | Leaves protein % | Leaves fiber g $kg^{-1}$ | WUE kg f.w. $m^{-3}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **2022 season** | | | | | | | | | | | |
| Mombasa | 80 x 30 cm | 125.7 | 70.56 | 2.78 | 46.1 | 18.12 | 2714 | 1198 | 15.03 | 184.1 | 2.56 |
| | 70 x 40 cm | 127.4 | 72.26 | 2.95 | 48.4 | 18.97 | 2828 | 1283 | 15.36 | 175.5 | 2.66 |
| | 60 x 50 cm | 130.3 | 75.16 | 3.34 | 54.0 | 20.03 | 3133 | 1395 | 16.19 | 167.1 | 2.93 |
| | 50 x 60 cm | 129.1 | 73.96 | 3.14 | 52.5 | 19.37 | 3017 | 1319 | 15.57 | 169.3 | 2.84 |
| Tanzania | 80 x 30 cm | 122.4 | 69.59 | 2.62 | 44.0 | 17.20 | 2634 | 1090 | 14.10 | 191.3 | 2.47 |
| | 70 x 40 cm | 124.1 | 71.29 | 2.79 | 46.3 | 18.05 | 2748 | 1176 | 14.44 | 182.7 | 2.58 |
| | 60 x 50 cm | 125.6 | 45.32 | 3.04 | 50.6 | 18.53 | 2963 | 1246 | 15.18 | 176.4 | 2.87 |
| | 50 x 60 cm | 125.8 | 72.99 | 2.98 | 49.1 | 18.35 | 2937 | 1212 | 14.64 | 178.5 | 2.76 |
| Arowana | 80 x 30 cm | 128.0 | 72.29 | 2.99 | 42.3 | 19.58 | 2815 | 1245 | 15.54 | 176.8 | 2.65 |
| | 70 x 40 cm | 129.7 | 73.99 | 3.16 | 44.7 | 20.43 | 2929 | 1330 | 15.87 | 168.3 | 2.76 |
| | 60 x 50 cm | 132.6 | 76.89 | 3.55 | 50.3 | 21.48 | 3234 | 1442 | 16.70 | 159.8 | 2.94 |
| | 50 x 60 cm | 131.4 | 75.69 | 3.35 | 48.7 | 20.83 | 3118 | 1366 | 16.08 | 162.0 | 2.03 |
| **LSD at 5%** | | **1.1** | **0.58** | **0.10** | **1.1** | **0.12** | **24** | **28** | **0.16** | **1.3** | **0.04** |

PD: Plant densities, 80 x 30 cm, etc.: Distance between the rows x Distance between the plants, NPR: Net photosynthetic rate, **WUE** kg f.w. $m^{-3}$**:** water use efficiency (kg fresh weight per $m^3$ water).

## Pearson's correlation coefficient

Investigating the primary impacts of three Panicum cultivars and plant densities in heat-stress hyper-arid environments without rainwater precipitation. A Pearson's correlation analysis was conducted to examine the association between crop yield and other observed characteristics. As shown in Figure 1a and b, the number of positive correlations among the examined tparameters was greater in the 2021 season than in the 2022 season. The variables PH, NT/plant, LAI, RL, NPR, GFY, DFY, LP, and WUE exhibited statistically significant relationships in the first season of 2021 ($P<0.01$). The present study found that LF had strong negative associations with all the factors investigated, including pH, NT/plant, LAI, RLNPR, GFY, DFY, % LP, and WUE ($P<0.01$) (Figure 1a). A Pearson's correlation analysis was conducted in the second season of 2022 to examine the relationship between crop yield and other traits under investigation. The total number of positive correlations among the examined tparameters was greater in the 2021 season compared to the 2022 season (Fig. 1a, b). The variables PH, LAI, NPR, GFY, DFY, LP and WUE exhibited a statistically significant link in the first season of 2021 ($P<0.01$), In this regard, LF exhibited strong negative relationships with majority of the measures investigated, including PH, LAI, NPR, GFY, DFY and % LP ($P<0.01$) (Figure 1b).

Water use efficiency (WUE) exhibited a strong positive correlation with yield-related traits, underscoring its crucial role under heat-stressed arid conditions.

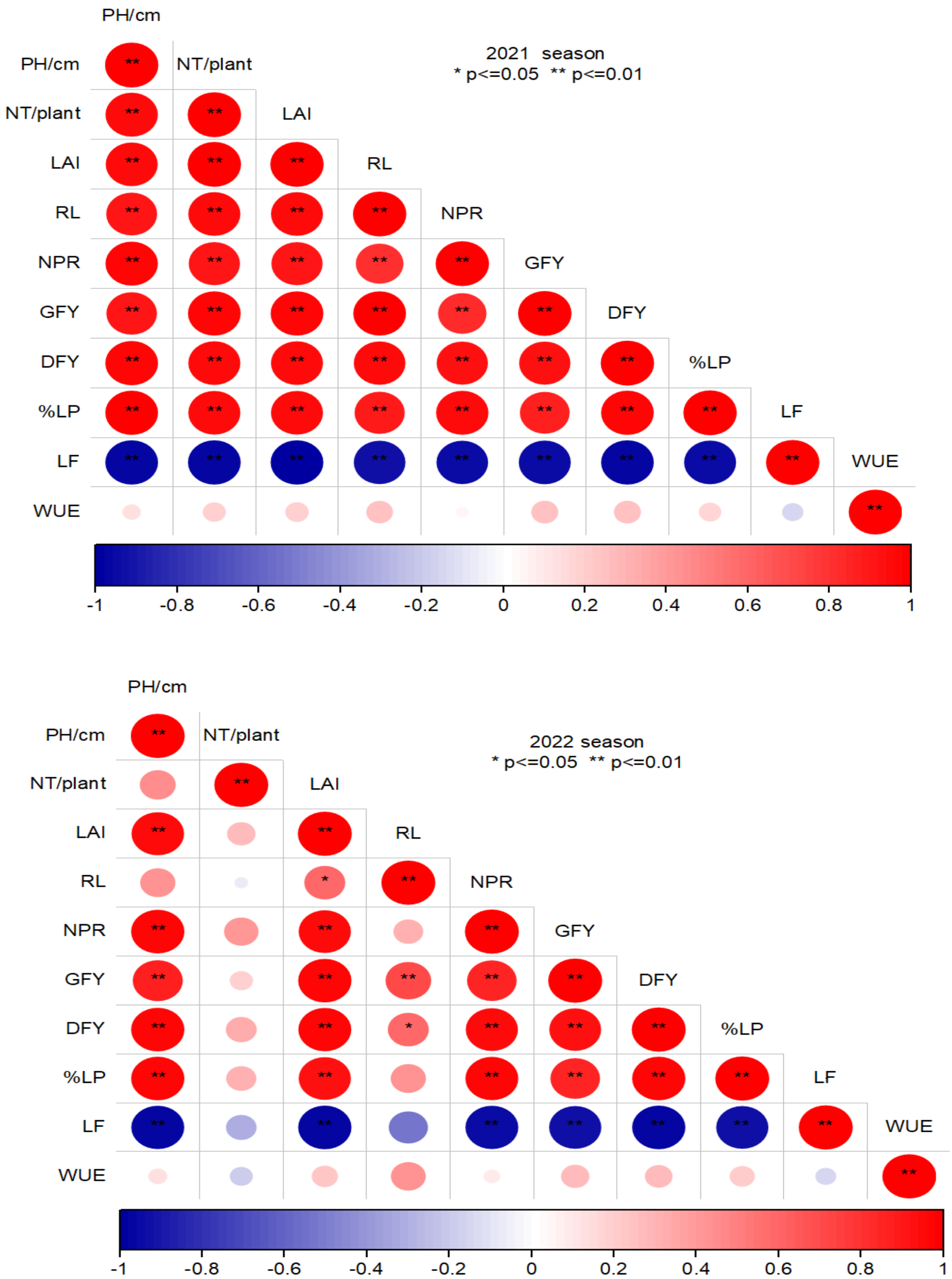


**Fig. 1a and b: Heat map illustrating Pearson's correlations among the studied traits of *Panicum* cultivars and plant densities under heat stress in hyper-arid conditions without rainfall during the 2021 (a) and 2022 (b) growing seasons. Large and medium red circles indicate significant positive correlations, whereas large and medium blue circles indicate significant negative correlations (P < 0.05, P < 0.01). Small red or blue circles represent non-significant correlations.**

## Principal component analysis (PC)

The study employed Principal Component Analysis (PCA) to investigate the correlations among the examined traits of three Panicum cultivars grown under different planting densities and subjected to heat stress in hyper-arid, rainless conditions. Table 6 summarizes the eight principal components (PCs) derived from the analysis of these traits. The first two components, PC1 and PC2, had eigenvalues greater than one, specifically 7.123 and 1.155, and together they accounted for 99.99% of the total variance of the measured variables. In contrast, the eigenvalues of the fourth and fifth components were less than one (Eigenvalue <1), indicating a minimal contribution to the overall variation.

Principal component analysis (PCA) further supported these correlations, where PC1 and PC2 explained 79.15% and 12.84% of the total variance, respectively. These two components provided a robust framework for interpreting the interrelationships among measured traits as influenced by cultivar type and planting density. (Fig. 2a and b) A strong positive association was detected between PC1 and both crop yield and WUE, as well as most other growth and physiological parameters, except for LF. Meanwhile, PC2 exhibited a significant correlation with NT/plant, NPR, DFY, and %LP, highlighting its relevance in explaining variations in productive efficiency and physiological adaptation.

**Table 6: Results of principal component analysis (PCs) in the first seven PCs for the studied traits during the main effects of experimental factors.**

| | **2021 season** | | | | | | |
|---|---|---|---|---|---|---|---|
| | PC1 | PC2 | PC3 | PC4 | PC5 | PC6 | PC7 |
| NT/plant | 0.33 | 0.07 | -0.31 | 0.41 | 0.02 | 0.08 | -0.61 |
| LAI | 0.33 | 0.08 | -0.32 | 0.27 | 0.13 | -0.08 | 0.74 |
| RL | 0.32 | 0.48 | 0.33 | 0.02 | -0.51 | 0.48 | 0.05 |
| NPR | 0.31 | -0.62 | -0.31 | -0.13 | -0.01 | 0.53 | 0.00 |
| GFY | 0.33 | 0.44 | -0.23 | 0.04 | 0.37 | -0.16 | -0.13 |
| DFY | 0.33 | -0.09 | 0.59 | -0.15 | 0.63 | 0.09 | -0.06 |
| %LP | 0.32 | -0.37 | 0.39 | 0.49 | -0.28 | -0.40 | 0.03 |
| LF | 0.33 | 0.06 | 0.13 | 0.53 | 0.29 | 0.51 | 0.16 |
| **Eigenvalue** | **8.57** | **0.29** | **0.08** | **0.04** | **0.01** | **0.00** | **0.09** |
| **Variance %** | **95.25%** | **3.26%** | **0.86%** | **0.48%** | **0.10%** | **0.05%** | **0.00%** |
| **Cumulative%** | **95.25%** | **98.51%** | **99.37%** | **99.85%** | **99.95%** | **100.00%** | **100.00%** |
| | **2021 season** | | | | | | |
| NT/plant | 0.12 | 0.74 | 0.64 | -0.02 | 0.06 | -0.04 | -0.26 |
| LAI | 0.37 | -0.03 | -0.07 | -0.27 | 0.38 | 0.22 | 0.3 |
| RL | 0.22 | -0.58 | 0.65 | 0.24 | -0.04 | -0.13 | 0.3 |
| NPR | 0.22 | 0.22 | -0.28 | -0.06 | -0.07 | 0 | 0.67 |
| GFY | 0.35 | -0.19 | 0.07 | -0.54 | 0.41 | -0.1 | -0.42 |
| DFY | 0.37 | 0.01 | -0.02 | 0.37 | -0.11 | 0.67 | -0.33 |
| %LP | 0.35 | 0.09 | -0.23 | 0.62 | 0.39 | -0.45 | -0.14 |
| LF | -0.37 | -0.02 | 0.09 | 0.17 | 0.6 | 0.46 | 0.2 |
| **Eigenvalue** | **7.123** | **1.155** | **0.574** | **0.103** | **0.038** | **0** | **0.0656** |
| **Variance %** | **79.15%** | **12.84%** | **6.38%** | **1.14%** | **0.42%** | **0.05%** | **0.01%** |
| **Cumulative** | **79.15%** | **91.99%** | **98.37%** | **99.51%** | **99.93%** | **99.98%** | **99.99%** |

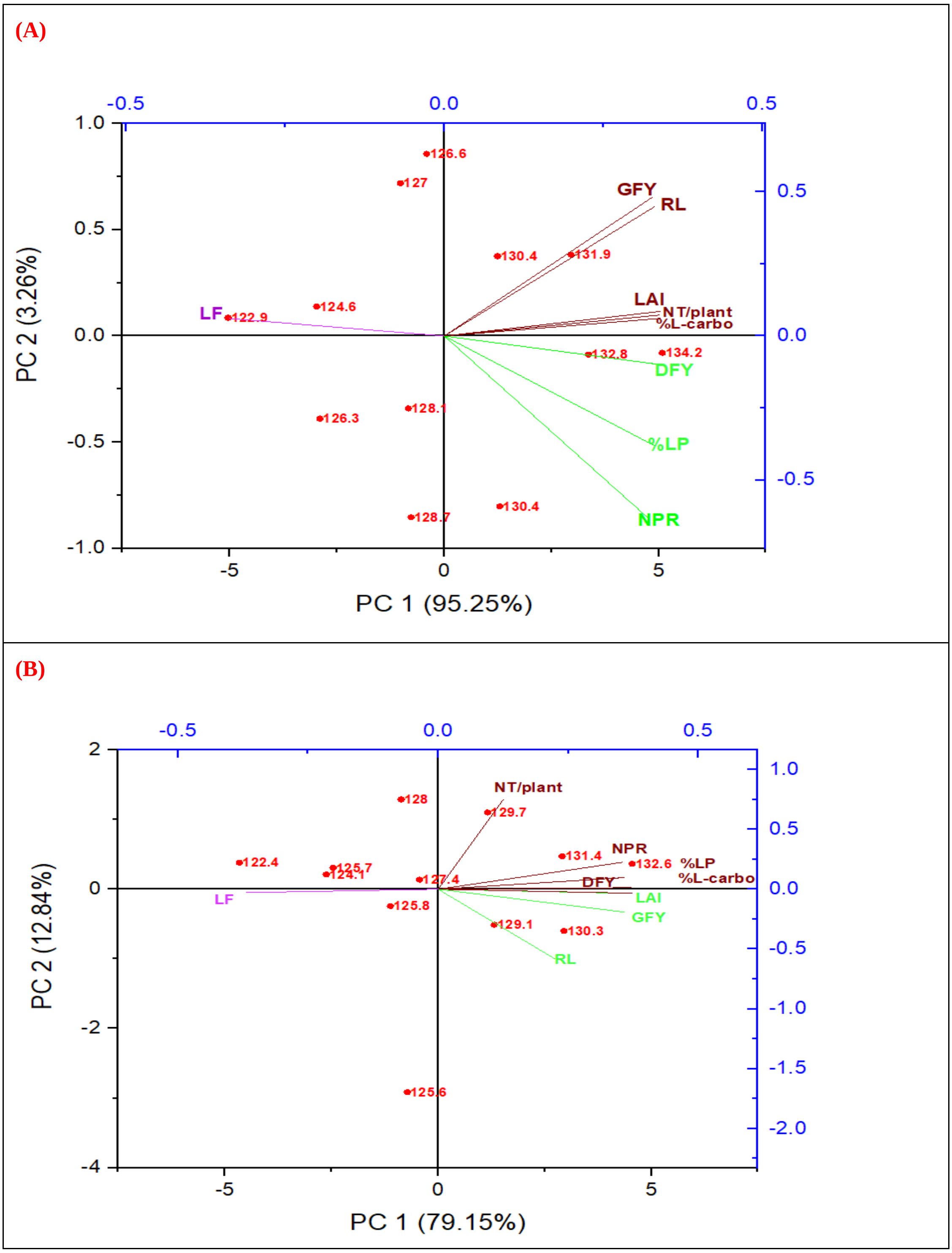


**Fig 2a and b: A biplot diagram based on PC1 and PC2 shows similarities and dissimilarities relationships among the measured traits across the three Panicum cultivars and different plant distances in both means.**

## CONCLUSION

The study highlights the critical role of cultivar selection and planting density in maximizing the growth, yield, and quality of Panicum under hyper-arid, rainless conditions. The cultivar Arowana, particularly at a 60 × 50 cm spacing, consistently demonstrated superior performance in terms of growth, forage yield, and nutritional quality, while minimizing leaf fiber content. Strong correlations among growth, yield, and nutritional traits, supported by PCA, underscore the importance of optimizing these agronomic factors. Moreover, the close alignment between yield traits and water use efficiency (WUE) confirms that selecting the appropriate cultivar and planting density enhances both productivity and water utilization. These findings provide a practical strategy for sustainable forage production in water-limited desert regions.

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# تأثير الكثافة النباتية على إنتاجية بعض أصناف البانيكم بالأراضى الصحراوية

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## الملخص العربي

في ظل تزايد ندرة المياه والحاجة الملحّة إلى إنتاج أعلاف مستدامة في المناطق الجافة، أُجريت تجربتان حقليتان في محطة التجارب الزراعية التابعة لمركز بحوث الصحراء (D.R.C) بواحة الخارجة، محافظة الوادي الجديد، مصر، خلال موسمي ٢٠٢١ و٢٠٢٢. هدفت الدراسة إلى تقييم تأثير الكثافة النباتية على نمو وإنتاجية أصناف البانيكم تحت ظروف الجفاف السائدة في الوادي الجديد. وقد أظهرت النتائج وجود فروق معنوية بين الأصناف المستخدمة في كلا الموسمين، حيث تفوق الصنف أروانا بوضوح على باقي الأصناف في جميع الصفات المدروسة، تلاه الصنف مومباسا, كما أثرت الكثافة النباتية تأثيرًا معنويًا في جميع الصفات المدروسة، حيث أثبتت مسافة الزراعة ٦٠ سم بين الصفوف و٥٠ سم بين النباتات كفاءتها الأعلى، خاصة في موسم ٢٠٢١، إذ سجل الصنف أروانا أطول النباتات (١٣٤,٢ سم)، وأعلى عدد من الأشطاء للنبات الواحد (٢٢,٠٣)، وأعلى معدل لصافي التمثيل الضوئي (٢١,٨١ ميكرومول $CO_2$ □م$^2$ □ث$^1$)، وأعلى إنتاج من العلف الأخضر والجاف بمتوسط بلغ ٣٢٧١ و ١٤٩٨ كجم/ فدان/ حشة على التوالي. كما أظهر الصنف أروانا أعلى كفاءة لإستخدام المياه والتي بلغت٢,٩٧ كجم مادة خضراء/متر مكعب ماء. وعلى النقيض، سجلت مسافة الزراعة (٨٠ × ٣٠ سم) أقل القيم لمعظم الصفات، بإستثناء محتوى الألياف في الأوراق الذي أظهر اتجاهًا معاكسًا. بشكل عام، تؤكد النتائج أن إختيار الكثافة النباتية المثلى (٦٠ × ٥٠ سم) يُعدّ عاملًا حاسمًا في تحسين نمو وإنتاجية نبات البانيكم وكفاءة إستخدام المياه تحت ظروف البيئات الصحراوية القاسية، مما يسهم في دعم إنتاج الأعلاف المستدامة وتعزيز مرونة النظم الزراعية في المناطق الجافة.