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Deficit irrigation scheduling with mulching and yield prediction of guava (*Psidium guajava* L.) in a subtropical humid region

Rajkumar Jat[1,2]*, V. P. Singh[1], Salwan Ali Abed[3], Nadhir Al-Ansari[4]*, P. K. Singh[5], Dinesh Kumar Vishwakarma[5], Ashok Choudhary[1], Mohammad Khalid Al-Sadoon[6], Raj C. Popat[2] and Suresh Kumar Jat[7]

[1]Department of Horticulture, College of Agriculture, G.B. Pant University of Agriculture and Technology, Pantnagar, India, [2]School of Agriculture, ITM University, Gwalior, India, [3]College of Science, University of Al-Qadisiyah, Al Diwaniyah, Iraq, [4]Civil Environmental and Natural Resources Engineering, Lulea University of Technology, Lulea, Sweden, [5]Department of Irrigation and Drainage Engineering College of Technology, G.B. Pant University of Agriculture and Technology, Pantnagar, India, [6]Department of Zoology, College of Science, King Saud University, Riyadh, Saudi Arabia, [7]Department of Plant Protection, College of Horticulture and Forestry, Agriculture University, Kota, India

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EDITED BY
Taimoor Hassan Farooq,
Bangor College China, a joint unit of Bangor University and Central South University of Forestry and Technology, China

REVIEWED BY
Vivek Yadav,
Northwest A&F University, China
Vijay Rakesh Reddy Sanikommu,
Indian Institute of Horticultural Research (ICAR), India
Varucha Misra,
Indian Institute of Sugarcane Research (ICAR), India

*CORRESPONDENCE
Rajkumar Jat,
rajrulez95@gmail.com
Nadhir Al-Ansari,
nadhir.alansari@ltu.se

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Drip irrigation and mulching are often used to alleviate the problem of poor water management in many crops; however, these technologies have not yet been tested for applying water at critical stages of guava orchard growth in subtropical humid Tarai regions of India to improve the yield and quality. A field experiment was conducted over 2020 and 2021 which included three irrigation strategies: severe deficit irrigation (DI_{50}), moderate deficit irrigation (DI_{75}), and full irrigation (FI_{100}), as well as four mulching methods: silver-black mulch (M_{SB}), black mulch (M_B), organic mulch (M_{OM}), and a control without mulch (M_{WM}). The results showed that both the relative leaf water content (RLWC) and the proline content exhibited an increasing trend with a decrease in the irrigation regime, resulting in a 123% increase in the proline content under DI_{50} conditions compared with FI_{100}, while greater plant growth was recorded in fully irrigated plants and using silver-black mulch. Leaf nutrient analysis showed that FI_{100} and M_{OM} produced significantly higher concentrations of all nutrients. However, moderate deficit irrigation (DI_{75}) along with silver-black mulch (M_{SB}) produced higher numbers of fruits per plant, higher average fruit weights, higher fruit yields, and maximum ascorbic acid contents. The irrigation water productivity (IWP) decreased with an increase in the irrigation regime; from severe water deficit to full irrigation, resulting in a 33.79% improvement in IWP under DI_{50} conditions as compared with FI_{100}. Regression analysis outperforms principal component regression analysis for fruit yield prediction, with adjusted R^2 = 89.80%, RMSE = 1.91, MAE = 1.52, and MAPE = 3.83. The most important traits affecting the fruit yield of guava, based on stepwise regression, were leaf proline, leaf Cu, fruit weight, and IWP.

KEYWORDS

guava, deficit irrigation, mulching, plant water relations, irrigation water productivity

1 Introduction

Guava (*Psidium guajava* L.) is one of the most important fruit crops and is widely cultivated in tropical and sub-tropical regions of the world. Guava is known as the “Apple of the tropics” because it is the only tropical fruit which is as nutritionally beneficial as the apple (Khan et al., 2013; Nimisha et al., 2013; Takeda et al., 2022). Over the past two decades, guava land areas and their production have increased at a tremendous pace as the demand for fruits has increased due to their nutritional superiority and affordable prices (Preet et al., 2021). Guava land areas, production, and productivity have increased from 1.55 Mha, 17.15 MT, and 11.10 t/ha, respectively, in 2001 to 2.92 Mha, 43.61 MT, and 14.93 t/ha in 2019–20 (Indiastat-focused on facts). This indicates the mounting importance of this fruit crop as the land area has just less than doubled, with 2.5 times higher production (Anonymous, 2019). In the Uttarakhand plains, its land area has also increased, corresponding to a large area of India; however, the productivity (5.67 t/ha) is still very low as compared with the national average (Department of horticulture and food processing, 2018). The main factor behind the low productivity is poor orchard management practices, resulting in biotic and abiotic stresses (Joshi et al., 2012). Water stress during the critical stages of fruit growth and development is the main reason for poor productivity of guava (Usman et al., 2022). Water management, especially during the period of fruit maturation, plays an important role in improving the yield as well as the quality.

Water shortage is a major barrier in crop production in almost every region of the world (Shao et al., 2009; Bartlett et al., 2019; Kogan et al., 2019). The scarcity of fresh water resources has stimulated research into water-saving strategies in agriculture, with the aim to produce more crop per drop (Stefanelli et al., 2010). India accounts for approximately 18% of the world’s population and contains 4% of the world’s fresh water, out of which 80% is used in agriculture. According to international criteria, a country is categorized as water-stressed and water-scarce if the per capita water availability falls below 1700 m^3 and 1000 m^3 respectively. India is already a water-stressed country, with 1544 m^3 per capita water availability and is approaching the water-scarce category (Dhawan, 2017). Thus, the main challenge confronting both rain-fed and irrigated agriculture is to improve water use efficiency (WUE) and sustainable water use for agriculture (Berihun, 2011). The use of micro-irrigation systems was found to result in 30–70% water savings in various orchard crops, along with 10–60% increases in yields as compared with conventional methods of irrigation. It is prudent to make efficient use of water and to irrigate larger land areas using the available water resources. This can be achieved by introducing advanced methods of irrigation and improved water management practices (Zaman et al., 2001). In recent years, the implementation of deficit irrigation in various fruit crops has gained popularity due to its excellent influence on water savings, productivity, and produce quality (Galindo et al., 2018).

In order to maximize economic returns while using limited water, deficit irrigation (DI) is used and is the practice of providing irrigation below crop evapotranspiration (ET_c) requirements (Fereres and Soriano, 2007). During various growth stages of the crop, reducing water delivery to the right requirements improves the water use efficiency and produce quality without significantly impacting the yield (Panigrahi et al., 2014). Certain studies have shown that crops can adapt to water shortages, and that a modest water shortage may not have a substantial impact on agricultural productivity (García-Tejero et al., 2010b; Zhong et al., 2019). Scholars have conducted extensive studies to assess the response of fruit tree development to deficit irrigation, most notably on apples (Zhong et al., 2019), almonds (López-López et al., 2018), oranges (Zapata-Sierra and Manzano-Agugliaro, 2017), grapes (Faci et al., 2014), and pear-jujubes (Cui et al., 2008). El Jaouhari et al. (2018) discovered that a moderate deficit irrigation (75% ET_c) can increase the WUE and the quality parameters without sacrificing the yield; however, a severe deficit (50% ET_c) was insufficient to maintain an acceptable fruit size.

Drip irrigation in combination with mulch is one of the best management practices to significantly improve the WUE. Mulching creates an isolating layer between the soil surface and the atmosphere, reducing water vapor interaction between the soil surface and the atmosphere (Zribi et al., 2015). Consequently, water evaporation from mulched soil is reduced compared with bare soil, resulting in more available water for beneficial crop transpiration (Sarkar and Singh, 2007; Hou et al., 2010). Surface mulches have been used to reduce the soil temperature and the wind velocity at the soil surface (Kay, 1978; Jalota and Prihar, 1990).

From a commercial standpoint, VNR Bihi is the dominant guava variety in India, since its larger-sized fruits fetch a decent price in both domestic and foreign markets. This variety’s cultivation is mostly limited to central and northern India, where 90% of the annual rainfall occurs in three to 4 months (June–September). Irrigation is mostly used during the fruiting season (September to January) to boost the water productivity and to increase the yield of larger fruits. VNR Bihi guava is, however, well-suited to drip irrigation. One of the key factors for sustaining guava production in this location is to schedule deficit watering with mulching.

Deficit irrigation and mulching have been examined in various field tests as water conservation and water-saving strategies. Furthermore, according to the current literature, there is no information comparing the influence of deficit irrigation with mulching on leaf physiological parameters, nutrient uptake, yield, fruit quality, and irrigation water productivity in guava. Therefore, this study was conducted to determine the best irrigation schedule for VNR Bihi guava, in terms of yield, leaf nutrient content, and irrigation water productivity.

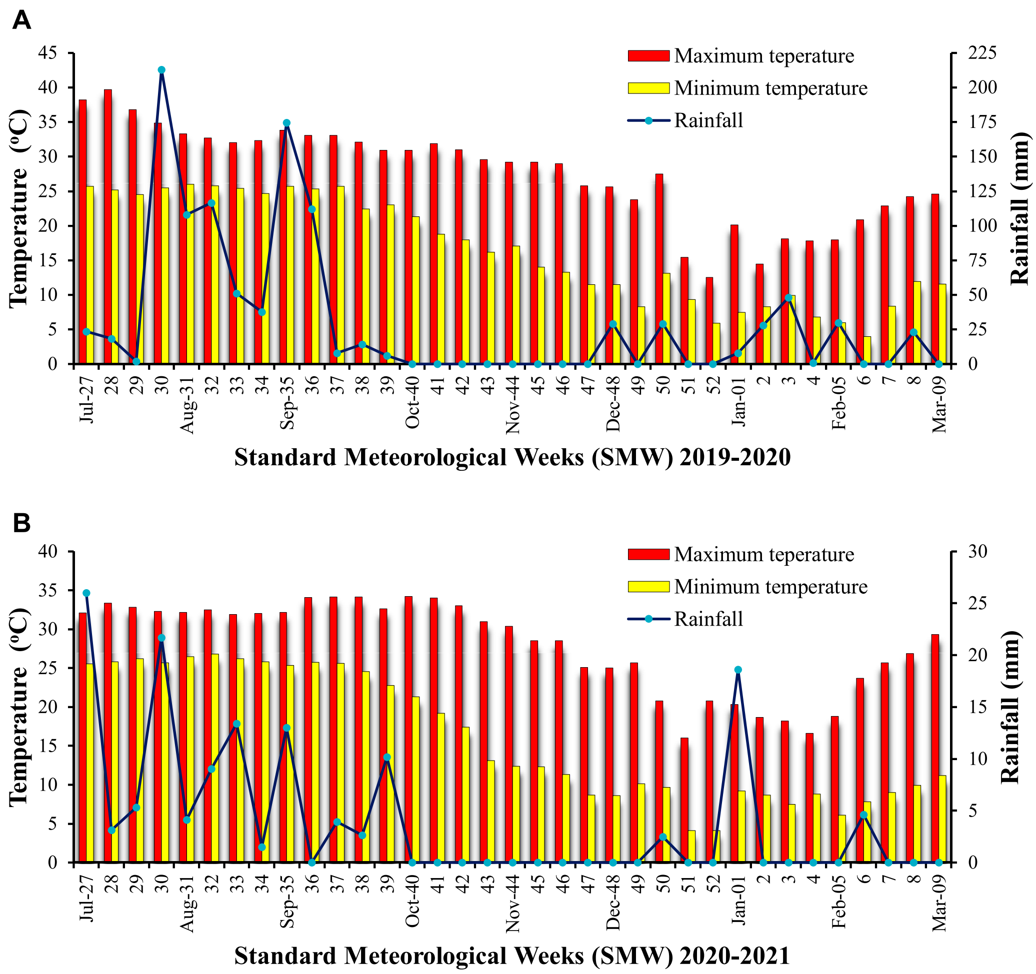

FIGURE 1
Weekly meteorological data during crop growth period for **(A)** 2019–2020 and **(B)** 2020–2021.

2 Materials and methods

2.1 Experimental site

The field experiment was performed at the G. B. Pant University of Agriculture and Technology's Horticulture Research Centre in Uttarakhand, India. The experimental site is located in the Himalayas (29.0 N, 79.5 E). The experiment was conducted on five-year-old guava trees cv. VNR Bihi (wedge grafted) planted at a spacing of 5 m × 3 m under a medium-to high-density planting scheme for two consecutive years (2019–20 and 2020–21). From the first year of planting, the trees were drip irrigated.

The climate of the experimental site has been categorized as sub-humid and sub-tropical with a hot and dry summer and an extremely cold winter. The details of the weather parameters recorded during the crop growth period are depicted in Figures 1A,B. The mean annual rainfall in this region is 1450 mm, out of which 70% occurs during the rainy season (July–September). The total rainfall was 1296.6 and 1252.8 mm during the years 2019–20 and 2020–21, respectively. The soil of the experimental site has been classified as Mollisol. The texture of the experimental soil was silt loam, with a neutral pH (7.1) and EC (0.38 ds/m), medium organic carbon content (0.67%), low available nitrogen (185.95 kg ha^{-1}), and both medium available phosphorus (28.92 kg ha^{-1}) and potassium (220.34 kg ha^{-1}).

2.2 Treatments and layout

The experiment was carried out under natural field conditions in a Factorial Randomized Block Design (FRBD), with three replications comprised of two factors (deficit irrigation and mulching). A total of three irrigation regimes were designed, including severe deficit irrigation

(DI_{50}), moderate deficit irrigation (DI_{75}), and full irrigation (FI_{100}). The irrigation levels were applied on the basis of the crop-evapotranspiration requirement (ET_c): DI_{50}—deficit irrigation at 50% ET_c, DI_{75}—deficit irrigation at 75% Et_c, and FI_{100}—full irrigation at 100% ET_c. Irrigation was applied mainly during the fruit growth period using a drip system. The water supply was stopped during the monsoon season (July–September) due to adequate rainfall fulfilling the crop water need during this period. Four mulching treatments were employed: silver-black mulch (M_{SB}), black mulch (M_B), organic mulch (M_{OM}), and a control without mulch (M_{WM}). Silver-black and black colored polyethylene mulches 100 microns thick and 1.2 m width were used as inorganic mulches (Figure 2A). A 10 cm thick organic mulch (rice straw) was applied uniformly in each replication in the experiment (Figure 2B). Various mulching treatments were given the same quantity of irrigation under the same water deficit schemes.

2.3 Irrigation scheduling and crop management practices

Every other day, four on-line 6 l h^{-1} pressure-compensated drip emitters per plant were installed on two 16 mm diameter lateral pipes to provide irrigation. The emitters were set at a distance of 1 m from the plant stem. Based on a 100% class-A pan evaporation rate, the water quantity applied during full irrigation (FI, 100% ET_c) was estimated using the following formula:

$$ET_c = K_p \times K_c \times E_p \tag{1}$$

where ET_c is the crop evapotranspiration (mm/day), K_p is the pan coefficient (0.7), E_p is the 2-day cumulative pan evaporation (mm), and K_c is the crop coefficient (0.8 for no mulching and 0.56 for mulches). The K_c values decrease by an average of 10–30% due to the 50–80% reduction in soil evaporation under mulching (Allen et al., 1998). The volume of water applied by the drip irrigation system was estimated using the following relationship:

FIGURE 2
Guava plants with **(A)** polyethylene mulches and **(B)** organic mulch treatments.

TABLE 1 The crop coefficient (Kc), rainfall and irrigation applied during irrigation season under different irrigation and mulching treatments.

Treatments	K_c	E_{pan}	Rainfall (mm)	Effective rainfall (mm)	Irrigation water applied per plant (mm)
2019–2020					
FI_{100} + Mulch	0.56	455.2	541	338.53	802.94
FI_{100} + Without mulch	0.8	455.2	541	338.53	808.56
DI_{75} + Mulch	0.56	455.2	541	338.53	602.21
DI_{75} + Without mulch	0.8	455.2	541	338.53	606.42
DI_{50} + Mulch	0.56	455.2	541	338.53	401.47
DI_{50} + Without mulch	0.8	455.2	541	338.53	404.28
2020–2021					
FI_{100} + Mulch	0.56	552.9	82	76.31	975.31
FI_{100} + Without mulch	0.8	552.9	82	76.31	1316.97
DI_{75} + Mulch	0.56	552.9	82	76.31	731.48
DI_{75} + Without mulch	0.8	552.9	82	76.31	987.73
DI_{50} + Mulch	0.56	552.9	82	76.31	487.66
DI_{50} + Without mulch	0.8	552.9	82	76.31	658.49

K_c, crop coefficient; Epan, pan evaporation; DI_{50}, deficit irrigation at 50% ETc; $DI_{75,}$ deficit irrigation at 75% ET_c; FI_{100} - full irrigation at 100%; ET_c; ET_c, crop evapotranspiration.

$$V = \sum\left(E_p \times K_p \times K_C \times S_p \times S_r \times W_p - E_R\right) \quad (2)$$

where V = the total amount of water applied (L/day/plant), E_p = the open pan evaporation (mm/day), K_p = the pan coefficient, K_c = the crop coefficient, S_p = the plant to plant spacing, S_r = the row to row spacing, W_p = the wetting factor, and E_R = the effective rainfall. The irrigation efficiency of the drip was considered to be 90%. The effective rainfall was calculated monthly, based on the USDA, S.C.S. method (United States Department of Agriculture, Soil Conservation Services):

$$ER = P_t\left[\frac{125 - 0.2 \times P_t}{125}\right] \text{for } P_t < 250\,\text{mm} \quad (3)$$

$$ER = 125 + 0.1 \times P_t \text{ for } P_t < 250\,\text{mm} \quad (4)$$

where ER = the effective rainfall (mm) and P_t = the total rainfall (mm).

The crop coefficient (K_c), rainfall, and irrigation applied during the irrigation season, under different irrigation treatments, are shown in Table 1. One pair leaf pruning was practiced in the last week of April to regulate rainy season flush and to optimize winter season flowering. Standard recommended doses of fertilizer, i.e., $N:P_2O_5:K_2O$ at 375:325:250 g/tree/year were applied during both years.

2.4 Measurement and analysis

2.4.1 Leaf physiological parameters

For determining the relative leaf water content (RLWC), two leaves per plant in a similar position were cut from each shoot at midday. The RLWC was calculated using the formula given by Bowman (1989):

$$RLWC\,(\%) = \left[\frac{(FW - DW)}{TW - DW}\right] \times 100 \quad (5)$$

The proline content of the guava leaves was estimated according to the procedure of Bates et al. (1973). The total chlorophyll content was estimated in fresh guava leaves using the method described by Hiscox and Israelstam (1979). The total chlorophyll content was then calculated by using following formula:

$$\text{Total chlorophyll} = \left[\frac{(20.2 \times A645) + (8.02 \times A663)\,x\,V}{\text{Weight }(g)\,x\,1000}\right] \quad (6)$$

where, A = the absorbance of chlorophyll extract at a specific indicated wavelength, V = the final volume of the sample, and W = the fresh weight of tissue extracted.

Towards the end of each irrigation season, fully expanded, mature leaves (without petioles) were collected from the plant canopy for each treatment and analyzed for macronutrients (N, P, and K) and micronutrients (Fe, Mn, Cu, and Zn). Two leaves displaying opposite phyllotaxy and emerging simultaneously were considered as a single leaf. As the majority of the shoots (95%) contained six leaf pairs, leaves from six different positions were sampled and indicated as leaf position I-VI from the base to the top. The leaves were spread in all four directions and were located at a height of 0.5–2 m above the soil level. The sample sizes consisted of 20 leaves per sample per replication. The leaf samples were thoroughly washed and dried at 65°C for 48 h. The dried samples were homogenously powdered and digested in a tri-acid mixture made up of two parts $HClO_4$ + five parts HNO_3 + one part H_2SO_4. Leaf acid extracts were analyzed for N using the modified micro-Kjeldahl method, P using the vanadomolybdo-phosphoric acid method, K using flame photometry, and micronutrients (Fe, Mn, Cu, and Zn) using an atomic absorption spectrophotometer (Model-908, GBC Scientific equipment, Australia).

The plant height, average plant spread (mean diameter of the canopy spread in E–W and N–S directions), and stem girth diameter (stem diameter measured 50 cm above the ground surface) were recorded annually. The plant canopy volume was calculated using the following formulae and was expressed in cubic meters (m^3):

$$\text{Canopy volume} = \tfrac{4}{3}\left[\pi r^2 h\right] \quad (7)$$

where, r = the radius of the plant canopy (m), h = the total height of the plant, and π = 3.14.

The numbers and weights of complete fruits collected from each experimental plant were recorded, and the mean yield per plant was computed by multiplying the number of fruits per plant by the average fruit weight undergoing the various treatments (Figure 4). The fruit lengths and fruit diameters were measured using a Digital Vernier's Caliper for ten fruits/replication, randomly selected from tagged guava fruits grown under different treatments. The fruit yield per unit quantity of irrigation water applied was calculated to determine the irrigation water productivity (IWP). The ascorbic acid content of the guava fruits was determined by using a 2,6-dicholorophenol-indophenol visual titration method described by Ranganna (1986). Ten grams of pulp was weighed and crushed using a mortar and pestle. The juice was filtered from the crushed pulp into a 100 ml volumetric flask and the final volume was made up to 100 ml by adding 3% metaphosphoric acid (HPO_3) solution. A 10 ml aliquot was taken from the obtained solution and was used for titration against the dye (2,6-dicholorophenol-indophenol) until a light pink color appeared and persisted for at least for 15 s (end point). The titer value was recorded, and the ascorbic acid content was calculated and expressed as mg/100 g of pulp:

$$\text{Ascorbic acid (mg/100g)} = \frac{\text{Titre value} \times \text{dye factor} \times \text{volume made up} \times 100}{\text{Weight or volume of sample taken} \times \text{volume of aliquot taken}} \quad (8)$$

$$\text{Dye factor} = \frac{0.5}{\text{Titre value}} \quad (9a)$$

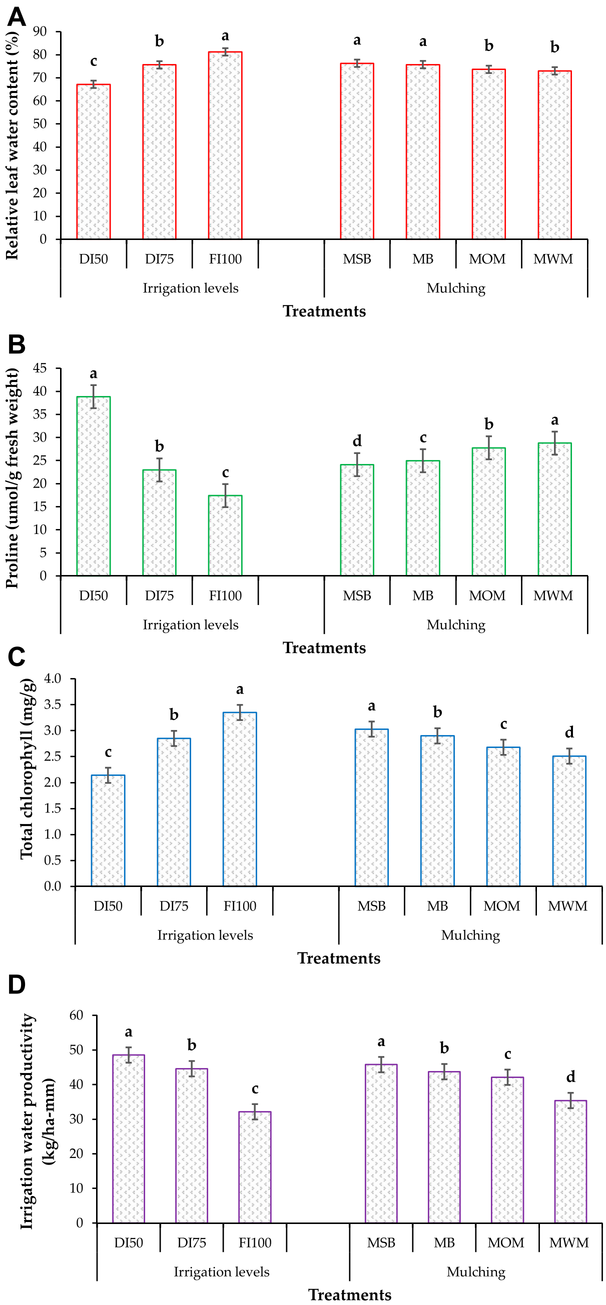

FIGURE 3
(A) Relative leaf water content (RLWC), **(B)** proline content, **(C)** total chlorophyll content and **(D)** irrigation water productivity influenced by irrigation levels and mulching. Different letters **(A–D)** indicate significantly different values at $p \leq 0.05$ according to Duncan's multiple range test. The vertical bar at each data point represents the standard error of mean.

2.5 Statistical analysis

Statistical analysis of two FRBDs was carried out by using the R package (Popat and Banakara, 2020). The means of the levels of significant factors were compared using Duncan's new multiple range test (Tallarida and Murray, 1987). The graphs presented in this manuscript were prepared using the R package ggbiplot2 (Wickham, 2016). The Pearson correlation was determined for all variables in the study (Obilor and Amadi, 2018). The significance of correlation was tested using a t-test (n = 72).

Stepwise regression analysis was performed by using the fruit yield (kg/plant) as the dependent variable, and remaining variables were used as independent variables. Residual analysis of the regression model was performed by using a run test (Siegel, 1988) and a Shapiro–Wilk test (Shapiro and Wilk, 1965) was used to test the assumptions of randomness and the normality of residuals. Goodness of fit statistics such as the RMSE (root mean squared error), MAE (mean absolute error), and MAPE (mean absolute percentage error) were determined for the regression model. All 20 variables were first subjected to principal component regression analysis using the R package prcomp. Among the principal components obtained, those with eigen values greater than 1 were used as independent variables and the yield was used as the dependent variable. All analyses were performed using R software, version 4.0.5 (Shukla et al., 2021; Elbeltagi et al., 2022).

3 Results and discussion

3.1 Leaf physiological parameters

The mean relative leaf water contents (RLWC) under different irrigation treatments were affected significantly (Figure 3A). The highest values for the RLWCs (81.35% and 81.10%) were observed for fully irrigated plants, whereas the lowest values were observed for plants under DI50 (67.75% and 66.58%), in 2019–20 and 2020–21, respectively. However, the lower values of the RLWC in 2020 compared with those in 2019 reflect the higher plant water status in the former year. The lower atmospheric evaporative demand, coupled with the better rainfall distribution in 2019 are probably responsible for the higher plant water potential in 2019.

The increased values of the RLWC indicates that the plant received its required water level to accomplish different plant physiological functions. The RLWC is an integrative index of the plant water status, and is used to evaluate the plant's tolerance to water stress. A reduction in the RLWC under water stress leads to stomatal closure, resulting in decreased CO_2 assimilation (Gindaba et al., 2004). Similar results were also reported by Abdel-Razik (2013) and Khalifa (2013) in mangos, and by Hamdy et al. (2016) in pomegranates; the authors reported that the plants produced low values of relative leaf water content in deficit irrigation conditions.

Different mulches also substantially influenced the RLWC of guava plants. The highest values for the RLWCs were observed with MSB, which was statistically at par with MB, whereas the lowest value was observed for MWM plants during both years of experimentation (Figure 3A). Moreover, interactive effects between deficit irrigation and mulching, with respect to the relative leaf water content, were significant during both years. Pooled data for the 2 years revealed that the highest value for the RLWC (82.31%) was observed with FI100MB (full irrigation at 100% ETc and with black mulch), whereas the lowest value of the RLWC (63.09%) was observed with plants under DI50MWM conditions (deficit irrigation at 50% ETc without mulch). These findings are in accordance with the findings of Pratima (Pratima, 2014), who reported significantly higher relative leaf water content in kiwifruits under deficit irrigation conditions coupled with black polyethylene mulching as compared with un-mulched conditions.

The proline accumulation in leaves significantly increased when plants were irrigated at DI50 in comparison with fully irrigated plants, over both years of the experiment (Figure 3B). During 2019–20, the average leaf proline content increased from 17.29 µmol/g fresh weight under FI100 conditions to 38.80 µmol/g fresh weight when plants were irrigated at DI50 conditions.

Similarly, in 2020–21, the leaf proline content increased from 17.52 µmol/g fresh weight in FI100 conditions to 38.88 µmol/g fresh weight under DI50 conditions. The proline content of leaves increased as the irrigation water decreased, implying that proline production is a common response of plants that are under water stress, as proline regulates cell osmotic equilibrium and protects against the harmful effects of water stress (Sampathkumar et al., 2014). Similar findings were also reported by Srikasetsarakul et al. (2011) in mangos and by Teixeira and Pereira (2007) in potatoes. Moreover, the minimum leaf proline content (24.05 µmol/g fresh weight) was recorded in MSB (silver-black) mulch, whereas the maximum (28.68 µmol/g fresh weight) in MWM (without mulch) plants. Similarly, in 2020–21, the minimum leaf proline content (24.17 µmol/g fresh weight) was recorded in MSB (silver-black) mulch, whereas the maximum (28.86 µmol/g fresh weight) in MWM (without mulch) plants. The interaction effect of deficit irrigation and mulching on the leaf proline contents was non-significant during both years.

Leaf chlorophyll content is a vital component for photosynthesis, and indicates the amount of photosynthates present in the plant system, which help to regulate plant growth. The total chlorophyll content was significantly affected by deficit irrigation and mulching treatments during both years of experimentation (Figure 3C). Pooled data indicated that plants irrigated at 100% ETc exhibited the highest chlorophyll content: 3.35 mg g−1, whereas the minimum (2.14 mg g−1) was recorded for DI50 conditions. The reduction in chlorophyll content with respect to water deficit may be due to the fact that photosynthetic pigments are very sensitive to drought stress, resulting in the destruction of chlorophyll. Under stressful conditions, glutamate, which is a fundamental source for both chlorophyll and proline formation, is thought to be primarily utilized for proline production, as a protectant suitable solute (Jaleel et al., 2009). Furthermore, during shortage irrigation, activation of the chlorophyllase enzyme can produce a drop in chlorophyll concentrations (Farooq et al., 2009).

Plants mulched with silver-black (MSB) registered significantly higher total leaf chlorophyll contents as compared with black mulch and MWM (without mulch) during both years (Figure 3C). The increased total chlorophyll might be due to the fact that the plastic mulching increased the soil microbial population along with the nitrogen absorption, consequently increasing the chlorophyll content of the plant leaves, as mentioned by Eissa (2002). The greater chlorophyll concentration in plants growing on polyethylene mulch could be due to a difference in chlorophyll synthesis and breakdown. Furthermore, the greater activity of the enzyme chlorophyllase could be related to the lower chlorophyll contents in non-mulched leaves. Differences in chlorophyll levels could also be attributable to differences in the degree of light reflection by the mulches (Pandey et al., 2016; Farooq et al., 2021, 2022; Kumar et al., 2022). Similar results were also reported by Deb et al. (2014), who recorded maximum total chlorophyll contents in polyethylene mulches in strawberries.

3.2 Leaf nutrient composition

The macronutrient (N, P, and K) and micronutrient (Cu, Mn, Zn, and Fe) concentrations in leaves responded differently to various irrigation regimes, according to leaf nutrient analyses (Tables 2, 3). The FI100 regime produced significantly higher leaf N, P, and K contents, which were statistically comparable to the DI75 condition, but significantly higher than the DI50 regime. The increased availability of such nutrients in the soil under FI100 resulted in higher N, P, and K contents in leaves of completely irrigated plants. The decrease in leaf nitrogen content under deficit irrigation conditions could be due to a decrease in the nitrogen solubility caused by soil water stress: the plant does not absorb enough nitrogen (Tahir et al., 2003). Similar results were also reported by Khattab et al. (2011); the leaf nitrogen percentage of pomegranates increased with increasing irrigation water levels compared with drought stress conditions, and the available N in the soil (NO_3^- and NH_4^+), nitrogen fixation, uptake, and nitrogen use efficiency were significantly reduced, leading to lower nitrogen accumulation in plants. These findings agree with the earlier studies of Panigrahi et al. (2012) on Kinnow mandarins, Gupta, (2019) on litchi, and Preet et al. (2021) on the response of guava to integrated nutrient and water management. Leaf N, P, and K contents also significantly differed when guava plants were mulched using silver-black, black, and organic mulch (rice straw) for two consecutive years. Furthermore, mulching with different types of mulches significantly influenced the leaf N, P, and K contents; a maximum was observed for MOM, followed by MSB, and a minimum for MWM over two consecutive years. The interaction effects of deficit irrigation and mulching had non-significant influences on the N, P, and K contents of leaves during both years of experimentation.

Moreover, the highest concentrations of micronutrients were registered for FI100 conditions (Cu, 15.64–16.21 ppm; Mn, 60.01–61.13 ppm; Zn, 48.67–48.97 ppm; and Fe, 192.33–193.36 ppm), followed by DI75 conditions (Cu, 13.52–14.07 ppm; Mn, 56.01–56.48 ppm; Zn, 43.59–43.85 ppm; and Fe, 179.70–180.39 ppm), and the minimum were recorded for DI50 conditions (Cu, 11.29–11.77 ppm; Mn, 53.32–53.59 ppm; Zn, 40.91–41.18 ppm; and Fe, 171.90–172.41 ppm), presented in Table 3. The increased availability of micronutrients under full irrigation conditions might be attributed to a low redox potential due to a low oxygen content, the increased solubility of the reduced form of iron (Fe^{3+} to Fe^{2+}), and other micronutrients in soil (Marathe et al., 2009). Increased micronutrient concentrations in leaves under the full irrigation regime were also reported by Khan et al. (2013) for guava, Panigrahi et al. (2014) for Kinnow mandarins, and Nadu (2018) for pomegranates. Various mulches also significantly influenced the leaf micronutrient concentrations (Cu, Mn, Zn, and Fe) during 2019–20 and 2020–21. The highest concentrations of the micronutrients were registered for MWM, followed by MSB, while the minimum concentrations of micronutrients was recorded in un-mulched plants. Barman et al. (2017), for guava cv. Lalit, also reported increased concentrations of micronutrients under mulched conditions.

3.3 Plant vegetative growth

Different growth parameters such as plant height, average plant spread, stem girth diameter, canopy volume, and leaf area were significantly influenced by different irrigation treatments and mulch types (Table 4). Among the irrigation regimes, FI100 treatment registered significantly higher plant heights, average plant spreads, stem girth diameters, canopy volumes, and leaf areas, whereas minimum values were observed for DI50 conditions during both years. The increased ABA biosynthesis in the roots and the reduction of cytokinin synthesis in the roots, branches, and buds in deficit irrigation conditions affects the vegetative growth of plants (Dodd, 2005). Earlier studies by Panigrahi et al. (2014) on Kinnow mandarins also showed similar findings; a decrease in vegetative growth upon deficit irrigation treatment.

The maximum plant height was recorded for MSB, and the minimum under MWM conditions. Moreover, MSB, MB, and MOM were statistically at par with one another during both years of experimentation. On the basis of pooled data, the canopy volume was 27.59% higher for MSB compared with MWM. The leaf area was also significantly higher for MSB: 8.56% higher than that of MWM. The increased plant growth parameters due to mulching might be caused by higher plant physiological processes as congenial moisture and a range of temperatures were available over the experimental period (Khan et al., 2013). Moreover, optimum moisture availability in silver-black

TABLE 2 Macronutrient (N, P and K) content in leaves of VNR Bihi guava influenced by irrigation levels and mulching.

Treatments	Leaf N (%)			Leaf P (%)			Leaf K (%)		
	2019–2020	2020–2021	Pooled	2019–2020	2020–2021	Pooled	2019–2020	2020–2021	Pooled
(A) Irrigation levels									
DI50	1.90^{c}	1.95^{c}	1.92^{c}	0.174^{c}	0.175^{c}	0.175^{c}	0.95^{c}	0.96^{c}	0.95^{c}
DI75	1.97^{b}	2.03^{b}	2.00^{b}	0.212^{b}	0.216^{b}	0.214^{b}	1.02^{b}	1.04^{b}	1.03^{b}
FI100	2.06^{a}	2.14^{a}	2.10^{a}	0.231^{a}	0.235^{a}	0.233^{a}	1.16^{a}	1.18^{a}	1.17^{a}
(B) Mulching									
Silver-black	2.00^{ab}	2.05^{ab}	2.02^{ab}	0.207^{ab}	0.211^{ab}	0.209^{b}	1.05^{ab}	1.07^{ab}	1.06^{b}
Black	1.96^{ab}	2.03^{ab}	1.99^{bc}	0.203^{b}	0.206^{b}	0.205^{b}	1.04^{ab}	1.06^{b}	1.05^{b}
Organic	2.03^{a}	2.10^{a}	2.06^{a}	0.215^{a}	0.219^{a}	0.217^{a}	1.08^{a}	1.10^{a}	1.09^{a}
Without mulch	1.93^{b}	1.98^{b}	1.95^{c}	0.198^{b}	0.197^{c}	0.198^{c}	1.01^{b}	1.02^{c}	1.01^{c}
Interaction (A × B)	NS	NS	NS	NS	NS	NS	NS	NS	NS

N, nitrogen; P, phosphorus; K, potassium; DI_{50}, deficit irrigation at 50% ETc; DI_{75}, deficit irrigation at 75% ETc; FI_{100}, full irrigation at 100% ETc. Values marked by a different letter differ significantly according to Duncan's multiple range test ($p \leq 0.05$).

mulch maintains proper turgor pressure, required for stomatal opening for gaseous exchange, which eventually led to a higher photosynthetic rate (Ayotamuno et al., 2007). The above findings are in agreement with the results of Singh et al. (2020) and Preet et al. (2021); the authors reported maximum canopy volumes with silver-black mulch as compared with no mulch in guava cv. VNR Bihi.

3.4 Yield parameters

Table 5 presents the numbers of fruits per plant, average fruit weights, fruit yields, fruit lengths, and fruit diameters produced under various irrigation regimes and mulches. The number of fruits harvested per plant and the mean fruit weights increased with increasing irrigation regime, i.e., from 50% ETc to 75% ETc under DI conditions, and were slightly lower in FI100 (full irrigation at 100% ETc) as compared with DI75 (deficit irrigation at 75% ETc) during both years. However, regarding the fruit weights, FI100 and DI75 treatments were statistically at par with each other during both years of the study. Moreover, the number of fruits harvested per plant was higher in 2019 than in 2020, due to better flowering, higher average rainfall, and lower fruit cracking in 2019 than in 2020. In contrast, the mean fruit weights were higher in 2020 than in 2019, due to a lower number of fruits per plant in 2020 than in 2019. Intrigliolo et al. (2013) reported a significant increase in the fruit numbers and fruit weights for pomegranates under deficit irrigation conditions; the authors concluded that mitigated competition between vegetative growth and reproductive organs, caused by mild water stress, reduced the abscission of reproductive organs. Drip irrigation provides a consistent soil moisture regime in which roots remain active throughout the season, resulting in an optimum availability of nutrients and proper translocation of food materials, which accelerates fruit growth and development in guava. The authors recorded a maximum fruit weight at 80% irrigation using plastic mulching in guava cv. Allahabad Safeda (Singh et al., 2015). Panigrahi et al. (2012) also reported similar decreased mean fruit weights as the irrigation regime decreased from 80% Ecp to 40% Ecp under DI conditions, in Nagpur mandarins.

The highest fruit yields were recorded for DI75 (44.51 and 42.93 kg/plant), followed by FI100 (46.64 and 44.69 kg/plant) during 2019–20 and 2020–21, respectively. The fruit yields under different irrigation treatments were higher in 2020 than in 2019, due to higher fruit weights in the former year. On the basis of pooled data, the fruit yields increased by almost 37.54% upon increasing the irrigation level from 50% ETc to 75% ETc under DI. The possible reasons for higher fruit yields under DI75 might be that the water deficit (20–25% available soil water depletion) in the root zone under this treatment suppressed vegetative growth of the plants without much effect on the leaf photosynthesis rate; plants invested higher quantities of photosynthates towards reproductive growth (fruiting) than vegetative growth (Panigrahi et al., 2012). As guava is a hardy plant and can be grown in semi-arid and arid zones under water stress conditions, this might be a reason why plants irrigated with moderate water deficits (deficit irrigation at 75% ETc) performed better as compared with full irrigation. Similar results were reported by Kaushik et al. (2013), Singh et al. (2015), and Preet et al. (2021) in guava.

Mulching significantly influenced the guava plant yields during both years of study. MSB exhibited almost 14.19% and 16.46% higher fruit yields during 2019–20 and 2020–21, respectively, as compared with un-mulched plants (Table 5). The positive impact on yield parameters due to various mulches might be attributed to an alteration of the microclimate in favor of the guava plants *viz.*, temperature regulation, maintenance of appropriate soil moisture status, as well as reduced weed

TABLE 3 Micronutrients (Cu, Mn, Zn and Fe) content in leaves of VNR Bihi guava influenced by irrigation levels and mulching.

Treatments	Leaf Cu (ppm)			Leaf Mn (ppm)			Leaf Zn (ppm)			Leaf Fe (ppm)		
	2019–2020	2020–2021	Pooled	2019–2020	2020–2021	Pooled	2019–2020	2020–2021	Pooled	2019–2020	2020–2021	Pooled
(A) Irrigation levels												
DI50	11.29^{c}	11.77^{c}	11.53^{c}	53.32^{c}	53.59^{c}	53.45^{c}	40.91^{c}	41.18^{c}	41.05^{c}	171.90^{c}	172.41^{c}	172.16^{c}
DI75	13.52^{b}	14.07^{b}	13.79^{b}	56.01^{b}	56.48^{b}	56.24^{b}	43.59^{b}	43.85^{b}	43.72^{b}	179.70^{b}	180.39^{b}	180.04^{b}
FI100	15.64^{a}	16.21^{a}	15.92^{a}	60.01^{a}	61.13^{a}	60.57^{a}	48.67^{a}	48.97^{a}	48.82^{a}	192.33^{a}	193.36^{a}	192.85^{a}
(B) Mulching												
Silver-black	13.79^{b}	14.39^{b}	14.09^{b}	56.84^{ab}	57.77^{a}	57.31^{ab}	45.10^{ab}	45.32^{ab}	45.21^{ab}	182.66^{ab}	183.89^{ab}	183.28^{ab}
Black	13.30^{c}	13.90^{b}	13.60^{c}	56.02^{ab}	56.72^{ab}	56.37^{bc}	43.91^{bc}	44.28^{b}	44.10^{b}	179.78^{ab}	180.47^{ab}	180.13^{bc}
Organic	14.47^{a}	14.93^{a}	14.70^{a}	58.48^{a}	59.01^{a}	58.75^{a}	46.30^{a}	46.60^{a}	46.45^{a}	185.77^{a}	186.52^{a}	186.14^{a}
Without mulch	12.37^{d}	12.84^{c}	12.61^{d}	54.43^{b}	54.76^{b}	54.60^{c}	42.23^{c}	42.47^{c}	42.35^{c}	177.02^{b}	177.34^{b}	177.18^{c}
Interaction (A × B)	S	S	S	NS	NS	NS	NS	NS	NS	NS	NS	NS

Cu, copper; Mn, manganese; Zn, zinc; Fe, iron; DI_{50}, deficit irrigation at 50% ETc; $DI_{75,}$ deficit irrigation at 75% ETc; FI_{100} - full irrigation at 100% ETc. Values marked by a different letter differ significantly according to Duncan's multiple range test ($p \le 0.05$).

TABLE 4 Plant growth parameters of VNR Bihi guava influenced by irrigation levels and mulching.

Treatments	Plant height (m)			Canopy spread (m)			Canopy volume (m^3)			Stem girth (cm)			Leaf area (cm^2)		
	2019–2020	2020–2021	Pooled	2019–2020	2020–2021	Pooled	2019–2020	2020–2021	Pooled	2019–2020	2020–2021	Pooled	2019–2020	2020–2021	Pooled
(A) Irrigation levels															
DI50	3.76^{c}	3.88^{c}	3.82^{c}	2.77^{c}	3.39^{c}	3.08^{c}	30.51^{c}	46.77^{c}	38.64^{c}	9.56^{c}	10.46^{c}	10.01^{c}	44.38^{c}	42.83^{c}	43.61^{c}
DI75	3.93^{b}	4.07^{b}	4.00^{b}	3.22^{b}	3.81^{b}	3.52^{b}	42.86^{b}	61.98^{b}	52.42^{b}	10.62^{b}	11.79^{b}	11.20^{b}	48.60^{b}	49.55^{b}	49.08^{b}
FI100	4.06^{a}	4.21^{a}	4.14^{a}	3.49^{a}	4.08^{a}	3.78^{a}	52.04^{a}	73.48^{a}	62.76^{a}	11.50^{a}	13.13^{a}	12.32^{a}	53.40$_{a}$	54.81^{a}	54.10^{a}
(B) Mulching															
Silver-black	4.02^{a}	4.14^{a}	4.08^{a}	3.35^{a}	3.94^{a}	3.64^{a}	47.67^{a}	67.83^{a}	57.75^{a}	11.14^{a}	12.46^{a}	11.80^{a}	50.76^{a}	51.15^{a}	50.95^{a}
Black	3.93^{ab}	4.07^{ab}	4.00^{ab}	3.21^{b}	3.80^{ab}	3.50^{b}	42.91^{b}	62.37^{b}	52.64^{b}	10.98^{a}	12.16^{a}	11.57^{a}	49.59^{ab}	49.99^{ab}	49.79^{ab}
Organic	3.89^{ab}	4.03^{ab}	3.96^{bc}	3.11^{bc}	3.71^{bc}	3.41^{b}	40.07^{c}	58.80^{c}	49.44^{c}	10.31^{ab}	11.59^{ab}	10.95^{b}	47.91^{b}	48.19^{bc}	48.05^{bc}
Without mulch	3.83^{b}	3.96^{b}	3.90^{c}	2.99^{c}	3.58^{c}	3.29^{c}	36.55^{d}	53.96^{d}	45.26^{d}	9.81^{b}	10.96^{b}	10.38^{b}	46.92^{b}	46.94^{c}	46.93^{c}
Interaction (A × B)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

DI_{50}, deficit irrigation at 50% ETc; $DI_{75,}$ deficit irrigation at 75% ETc; FI_{100}, full irrigation at 100% ETc. Values marked by a different letter differ significantly according to Duncan's multiple range test ($p \le 0.05$).

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TABLE 5 Number of fruits harvested, average fruit weight, fruit yield, fruit length and fruit diameter of VNR Bihi guava influenced by irrigation levels and mulching.

Treatments	No. of fruits/plant			Fruit weight (g)			Fruit yield (kg/plant)			Fruit length (cm)			Fruit diameter (cm)		
	2019–2020	2020–2021	Pooled	2019–2020	2020–2021	Pooled	2019–2020	2020–2021	Pooled	2019–2020	2020–2021	Pooled	2019–2020	2020–2021	Pooled
(A) Irrigation levels															
DI_{50}	73.50^{b}	64.75^{c}	69.13^{c}	437.80^{b}	526.19^{b}	482.00^{b}	32.18^{c}	34.08^{c}	33.13^{c}	7.84^{c}	8.71^{c}	8.28^{c}	8.49^{c}	9.22^{c}	8.85^{c}
DI_{75}	88.00^{a}	77.50^{a}	82.75^{a}	504.96^{a}	601.02^{a}	552.99^{a}	44.51^{a}	46.64^{a}	45.57^{a}	8.80^{a}	9.73^{a}	9.27^{a}	9.40^{a}	9.98^{a}	9.69^{a}
FI_{100}	85.75^{a}	75.00^{b}	80.38^{b}	500.54^{a}	595.67^{a}	548.10^{a}	42.93^{b}	44.69^{b}	43.81^{b}	8.42^{b}	9.30^{b}	8.86^{b}	9.08^{b}	9.65^{b}	9.36^{b}
(B) Mulching															
Silver-black	85.33^{a}	74.67^{a}	80.00^{a}	495.24^{a}	592.98^{a}	544.11^{a}	42.55^{a}	44.57^{a}	43.56^{a}	8.62^{a}	9.42^{a}	9.02^{a}	9.17^{a}	9.78^{a}	9.47^{a}
Black	83.33^{ab}	73.33^{a}	78.33^{ab}	486.03^{ab}	576.08^{ab}	531.06^{ab}	40.75^{b}	42.44^{b}	41.59^{b}	8.44^{ab}	9.31^{ab}	8.88^{ab}	9.05^{ab}	9.67^{ab}	9.36^{ab}
Organic	81.33^{ab}	71.67^{ab}	76.50^{bc}	476.77^{bc}	568.94^{b}	522.86^{bc}	38.94^{c}	40.91^{b}	39.92^{c}	8.26^{ab}	9.19^{ab}	8.73^{bc}	8.94^{ab}	9.55^{b}	9.25^{bc}
Without mulch	79.67^{b}	70.00^{b}	74.83^{c}	466.36^{c}	559.16^{b}	512.76^{c}	37.26^{d}	39.29^{c}	38.27^{d}	8.09^{b}	9.06^{b}	8.57^{c}	8.80^{b}	9.47^{b}	9.13^{c}
Interaction (A × B)	NS	NS	NS	NS	NS	NS	S	S	S	NS	NS	NS	NS	NS	NS

DI_{50}, deficit irrigation at 50% ETc; DI_{75}, deficit irrigation at 75% ETc; FI_{100}, full irrigation at 100% ETc. Values marked by a different letter differ significantly according to Duncan's multiple range test ($p \leq 0.05$).

competition, soil compaction, and erosion, generating enhanced moisture and nutrient availability in the fruit plants. These favorable factors undoubtedly improved the guava plant yields (Singh et al., 2020). The interactive relationship between deficit irrigation and mulch, i.e., DIxM, and its effect on the fruit yield/plant varied and were statistically significant in both consecutive years (Table 6). On the basis of pooled data for the 2 years, it is pertinent to mention that the fruit yield/plant improved by 36.81% in guava plants irrigated under DI75MSB as compared with DI50MWM. Singh et al. (2015) also revealed higher fruit yields in guava cv. Allahabad Safeda., treated with drip irrigation at 80% Ecp and using plastic mulching.

The average fruit lengths and diameters were significantly lower in 2019–20 compared with 2020–21. In both years, these parameters were highest for DI75 treatment and were significantly different from the FI100 and the DI50 treatments. It is also clear from the pooled data for two consecutive years that fruit lengths and diameters improved by 10.67% and 8.66%, respectively, and were improved under DI75 as compared with DI50 conditions. The increased fruit lengths and diameters under moderate water deficit conditions might be due to balanced vegetative growth and maximum interception of light, as elucidated by Kumawat et al. (2017) for guava. Similar findings for guava were also reported by Kaushik et al. (2013) and Preet et al. (2021). Likewise, different types of plant mulches also significantly influenced the fruit lengths and widths during both years of investigation. Pooled data indicated that plants mulched with MSB exhibited substantially higher fruit lengths (9.02 cm) and fruit diameters (9.47 cm), followed by MB, and minimum values observed for un-mulched plants. The positive impact of various mulches on the fruit length might be due to the fact that the mulches provided consistently improved available soil moisture in the plant basin, in which the plant roots remained active throughout the season, resulting in optimum availability of nutrients and proper translocation of food materials, which accelerated fruit growth and development (Joshi et al., 2011). Higher fruit lengths and diameters caused by silver-black mulch were also reported by Singh (2020) in VNR Bihi guava and by Beelagi (2020) in pomegranates.

3.5 Irrigation water productivity

The irrigation water productivity was significantly affected by various deficit irrigation levels during both years of experimentation (Figure 3D). The irrigation water productivity decreased as the irrigation regime increased from DI50 to FI100. The irrigation water productivity improved by 33.27% and 34.43% under DI50 as compared with FI100 during 2019–20 and 2020–21, respectively. The rate of water loss through evaporation from the soil surface was much lower under deficit irrigation regimes. Hence, the irrigation water productivity was higher in this regime as compared with the full irrigation conditions. The increased yields and irrigation water productivity achieved under deficit irrigation might be due

TABLE 6 Interaction of irrigation levels and mulching on fruit yield/plant of VNR Bihi of guava.

Irrigation levels	Mulching				
	Silver-black	Black	Organic	Without mulch	Mean
	2019–2020				
DI_{50}	33.40^{e}	32.28^{e}	31.76^{e}	31.27^{e}	32.18^{c}
DI_{75}	49.10^{a}	46.04^{b}	42.55^{cd}	40.35^{d}	44.51^{a}
FI_{100}	45.16^{bc}	43.92^{bc}	42.50^{cd}	40.15^{d}	42.93^{b}
Mean	42.55^{a}	40.75^{b}	38.94^{c}	37.26^{d}	
	2020–2021				
DI_{50}	35.22^{e}	34.38^{e}	34.27^{e}	32.44^{e}	34.08^{c}
DI_{75}	51.72^{a}	47.10^{b}	44.80^{bcd}	42.93^{cd}	46.64^{a}
FI_{100}	46.76^{b}	45.85^{bc}	43.65^{cd}	42.50^{d}	44.69^{b}
Mean	44.57^{a}	42.44^{b}	40.91^{b}	39.29^{c}	
	Pooled				
DI_{50}	34.31^{e}	33.33^{ef}	33.02^{ef}	31.85^{f}	33.13^{c}
DI_{75}	50.41^{a}	46.57^{b}	43.68^{c}	41.64^{d}	45.57^{a}
FI_{100}	45.96^{b}	44.89^{bc}	43.07^{cd}	41.33^{d}	43.81^{b}
Mean	43.56^{a}	41.59^{b}	39.92^{c}	38.27^{d}	

DI_{50}, deficit irrigation at 50% ETc; $DI_{75,}$ deficit irrigation at 75% ETc; FI_{100}, full irrigation at 100% ETc. Values marked by a different letter differ significantly according to Duncan's multiple range test ($p \leq 0.05$).

to the excellent soil water relationship, with higher concentrations of oxygen present in the root zone and efficient utilization of water and nutrients. A deficit of or excessive water stress leads to stomatal closure, thereby improving the irrigation water productivity in water-stressed plants. An improvement in the irrigation water productivity in response to deficit irrigation compared with full irrigation was also reported in citrus (Pérez-Pérez et al., 2008; García-Tejero et al., 2010a), pomegranates (Dinc et al., 2018), mangos (Upreti et al., 2018), and guava (Preet et al., 2021).

The irrigation water productivity was influenced by different types of mulches, with plants mulched using MSB exhibiting significantly higher irrigation water productivities, followed by MB, with the lowest productivity observed in MWM over both years of study (Figure 3D). Sakariya et al. (2018) reported a higher irrigation water productivity using silver-black mulch in the papaya variety Madhu Bindu in Taiwan. Consistent with the above findings, da Silva et al. (2009) reported similar findings in mangos and Tiwari et al. (2014) in sapota. The interactive relationship between deficit irrigation and mulch, i.e., DIxM, and its effect on the irrigation water productivity varied significantly in both consecutive years. Pooled data for the 2 years indicated that the irrigation water productivity improved by 47.28% in guava plants irrigated under DI50MSB as compared with FI100MWM.

3.6 Ascorbic acid (mg/100 g)

The data presented in Table 7 reveal that various irrigation levels significantly influenced the ascorbic acid content of guava during 2019–20 and 2020–21. Plants irrigated at the DI75 (deficit irrigation at 75% ETc) level exhibited a maximum ascorbic acid content of 112.87 mg/100 g, followed by 102.85 mg/100 g for DI50 (deficit irrigation at 50% ETc), with a minimum recorded (90.41 mg/100 g) for FI conditions (full irrigation at 100% ETc). Similarly, during 2020–21, the maximum ascorbic acid concentration (115.44 mg/100 g) was recorded for DI75 (deficit irrigation at 75% ETc), and the minimum (93.30 mg/100 g) for FI (full irrigation at 100% ETc). In our study, the water deficit increased the vitamin C content of the fruit as compared with full irrigation. The tolerance to water deficit is correlated with ascorbic acid accumulation, which plays an important role in ROS (reactive oxygen species) detoxification (Wang et al., 2012). However, vitamin C is a major antioxidant in plants, capable of neutralizing active forms of oxygen. These results were

TABLE 7 Ascorbic acid content of VNR Bihi guava influenced by irrigation levels and mulching.

Treatments	Ascorbic acid (mg/100 g)		
	2019–2020	2020–2021	Pooled
(A) Irrigation levels			
DI50	102.85[b]	105.50[b]	104.17[b]
DI75	112.87[a]	115.44[a]	114.16[a]
FI100	90.41[c]	93.30[c]	91.85[c]
(B) Mulching			
Silver-black	105.74[a]	109.03[a]	107.39[a]
Black	103.61[a]	106.53[a]	105.07[b]
Organic	100.59[b]	103.03[b]	101.81[c]
Without mulch	98.23[b]	100.40[b]	99.32[d]
Interaction (A × B)	s	s	s

similar to those of Ripoll et al. (2016), who found that water stress during the maturation phase increased the vitamin C levels. This effect could be related to the overall attempt made by the tree to combat water stress *via* the *de novo* synthesis of ascorbic acid (Navarro et al., 2010). Kowitcharoen et al. (2018) also suggested that increases in ascorbic acid contents in water deficit trees bearing sugar apple fruits may have been caused by abiotic stress conditions. Normally, stress conditions can induce ABA biosynthesis, which can promote hydrogen peroxide production; hydrogen peroxide is classified as a type of stress signal that may induce the antioxidant system in the plant to maintain or increase the ascorbic acid content. Singh et al. (2015) and Gupta (2019) also reported similar findings for guava and litchi, respectively, with higher ascorbic acid contents observed at a mild water deficit condition as compared with full irrigation.

In the year 2019–20, the highest ascorbic acid content was 105.74 mg/100 g, recorded in plants mulched using silver-black, followed by plants mulched with black (103.61 mg/100 g), and the lowest value (98.23 mg/100 g) observed for MWM (without mulch). During the second year of the study, the highest ascorbic acid content (109.03 mg/100 g) was also observed for MSB (silver-black) mulch, and the lowest (100.40 mg/100 g) for MWM (without mulch). However, MSB and MB were statistically at par with each other in both years of the study (Table 7). The increase of the ascorbic acid contents in guava fruits under different mulches might be due to optimum soil moisture content, providing excellent fruit quality parameters and soil nutrient status throughout the experimentation period (Tiwari et al., 2014). Prakash et al. (2011) and Singh (2020) also reported significant increases in the ascorbic acid contents under various mulches, for mango and guava, respectively. Furthermore, the interactive effect of deficit irrigation and mulching (DIxM) indicated that the ascorbic acid content of guava fruit was statistically significant, as mentioned in Table 7. A maximum pooled value for the ascorbic acid content was obtained: 116.22 mg/100 g for DI75MSB (deficit irrigation at 75% ETc and using silver-black mulch), which was significantly higher than other treatments. Similar findings were also observed by Joshi et al. (2012), who reported that drip irrigation coupled with mulch application significantly improved the ascorbic acid content in litchi fruits.

3.7 Correlation matrix

The degree of linear association of the fruit yield with all other variables (plant height, canopy spread, canopy volume, stem girth, leaf area, number of fruits, fruit weight, fruit length, fruit diameter, RLWC, proline content, chlorophyll, leaf macronutrients and micronutrients, and IWP) is presented in a correlation matrix in Table 8 and in Figure 4. The yield positively correlated with the total chlorophyll content, leaf area, leaf P content, canopy volume, canopy spread, fruit diameter, plant height, RLWC, fruit weight, leaf Cu content, fruit length, number of fruits, and the leaf K and N contents, while significant negative correlations were observed with the IWP and the leaf proline content.

3.8 Stepwise regression analysis

Stepwise regression analysis was performed by using the fruit yield (kg/plant) as a dependent variable and the remaining variables as independent variables. The correlation matrix (Table 8) showed a significant correlation among independent variables, which generates a multicollinearity problem. Stepwise regression analysis overcomes the problem of multicollinearity. The results revealed that out of the 20 independent variables, four (leaf proline content, fruit weight, irrigation water productivity, and leaf Cu content) were considered to explain the variable fruit yield. The regression model was found to be highly significant, with F calculated to be 157.9 (p-value = 2.2 × 10–16). The regression coefficients for all variables are shown in Table 9. The four variables leaf proline content, fruit weight, IWP, and leaf Cu content were found to be significant, and can be used to predict the fruit yield. The regression model is as follows:

$$\text{Fruit yield} = 34.04 - 0.65 \times \text{leaf proline} - 0.64 \times \text{leaf Cu} + 0.21 \times \text{IWP} + 0.05 \times \text{fruit weight} \quad (9b)$$

The R^2 value was 0.904, which means that 90.40% of the variation in the dependent variable (fruit yield) is explained by the model. The adjusted R^2 value was 0.898. The low values for goodness of fit statistics such as the RMSE (1.91), MAE (1.52), and MAPE (3.83) indicate that there is a small deviation between

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TABLE 8 Pearson's correlation matrix for plant-based observation in VNR Bihi guava.

	YLD	PH	CS	CV	SG	LA	NF	FW	FL	FD	RLWC	PRL	CHL	N	P	K	CU	MN	ZN	FE	IWP
YLD	1																				
PH	0.69**	1																			
CS	0.7**	0.77**	1																		
CV	0.71**	0.8**	0.94**	1																	
SG	0.58**	0.64**	0.75**	0.82**	1																
LA	0.75**	0.67**	0.67**	0.68**	0.62**	1															
NF	0.59**	0.22NS	0.04NS	0.07NS	0.11NS	0.49**	1														
FW	0.68**	0.69**	0.87**	0.88**	0.65**	0.45**	−0.03NS	1													
FL	0.63**	0.69**	0.88**	0.91**	0.71**	0.59**	0.02NS	0.85**	1												
FD	0.69**	0.75**	0.88**	0.89**	0.71**	0.63**	0.13NS	0.81**	0.83**	1											
RLWC	0.69**	0.62**	0.59**	0.6**	0.61**	0.74**	0.56**	0.28*	0.56**	0.58**	1										
PRL	−0.86**	−0.72**	−0.66**	−0.7**	−0.66**	−0.85**	−0.67**	−0.53**	−0.62**	−0.68**	−0.87**	1									
CHL	0.8**	0.7**	0.7**	0.74**	0.74**	0.86**	0.59**	0.51**	0.65**	0.69**	0.88**	−0.95**	1								
N	0.51**	0.62**	0.6**	0.7**	0.64**	0.53**	0.17NS	0.53**	0.62**	0.55**	0.5**	−0.63**	0.62**	1							
P	0.75**	0.68**	0.65**	0.69**	0.71**	0.74**	0.5**	0.51**	0.61**	0.64**	0.81**	−0.9**	0.87**	0.76**	1						
K	0.58**	0.68**	0.6**	0.67**	0.64**	0.76**	0.36**	0.41**	0.61**	0.62**	0.73**	−0.79**	0.8**	0.73**	0.84**	1					
CU	0.68**	0.72**	0.7**	0.74**	0.69**	0.75**	0.44**	0.54**	0.66**	0.69**	0.8**	−0.85**	0.87**	0.75**	0.91**	0.84**	1				
MN	0.48**	0.58**	0.55**	0.59**	0.59**	0.6**	0.29*	0.28*	0.45**	0.56**	0.63**	−0.66**	0.7**	0.61**	0.73**	0.72**	0.81**	1			
ZN	0.57**	0.61**	0.59**	0.63**	0.55**	0.73**	0.27*	0.29*	0.57**	0.58**	0.74**	−0.75**	0.79**	0.68**	0.8**	0.84**	0.85**	0.71**	1		
FE	0.53**	0.55**	0.54**	0.6**	0.58**	0.69**	0.45**	0.24*	0.57**	0.57**	0.72**	−0.74**	0.77**	0.68**	0.77**	0.81**	0.82**	0.76**	0.82**	1	
IWP	−0.32**	−0.49**	−0.62**	−0.63**	−0.49**	−0.47**	0.08NS	−0.52**	−0.62**	−0.63**	−0.5**	0.54**	−0.49**	−0.52**	−0.54**	−0.63**	−0.56**	−0.46**	−0.51**	−0.53**	1

YLD, yield; PH, plant height; CS, canopy spread; CV, canopy volume; SG, stem girth; LA; leaf area; NF, number of fruits; FW, fruit weight; FL, fruit length; FD, fruit diameter; RLWC, relative leaf water content; PRL, proline; CHL, total chlorophyll; N, nitrogen; P,Phosphorus; K, potassium; CU, copper; MN, manganese; ZN, zinc; FE, iron; IWP, Irrigation water productivity. Correlation values followed by * indicates the significance of correlation at $p < 5\%$ probability level and correlation values followed by ** indicate significance at $p < 1\%$; NS: not significant.

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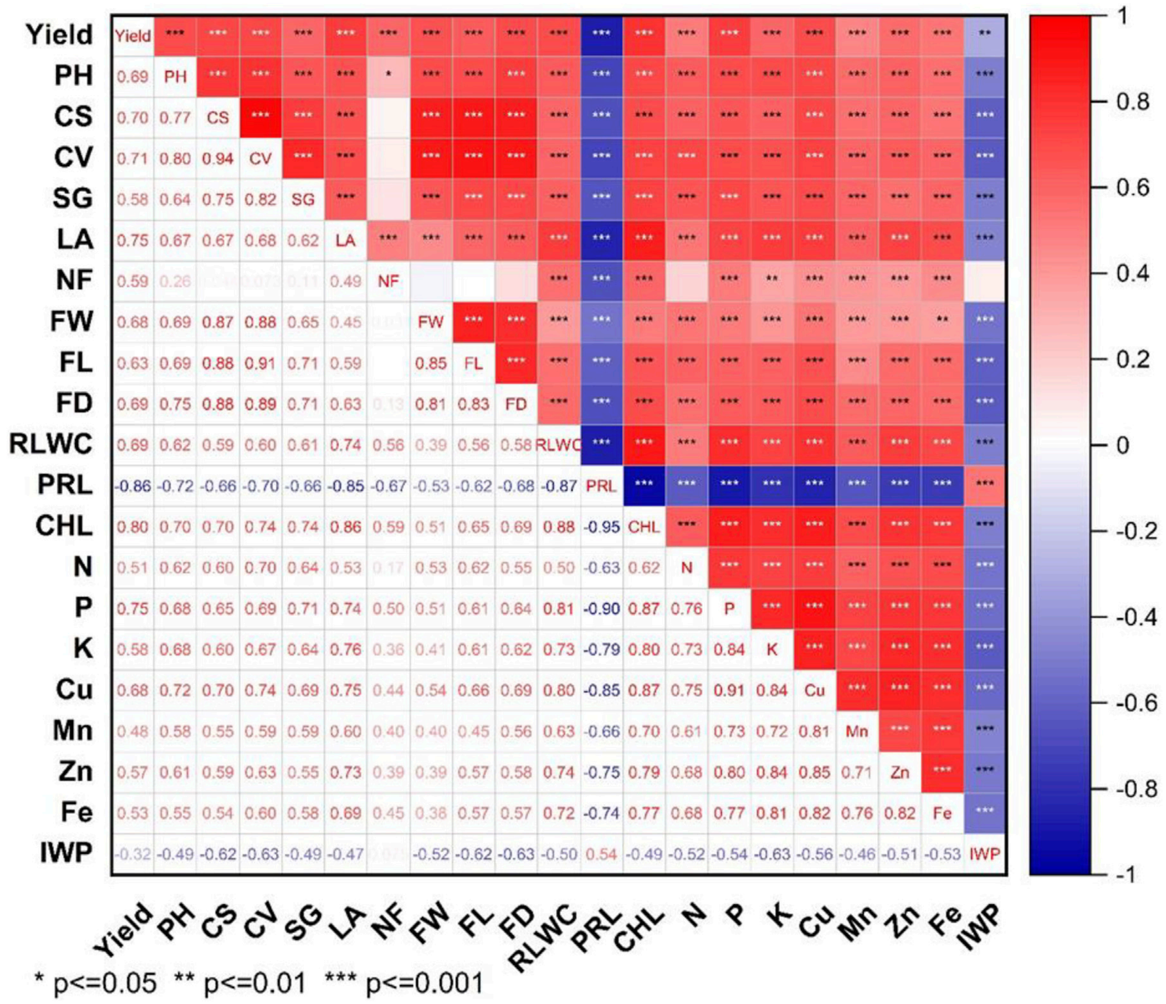

FIGURE 4
Pearson's correlation matrix for plant-based observation in VNR Bihi guava.

the actual values and the predicted values, as shown in Figure 5A. The run test statistic of the residuals was 37 with a p-value of 0.99, indicating that the residuals are random and do not follow any pattern. The Shapiro–Wilk test statistic was 0.99, with a p-value of 0.88, indicating that the residuals follow a normal distribution. Thus, residual analysis indicates that the regression model does not violate the assumption of normality or the randomness of the residuals.

3.9 Principal component regression analysis

PCA was performed for the 20 variables, and three principal components showing eigen values over one were used to predict the fruit yield. The results showed that the first three principal components captured 83.25% of the variation of the data set. The eigen values and the percentage of variance, explained by the principal component, is shown in Table 10. The multiple linear regression model was fitted using the three principal components as dependent variables and the yield as the independent variable.

The principal component regression model was found to be highly significant, with F calculated to be 125.1 (p-value = 2.2×10^{-16}). The regression coefficients for all variables are shown in Table 11. Among the three principal components, PC_1 and PC_3 exhibited significant regression coefficients. The regression model is as follows:

$$\text{Fruit yield} = 40.83 + 1.34 \times PC_1 - 0.27 \times PC_2 + 2.99 \times PC_3 \tag{10}$$

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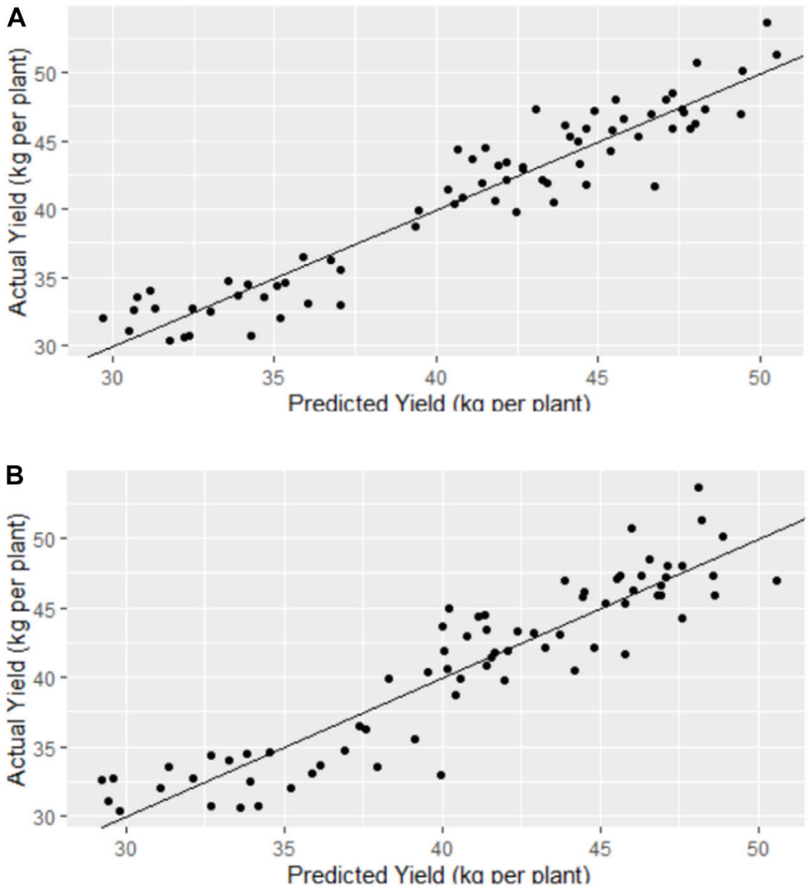

FIGURE 5
Actual yield vs. predicted yield of VNR Bihi guava plants by **(A)** step wise regression and **(B)** principal component regression.

TABLE 9 Regression coefficient estimates for different variables in step wise regression analysis.

Variable	Regression coefficient estimate
Intercept	34.04**
Leaf proline content	−0.65**
Fruit weight	0.05**
Irrigation water productivity	0.21**
Leaf copper content	−0.64**

"** Indicates significance level at p < 0.01."

The R^2 and adjusted R^2 values were 0.846 and 0.839, respectively. The lower values of goodness of fit statistics such as the RMSE (2.41), MAE (1.93), and MAPE (4.87) indicate that there is a small deviation between the actual values and the predicted values, as shown in Figure 5B. The run test statistic of the residuals was 24 with a *p*-value of 0.002, indicating that the residuals are not random. The Shapiro–Wilk test statistic was 0.98, with a *p*-value of 0.78, indicating that the residuals follow normal distributions. Thus, residual analysis indicates that the regression model does not violate the assumption of normality and does violate the randomness of the residuals.

TABLE 10 Principal components for plant-based variables with eigen values.

Principal component	Eigen value	Proportion of variance	Cumulative variance
PC1	3.65	0.66	0.66
PC2	1.53	0.11	0.78
PC3	1.03	0.04	0.83

PC1, Principal component 1; PC2, Principal component 2; PC3 Principal component 3.

TABLE 11 Regression coefficient estimates of principal components.

Variable	Regression coefficient estimate
Intercept	40.83**
PC1	1.34**
PC2	-0.27^{NS}
PC3	2.99**

PC1, Principal component 1; PC2, Principal component 2; PC3 Principal component 3.
"** Indicates significance level at p < 0.01 NS indicates non significant"

4 Conclusion

Fully-irrigated plants and silver-black mulch produced the highest vegetative growths and leaf nutrient contents. However, deficit irrigation at 75% Et_c, along with silver-black mulch used during the fruit growth period produced higher numbers of fruits per plant, higher average fruit weights, and higher fruit yields. Moreover, the irrigation water productivity also improved substantially in deficit irrigated plants. Out of both the techniques used for the prediction of fruit yield, the stepwise regression model presented a higher value of the adjusted R^2 and lower values of the RMSE, MAE, and MAPE. Furthermore, the stepwise regression model also follows the assumptions of normality and randomness of the residuals. Thus, we conclude that the stepwise regression model is preferred over the principal component regression model to predict the fruit yield in this study, using variables *viz.*, the leaf proline content, fruit weight, IWP, and leaf Cu content. Based on the present findings, it can be inferred that application of deficit irrigation at 75% ET_c using silver-black mulch imposed desirable levels of water stress on guava plants. This improved their irrigation water productivities, yields, and the fruits quality, and could be a superior option for guava cultivation in the subtropical, humid Tarai conditions of Uttarakhand, India, as well as in regions with similar agro-climatic conditions.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

Author contributions

Conceptualization, RJ, VS, and PS; methodology, DV; AC; software, RP; validation, RJ, VS, and PS; formal analysis, RP; investigation, SJ; resources, VS; data curation, RP; writing—original draft preparation, RJ, VS; writing—review and editing, NA-A and SA; visualization, RJ; supervision, VS; project administration, AC; funding acquisition, MA-S. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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