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Soil Nutrient Status and Morphometric Responses of Guava under Drip Irrigation and High-Tech Horticultural Techniques for Sustainable Farming

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Abstract: In the current study, efforts were made to standardize fertigation for providing the recommended doses of fertilizers (RDF) i.e., 300, 260, and 200 g/plant/year for N, P, and K, respectively, together with optimization of irrigation scheduling so that guava plants could avoid the frequent episodes of nutritional stress, water scarcity, or overwatering. The experiment's execution was confined to a three-factor randomized block design, with a total of 19 treatments that were replicated four times. Briefly, these treatments included drip irrigation and nutrient (NPK) application through fertigation dosages (RDF; 100, 80, and 60%) with and without silver-black plastic mulching. Different applied fertilizer dosages, together with different levels of irrigation and soil mulching, had a significant impact on the guava plant's vegetative, reproductive, and nutritional aspects. Under silver-black plastic mulch, drip irrigation at cumulative pan evaporation (CPE) 80 and 100% of the prescribed dosage of fertilizers, better macronutrient availability in the soil, and improved plant development were recorded ($M_1DI_2F_1$). Overall, using drip fertigation to provide NPK fertilizers close to the root zone increased the availability of nutrients to the plants as compared to the traditional fertigation and irrigation methods. Thus, this sustainable high-tech horticultural approach could be analyzed for its efficacy or applied to other crops to obtain adequate economic outcomes.

Keywords: mulching; fertigation; plant growth response; guava productivity; soil health

1. Introduction

Guava (*Psidium guajava* L.) is an important subtropical fruit crop that possesses both medicinal and nutritional values [1]. This fruit crop is incredibly popular because it is one of the considerable sources of ascorbic acid, pectin, phosphorus, and calcium, and contains enough thiamine and riboflavin [2]. It contributes to ∼15% of the world's total fruit production. Additionally, 4.05 million tons of fruit per year over an area of 265 thousand ha is produced, which contributes ~4% of India's total fruit production [3]. Being beneficial to both farmers and consumers, guava has witnessed a tremendous expansion of area across India. However, in the past decades, there has been a dynamic transition in production techniques, leading it to move from subsistence cultivation to commercial scale. Water and fertilizers have been identified as being significantly important for achieving the desired product and economic outputs of this fruit crop [4]. Optimum soil moisture near the root zone is the prime requirement to assure the availability of nutrients to the plants during the growing phase [5] and to achieve the targeted fruit yield, the soil must be fertilized generously with water-soluble fertilizers through drip [4]. In this context, a study reported a significant increase in yield by combining drip irrigation with polythene mulching compared to the ring basin irrigation approach [6]. Additionally, it was noted that using the ring basin method of irrigation results in excessive water wastage along with leaching losses of nitrogen and other crucial nutrients far outside the root zones of the plants. As a result, drip irrigation was recommended as a better approach, conserving up to 80% of the water and nutrients [7]. Therefore, utilizing plastic mulch along with drip irrigation can provide higher yields with superior quality traits while also conserving significant water and fertilizer [8].

The Tarai region's climate is characterized as both hot and humid. Summer temperatures rise to 43 °C in April, May, and June. Globally, this temperature comes under the category of megathermal type of climate. Climate change has brought scientists as well as decision-makers to make some important strategies for saving water and the future of water resources [9]. Water scarcity is a limiting factor due to shrinkage in water bodies [10] and excessive water application via conventional methods that lead to water logging conditions, soil salinity, poor soil aeration, contamination of water bodies, and weed infestation [11]. Therefore, some reports suggested the use of high-tech irrigation systems in place of conventional surface irrigation methods such as ring basins or furrow irrigation [12,13]. It has been discerned that due to higher financial returns obtained, the microirrigation technique is being extensively used in horticultural crops [14]. An improvement in microirrigation technology in India is gaining acceptance and popularity since it offers greater water savings (12–84%) and increased fertilizer usage efficiency (10–55%) by the plants and is found to be dependent on soil type and climates [7,15]. The guava cultivar VNR Bihi was cultivated for the first time in the Terai region of Uttarakhand and is widely accepted by farmers because it performs extremely well under drip fertigation and plastic mulching [16]. However, irrigation and fertigation scheduling for guava in the Tarai region of Uttarakhand have been practiced arbitrarily due to the lack of systematic and scientifically sound technologies for judicious water management through microirrigation, fertigation, and water conservation practices [17]. Hence, with this background, the response to changing the method of applying nutrients and irrigation water on vegetative attributes of guava plants and availability of soil nutrients is to be examined and scheduling of irrigation is needed to be designed. Thereby, the main objective of the present study is to evaluate the efficacy of drip fertigation along with plastic mulching compared to the conventional irrigation and fertilization system on vegetative characteristics and soil nutrient availability in guava cv. VNR Bihi.

2. Materials and Methods

2.1. Experimental Site Details

A two-year field experiment on guava cv. VNR Bihi was executed at HRC Patharchatta of G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India, during the winter season of 2017 and 2018. The age of the orchard at the time of investigation was 3 years, planted at a spacing of 5 m × 3 m. The experimental site, located at 29°1′43.8234″ N latitude and 79°24′29.7354″ E longitude, annually receives ~1400 mm rainfall, most of which occurs during the monsoon period (June to September). Weekly data for weather parameters, viz., rainfall, temperature, humidity, wind velocity, sunshine hours, etc., have been presented in the Supplementary Materials (Figure S1). The plant spacing in the present experiment was 5 m × 3 m. The soils of selected guava orchards are alluvium, having a silty loam texture with a proper drainage outlet. The status of physicochemical attributes of soil in advance of the execution of experiments is presented in the Supplementary Materials (Table S1). The quality parameters of irrigation water used were in acceptable range. The pH, EC, and TDS contents of applied water were 7.2, 0.5 dS m^{-1}, and 380 ppm, respectively.

2.2. Experimental Design with Treatment Details

The experiment was laid out under a three-factor randomized block design (2 × 3 × 3) with two levels of mulching, three levels of drip irrigation, and three levels of the recommended dose of fertilizers (RDF). Mulching treatments include no mulch and plastic mulch (silver-black plastic, 100 μ). Drip irrigation treatment comprises irrigation at cumulative pan evaporation (CPE) of 100, 80, and 60%. The drip irrigation was applied via lateral lines with 2 emitters per tree having a discharge rate of 8 L/h/emitter. The emitters were placed at 50 cm away from the trunk of guava tree. Each lateral line was separated by 3 m and contained a small valve which controlled the irrigation in different treatments. The drip irrigation depth was observed from 0 to 70 cm. The estimation of irrigation water requirement was calculated based on crop evapotranspiration using the following formula proposed by Vermeiren and Jobling [18]:

$$V = E_p \times K_p \times K_c \times K_r \times \text{Ground cover area} \quad (1)$$

where E_p is panned evaporation (mm/day), K_p is a pan coefficient (0.85), K_c is the crop coefficient (0.8), K_r is a reduction coefficient (1), and the ground cover area is 5 × 3 m^2. The water received through the rain was accommodated in the irrigation schedule on successive days in all the treatments except control. Drip irrigation was provided thrice a week during summer and twice a week during winter based on 100, 80, and 60% of CPE.

However, the nutrient levels were 100, 80, and 60% recommended dose of fertilizers (RDF). The RDF for guava under the present investigation was assumed to be 300, 260, and 200 g NPK/plant/year. Different grades of water-soluble fertilizers, i.e., Nitrogen: Phosphorus: Potassium (18:18:18), Urea (46% N), MPP (Nitrogen: Phosphorus: Potassium 00:52:34), and Potassium Sulfate (50% K) were used to provide the RDF (NPK) into the root zone through the drip irrigation or fertigation system. Fertigation of NPK was started in the second fortnight of May at 10-day intervals. Nitrogen and potassium were continuously applied throughout the year while phosphorus was applied until the commencement of the fruit set. The total number of treatment combinations obtained was 18 and one absolute control treatment (flooded irrigation with no mulch and 100 % RDF) was also included for conventional irrigation and water management practice. Hence, the sum of 19 treatments given in Table 1 was taken into consideration with four replications.

2.3. Observations and Laboratory Analyses

During the investigation, the effect of mulching, drip irrigation, and fertilization was evaluated on plant growth dynamics and soil nutritional status. The plant growth observations, viz., plant spread, canopy volume, leaf area, and the number of flowers/shoots, were recorded. The observations regarding the increase in plant vegetative parameters such as east to west (EW) and north to south (NS) plant spread and canopy volume were noted before starting and after completion of the trial and expressed as a percent increase over the initial value. Canopy volume was computed by using the formula $4/3\ \pi hr^2$, where h is half of the tree height and r is half of the tree spread [19]; it was also computed on an initial and final basis and was later expressed as the percent increase in canopy volume. For the leaf area, from each tree of all the treatments, 15 fully developed and matured leaves were randomly selected from all four directions of the tree canopy. Their area was measured with the help of an automatic leaf area meter (Licor Model 3100) in the laboratory and average values were expressed in cm^2. The total number of flowers was counted on the five randomly selected shoots from the whole plant and the average number of flowers per shoot was calculated.

Table 1. Details of the treatment combinations.

Serial No.	Treatment	Treatment Details
1	MDI_1F_1	Mulch + 100% CPE + 100% RDF
2	MDI_1F_2	Mulch + 100% CPE + 80% RDF
3	MDI_1F_3	Mulch + 100% CPE + 60% RDF
4	MDI_2F_1	Mulch + 80% CPE + 100% RDF
5	MDI_2F_2	Mulch + 80% CPE + 80% RDF
6	MDI_2F_3	Mulch + 80% CPE + 60% RDF
7	MDI_3F_1	Mulch + 60% CPE + 100% RDF
8	MDI_3F_2	Mulch + 60% CPE + 80% RDF
9	MDI_3F_3	Mulch + 60% CPE + 60% RDF
10	$M_0DI_1F_1$	No Mulch + 100% CPE + 100% RDF
11	$M_0DI_1F_2$	No Mulch + 100% CPE + 80% RDF
12	$M_0DI_1F_3$	No Mulch + 100% CPE + 60% RDF
13	$M_0DI_2F_1$	No Mulch + 80% CPE + 100% RDF
14	$M_0DI_2F_2$	No Mulch + 80% CPE + 80% RDF
15	$M_0DI_2F_3$	No Mulch + 80% CPE + 60% RDF
16	$M_0DI_3F_1$	No Mulch + 60% CPE +100% RDF
17	$M_0DI_3F_2$	No Mulch + 60% CPE + 80% RDF
18	$M_0DI_3F_3$	No Mulch + 60% CPE + 60% RDF
19	Control	Conventional system (CS) + 100% RDF

CPE: cumulative pan evaporation; RDF: recommended dose of fertilizers; M: mulch; M_0: without mulch.

The soil composite samples for 30 cm depth were collected from four sides under the drip line of each experimental tree with the help of a screw sampler before experimentation and after crop harvesting during both years. The soil samples were dried under shade, powdered, and then sieved through a 2 mm plastic sieve, and stored in cloth bags. Processed soil samples were analyzed for organic carbon following the Walkley and Black [20] method while soil N, P, and K availability (kg/ha) was analyzed using methods proposed by Subbiah and Asija [21], Olsen et al. [22], and Schollenberger and Simon [23], respectively. The dehydrogenase activity of soil was determined using the method listed by Casida et al. [24]. To 3 g soil sample in a flask, 0.5 mL of 3% triphenly tetrazolium chloride solution and 1.5 mL of water were added. The flasks were tightly stoppered and swirled for a few seconds. These samples were incubated for 24 h at 37 °C and extracted with 94% methanol. The extract was assayed at 485 nm using a spectrophotometer. The unknown values were calculated based on a standard curve compared with tri-phenyl formazon (TPF). Enzyme activity was expressed as gm of TPF released μg^{-1} of soil 24 h^{-1}.

2.4. Statistical Analyses

The data obtained during an investigation conducted in a two-factor randomized block design were processed with Windows Excel and statistical analysis was carried out using the Statistical Package for Social Sciences (SPSS v. 23.0) software. The significant difference between treatments was examined by two-way analysis of variance at a 5% level of significance ($p < 0.05$). The relationship between parameters has been presented with Pearson's correlation.

3. Results

The transition of the conventional system into a drip irrigation system for the cultivation of guava cv. VNR Bihi was done by scheduling fertigation and required irrigation at different intervals of time during the years 2017 and 2018, starting from the second fortnight of May onward. The significant changes in the nutritional status of soil and the vegetative characteristics of the guava plant are presented under various subheadings.

3.1. Growth Dynamics

The data recorded for plant growth response as an increase in plant spread, canopy volume, leaf area, and several flowers/shoots influenced by mulching, drip irrigation, and fertigation are pooled and presented in Table 2 and depicted in Figure 1. Both the sole and combined effect of mulch with drip irrigation and fertigation on increase in plant, spread (%), canopy volume (%), leaf area (cm^2), and several flowers/shoots were significant. Plastic mulching significantly increased the plant spread, canopy volume, and leaf area by 17.7, 25.6, and 7.6% compared to no mulching. The response of irrigation and fertigation on plant spread, canopy volume, leaf area, and the number of flowers/shoots were recorded as significantly higher under D_2 and F_1 (Table 2). The treatment combination of mulching with drip irrigation 80% and RDF 80% (MDI_2F_2) resulted in a maximum 33.58 percent increase in plant spread as compared to the control, 13.98 percent. Among the irrigation and fertigation treatments, DI_2 and F_2 reported significantly higher spread of 26.92 and 25.34%, respectively. The maximum increase in canopy volume was 41.98% under treatment MDI_2F_2 while the reported minimum was in the absolute control (14.54%). The combined effect of mulch with drip irrigation at 80% CPE was also found to be significant and recorded a significantly higher increase in canopy volume (37.78%) compared to other interactions. Similarly, the interaction effect of mulch with fertigation at 80% RDF resulted in a significantly higher (35.13%) increase in canopy volume. The combined response of mulch, drip irrigation, and fertigation was significant during the pooled study with the treatment combination, MDI_2F_2 exhibiting the maximum percent increase in canopy volume as well (Figure 1a). Maximum leaf area and flower counts were recorded under treatment MDI_2F_1 (79.59 and 42 cm^2), while these were reported lowest (61.79 and 26 cm^2) under $M_0DI_3F_3$ in which plants were kept without mulch and received irrigation at 60% CPE with 60% RDF. The irrigation scheduling at 80% CPE (D_2) showed a significantly higher leaf area (71.79 cm^2) compared to D_1 and D_3. Leaf area also varied significantly with the increments in fertigation levels, wherein the maximum leaf area of 72.59 cm^2 was observed under 100% RDF. Further, the interaction result of mulch with DI was found to be non-significant, whereas the interactive effect of drip irrigation × fertigation was found statistically significant. A maximum leaf area of 74.75 cm^2 was found in plants that were mulched and received 100 percent recommended dose of fertilizers (RDF), whereas the minimum was found in nonmulched plants (Figure 1b). The interactive effect of all the three sole parameters was also found to be statistically superior during both years of the study. Drip irrigation at 80% CPE gave significantly higher (35) flowers/shoot. The sole response of fertigation was also significant in exhibiting the maximum total number of flowers per shoot (37) under fertigation with 100% RDF. Further, the combined effect of sole factors—mulch, DI, and fertigation—i.e., of mulch × DI level, DI level × fertigation, and mulch × fertigation, was found significant during the entire course of the study. On a pooled basis, studies indicated that mulch with DI at an 80 percent level resulted in the maximum total number of flowers.

Table 2. Effect of plastic mulch, drip irrigation, and fertigation system on the plant growth dynamics and fruit yield of guava.

Treatments	Increase in Plant Spread (%)	Increase in Canopy Volume (%)	Leaf Area (cm^2)	Number of Flowers/Shoot	Fruit Yield (kg/plant)
Control					
M	25.34	32.69	72.51	35.92	44.36
M_0	21.53	26.02	67.39	30.09	40.42
SE(m)	1.03	0.53	0.22	0.3	0.12
C.D. at 5%	2.94	1.52	0.63	0.87	0.34
DI_1	20.96	29.31	70.25	33.17	42.33
DI_2	26.92	32.27	71.79	34.61	43.9
DI_3	22.43	26.49	67.81	31.23	40.94
SE(m)	1.26	0.65	0.27	0.37	0.15
C.D. at 5%	3.6	1.87	0.77	1.06	0.42
F_1	25.44	32.74	72.59	35.48	45.2
F_2	25.18	30.62	70.5	30.48	42.38
F_3	19.7	24.71	66.76	27.74	39.58
SE(m)	1.26	0.65	0.27	0.37	0.14
C.D. at 5%	3.6	1.87	0.78	1.06	0.41

M (mulch), M0 (no mulch); DI (drip irrigation level: 100% CPE, 80% CPE, 60% CPE); F (fertigation level: 100% RDF, 80% RDF, 60% RDF).

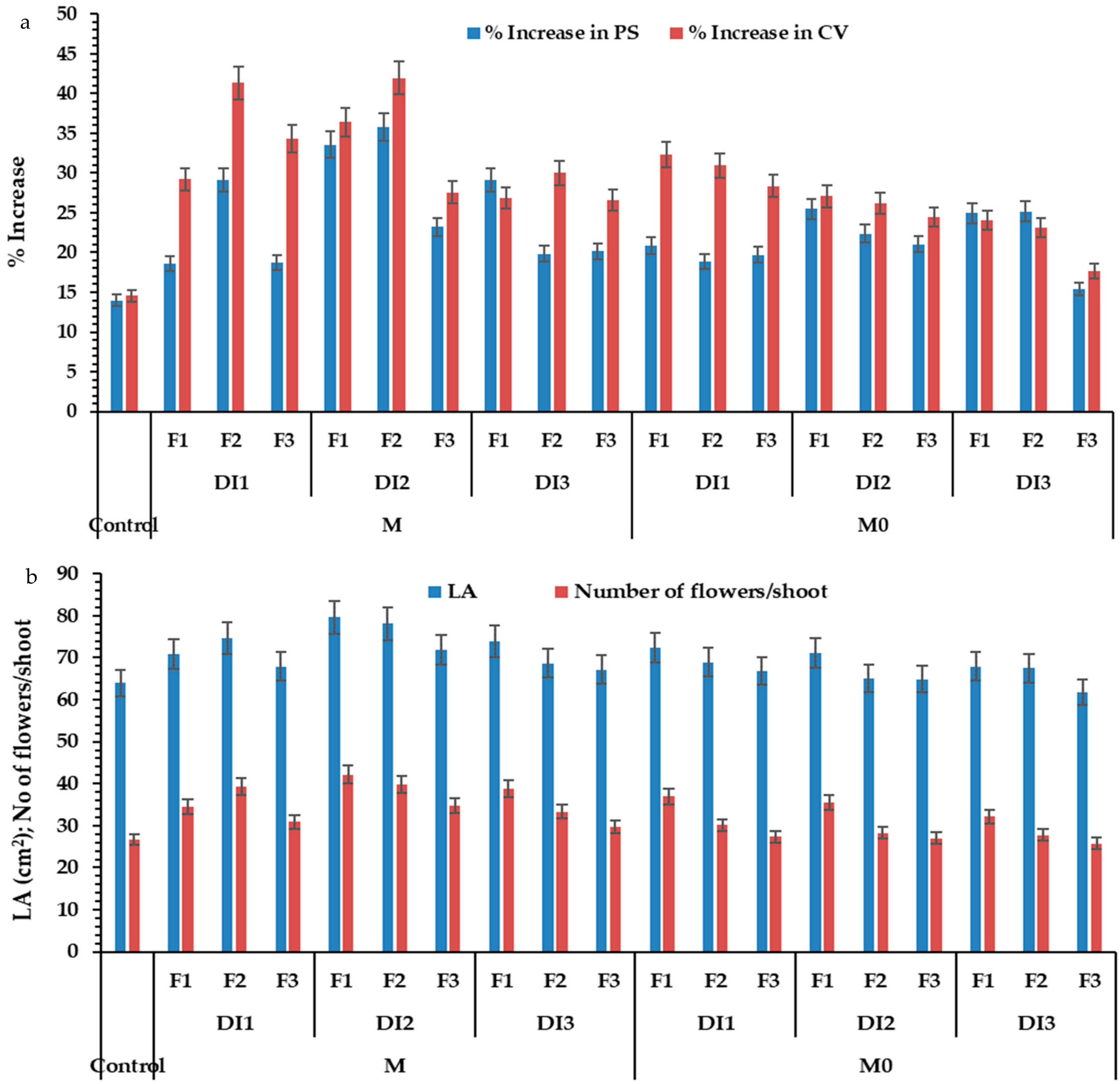

Figure 1. Interactive effect of mulching in combination with drip irrigation and nutrient management on (**a**) increase in plant spread and canopy volume and (**b**) leaf area and number of flower/shoot of guava cv. VNR Bihi. M (mulch), M0 (no mulch); DI (drip irrigation level: 100% CPE, 80% CPE, 60% CPE); F (fertigation level: 100% RDF, 80% RDF, 60% RDF).

3.2. Fruit Yield

The fruit yield data recorded from the experimental trials of 2017 and 2018 as influenced by mulching, drip irrigation, and fertigation was pooled and is presented in Table 2; interaction data are in the Supplementary Materials (Table S2). The fruit yield was significantly influenced by mulching, drip irrigation scheduling, and fertilizer doses. Plastic mulch gave a significantly higher yield of 17 and 9% over absolute control and no mulch treatment. Under irrigation scheduling, D_2 produced significantly higher fruit yields over D_1 and D3. The treatment combination MDI_2F_1 (mulch + 80% CPE + 100%

RDF) produced the maximum fruit yield (52.55 kg/plant) while lowest under absolute control (36.85 kg/plant). Among the three levels of drip irrigation, maximum fruit yield was attained under 80% CPE, followed by 100% CPE; similarly, in three levels of fertigation, 100 percent RDF resulted in higher fruit yield (45.20 kg/plant). Irrigation at 80% CPE with 100% RDF augmented the higher yields response to 48.20 kg/plant. Similarly, plastic mulch with 100% RDF resulted in fruit yield increment due to better nutrient and soil moisture distribution. Results revealed the significant effect of mulching and fertilization systems on plant carbon assimilation, photosynthesis, soil nutrient availability, and constant moisture supply, resulting in better fruit yield.

3.2.1. Soil Organic Carbon and Dehydrogenate Activity

The soil organic carbon and dehydrogenase, presenting the soil carbon pool and microbial activity pooled data in response to mulching, drip irrigation, and fertigation, are presented in Table 3 and depicted in Figure 2. The soil organic carbon under plastic mulch was slightly decreased over two years compared to absolute control and no mulch. Soil organic carbon also showed significant changes among the mulched and nonmulched plants, where a maximum (0.76%) was found under the nonmulched plants and a minimum (0.76%) was found in mulched. The effect of irrigation scheduling and interactions between plastic mulch, drip irrigation, and fertigation on SOC was nonsignificant. Treatment combination $M_0DI_1F_1$ (non-mulch + 100% CPE + 100% RDF) exhibited maximum organic carbon content (80 g/kg soil), while minimum (0.75 g/kg soil) was found under MDI_3F_2 and MDI_2F_3. Increment in fertigation level also revealed a positive trend toward increasing SOC, which might be associated with better root activities. Moreover, dehydrogenase enzyme activity resembling soil respiration or microbial activities was significantly influenced by mulching, drip irrigation, and fertigation practices. The results depicted a significant variation among the treatment combinations as well. The increasing amount of fertilizer dose did not play many roles in increasing the soil dehydrogenase activity because the maximum value (261.57 µg TPF/g/24 h) was found under the 80% recommended dose of fertilizers. Similarly, mulch also provided an environment conducive for microbe growth, which in turn increased the soil enzymatic activities.

Table 3. Effect of plastic mulch, drip irrigation, and fertigation system on the rhizospheric soil carbon content, enzyme activity, and nutrient availability under the guava.

Treatments	SOC (g/kg Soil)	Dehydrogenase Activity (µg TPF/g/24 h)	Nutrient Availability (kg/ha)		
			Nitrogen	Phosphorus	Potassium
Control	77	161.6	159.9	28.66	171.95
M	76	295.4	201.64	46.91	237.85
M_0	78	207.7	180.91	36.59	207.65
SE(m)	0.03	1.3	2.05	0.74	1.08
C.D. at 5%	0.09	3.6	5.82	2.1	3.06
DI_1	77	251.9	190.56	41.98	206.25
DI_2	77	263.7	198.15	45.27	210.82
DI_3	76	239	185.11	38	119.85
SE(m)	0.04	1.6	2.51	0.9	1.32
C.D. at 5%	NS	4.4	7.12	2.57	3.75
F_1	78	254.2	203.03	47.73	242.19
F_2	77	261.6	193.09	43.22	223.09
F_3	76	238.9	177.7	34.3	202.97
SE(m)	0.01	1.6	2.51	0.9	1.32
C.D. at 5%	0.04	4.1	7.12	2.57	3.78

M (mulch), M0 (no mulch); DI (drip irrigation level: 100% CPE, 80% CPE, 60% CPE); F (fertigation level: 100% RDF, 80% RDF, 60% RDF).

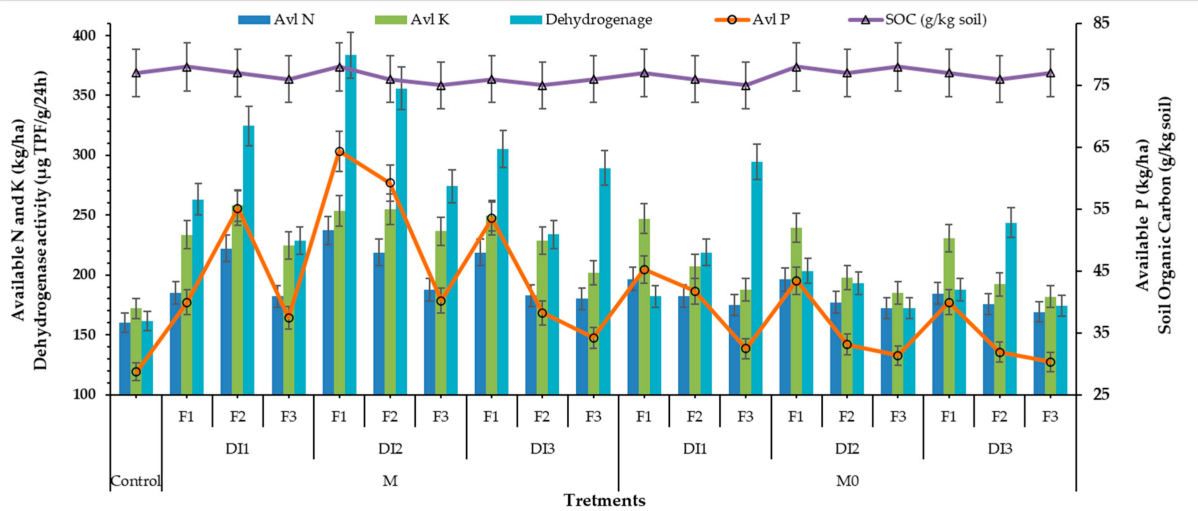

Figure 2. Nutrient availability (NPK, kg/ha) influenced by mulching and fertigation system (pooled data of two-year experiment). M (mulch), M0 (no mulch); DI (drip irrigation level: 100% CPE, 80% CPE, 60% CPE); F (fertigation level 100% RDF, 80% RDF, 60% RDF).

3.2.2. Nutrient Availability

The pooled data concerning nutrient availability (NPK, kg/ha) as influenced by mulching, drip irrigation, and fertigation are presented in Table 3 and depicted in Figure 2. Among the three levels of drip irrigation, drip irrigation at 80% CPE resulted in higher levels of available nitrogen (198.15 kg/ha) and was found to be the best among the rest of the irrigation levels. Similarly, the availability of nitrogen under varying fertigation levels was significantly higher (203.03 kg/ha) in the 100% recommended dose of fertilizers. Among mulched and nonmulched conditions, available nitrogen was maximum under mulched plants (201.64 kg/ha). The interaction among different levels of drip irrigation and fertigation showed that soil available N increased with the increasing rate of evaporation replenishment and NPK fertigation. Maximum availability of soil N (237.06 kg/ha) was observed in drip irrigation level at 80% of CPE with 100% of the recommended dose of fertilizers along with silver-black plastic mulch (MDI_2F_1), which was superior to the other treatment combinations. Similarly, the available N content in soil irrespective of RDF levels through drip fertigation was significantly more than the conventional method of soil fertilization at the time of fruit harvesting. Under irrigation scheduling, maximum phosphorus (45.02 kg/ha) was found with drip irrigation at 80% CPE, followed by 100% CPE, and minimum (38.00 kg/ha) under 60% CPE. The quantity of soil phosphorus content also triggered high with the increment in drip fertigation levels and the maximum (47.73 kg/ha) was found under the plant which received 100% RDF and the minimum (34.30 kg/ha) was in 60% RDF. Taking interaction into consideration, significant results were found and it was revealed that plants under silver-black plastic mulch along with 80% drip irrigation (DI) level and 100% RDF resulted in higher P content (64.35 kg/ha). In contrast, the minimum (28.66 kg/ha) was found under control. The amounts of available P in soil, regardless of NPK levels via drip system, were significantly higher than the conventional system of irrigation and fertilization at the time of harvesting. Data concerning K availability signified a positive trend toward increment in irrigation levels, similarly under mulched plants rather than nonmulched plants and fertigation treatments as compared to conventional fertilization treatment (absolute control). Among the sole factors, higher potassium content (227.82 kg/ha) as well was found to be maximum with a drip at 80% CPE and, in contrast, the minimum (214.11 kg/ha) was recorded for under 60%. The soil potassium content enhanced significantly with increasing fertigation levels as well. Among the interaction combinations, a significant increment was observed under MDI_1F_1 resulting in higher amounts of potassium content (257.91 kg/ha).

The soil properties as influenced by management practices have resulted in positive growth response and fruit yield, which is evident from correlation data presented in Figure 3. Increased plant growth parameters, viz., plant canopy spread, canopy volume, and flowering, due to management practices (mulching, drip irrigation, and fertigation) represent a higher correlation ($R^2 \geq 0.85$) with fruit yield. Vegetative growth parameters are again positively correlated with soil nutrient availability and dehydrogenase activity. Moreover, the soil parameters, viz., nitrogen, phosphorus, potassium availability, and dehydrogenase activities, had a significantly positive linear correlation with fruit yield (Figure 4) and correlation coefficients R^2 = 0.84, 0.89, 0.87, and 0.71. However, soil organic carbon content showed no such correlation.

	Yield	DHD	Avl N	Avl P	Avl K	SOC	CS	LA	Flowers
Yield	1.00								
DHD	0.71	1.00							
Avl N	0.84	0.68	1.00						
Avl P	0.89	0.68	0.77	1.00					
Avl K	0.87	0.56	0.74	0.77	1.00				
SOC	0.12	-0.21	0.06	0.06	0.05	1.00			
CS	0.86	0.70	0.80	0.79	0.81	0.01	1.00		
LA	0.91	0.76	0.81	0.87	0.83	0.07	0.85	1.00	
Flowers	0.91	0.65	0.80	0.82	0.89	0.01	0.83	0.87	1.00

Figure 3. Pearson's correlation of plant growth response, fruit yield, and soil properties, as augmented by management practices ($p < 0.05$, $n = 76$). DHD (dehydrogenase); Avl N (available nitrogen); Avl P (available phosphorus); Avl K (available potassium); SOC (soil organic carbon); LA (leaf area); CS (canopy spread). strong positive correlation; negative or no correlation; weak positive correlation.

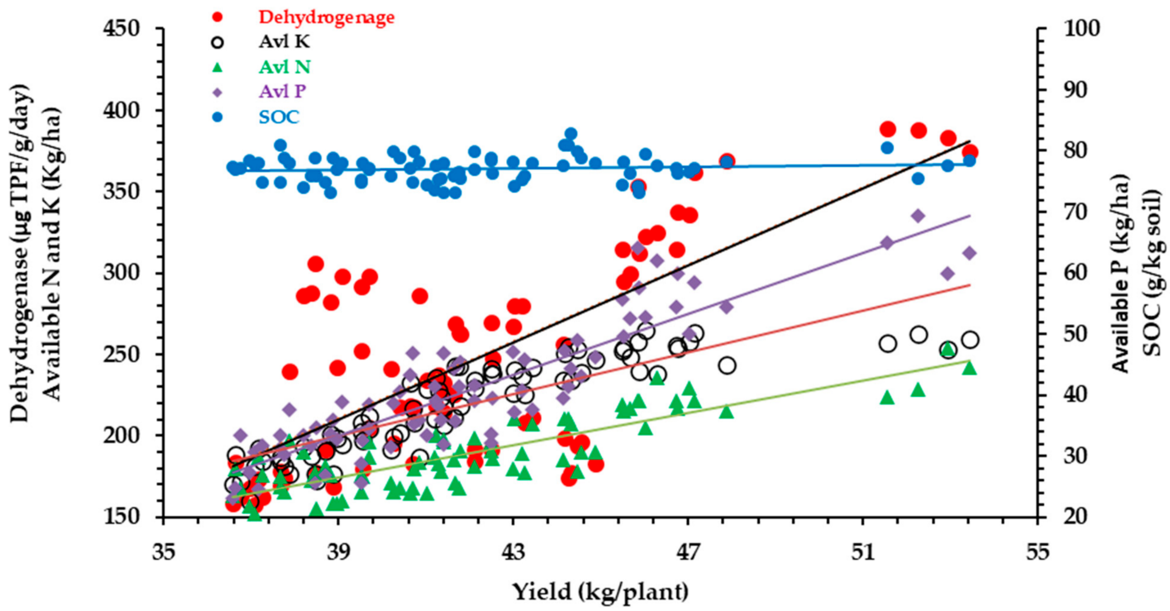

Figure 4. Correlation of soil properties as augmented by management practices with fruit yield ($p < 0.05$, $n = 76$).

4. Discussion

4.1. Plant Growth and Yield Response

This increase in plant spread is largely correlated with efficient use of nutrients by crops via timely and precise application of judicious amounts of nutrients, and through water availability to the crop root zone with a collateral reduction in N and K losses through leaching and percolation [25,26]. Soil mulching not only reduces the moisture losses during dry summers and weed growth, but also balances the soil temperature and increases microbial population and activities, resulting in elevated enzyme activities and plant nutrient uptake. In addition to reducing nutrient leaching losses, fertigation at an 80% CPE ratio with 300, 260, and 200 g NPK/plant/year sustains the moisture and nutrient bioavailability during growth. Additionally, Ramniwas et al. [27] and Khan et al. [28] affirmed that the combined response of mulch, fertigation, and drip irrigation increased the Allahabad cv. of guava plant growth response due to rhizospheric microclimate alteration. The increment in growth activity is also regulated by the amount and duration of bioavailable nutrients in the soil solution by optimizing photosynthesis and its partitioning; thus, a significant increment in canopy volume may have been the result of fertigation scheduling at 80% CPE [29]. Drip irrigation maintains a consistent moisture regime in the soil and roots remain active throughout the season, resulting in optimum availability of nutrients and proper translocation of food materials, which accelerate the fruit growth and development in guava. An increase in the vegetative growth with increasing fertigation levels might be attributed to better supplementation and utilization of nutrients and moisture, particularly in the plants with the highest dose of NPK when applied through fertigation, which in turn enhances cell division and formation of more tissues, results in more vegetative growth, and leads to higher annual extension and plant spread increase in leaf area [29]. A direct relationship between nitrogen application and vegetative growth is a well-established fact in guava [27]. In line with the present results, Pramanik et al. [7] also reported a significant effect of irrigation level and fertigation that had a significant effect on the leaf area of banana cv. Martaman. However, they revealed an insignificant effect of drip irrigation × fertigation on leaf area, and also reported that irrigation at 100% level proved to be superior in increasing the leaf area, which was at par with 75 percent irrigation level. The nutritional status of the crop, especially nitrogen, can markedly affect the rate of development of leaf area [30]. Balanced nutrition, primarily concerning nitrogen, plays a vital role in increasing the supply of auxins to the apical portion and may reduce the abscission flowering and indirectly increase the floral count and thereby the yield [29]. Better photosynthetic assimilates and hormonal balance due to balanced nutrition would have improved the sink strength through the acceleration of mega- and microsporogenesis and differentiation of axillary buds into reproductive ones [31]. In contrast to the lower level of NPK, the higher level resulted in rapid flower production due to the constant supply of water and nutrients, favoring better growth and development of the plants [27]. The nitrogen application also promotes the supply of auxins to the fruits, which also reduces the abscission thereby increasing the fruit yield. A combination of silver-black mulch with 100% drip irrigation level can play a definite role in augmenting the productivity of growing strawberries in a high tunnel in the Mediterranean environment, as it is also meant to increase the leaf area index that in turn helps to enhance photosynthesis and consequently the source–sink relationship [32]. Drip irrigation with mulching enhances the microflora of the soil by improving the environment around the root zone. Continuous application of different types of mulches helps improve the organic matter content of the soil that in turn improves the water-holding capacity of the soil. Therefore, drip irrigation along with plastic mulch offers a sound scientific basis for increasing crop yields [33].

4.2. Soil Health

The increase in soil organic carbon with increasing irrigation and fertilizer levels might be due to the gradual accumulation of root exudates and decaying dead roots in soil under a regular and optimal supply of water and nutrients by drip fertigation. Under a regular supply of soil moisture (drip irrigation), more of the roots proliferate laterally and concentrate near the surface. Soil organic carbon and nutrient status are significant indicators of soil fertility. Our study showed a significant increase in nitrogen availability under plastic film mulching, which might be attributed to increased mineralization as a result of regulated temperature and moisture conditions [34]. However, in our study, it could be noted that soil organic carbon was slightly decreased. The amount of organic C in the root zone is dependent on the rate of organic matter decomposition and the addition of residual biomass. Plastic mulching is likely to enhance decomposition by altering the moisture content, topsoil heat, and enhanced microbial activity. Similarly, Kotur [35] also framed that plastic mulching significantly lowers organic carbon. In contrast, [36] revealed a positive relationship of SOC dynamics with years of mulching that had been practiced, and reported a significant increase in increase SOC during the long term due to an increase in root biomass. Organic carbon content in surface soil was increased significantly due to the application of fertilizers as the application of fertilizer helped in increasing biomass production [37]. The soil enzyme activity, altered under mulching–irrigation modulated conditions, may lead to the alterations in soil properties, especially soil pH, which has a significant impact on investigated enzymes [38]. Soil dehydrogenase is considered an integral part of the intact cells of microorganisms and dehydrogenase activity is thought to reflect the total range of oxidative activities of the soil microflora [24]. The increased dehydrogenase activity, noted for drip fertigation at 100%, may be attributed to increased population of soil microbes. Dehydrogenase is thought to be an indicator of overall microbial activity because it occurs intracellularly in all living microbial cells and is linked with microbial oxidoreduction processes [39]. An increase in dehydrogenase activity per increment in fertilizer treatments was significantly higher, indicating that balanced fertilization leads to higher microbial metabolic activity than lower fertilization treatments [40].

Increased nutrient availability under drip irrigation level at 80% CPE can be attributed to the slower and smooth nutrient translocation applied through drip systems as fertigation rather than conventional soil application followed by basin systems irrigation. However, conventionally based systems of irrigation may cause leach losses and deep percolation beyond the crop rhizosphere, resulting in lower nutrients, primarily nitrogen availability. It has also been well documented that these nutrient dynamics in the soil system are closely related to the water movement and its distribution in soil [41]. These findings have a great significance because they offer moisture and water conservation techniques such as mulching and drip fertigation technology. Mulching offers significant advantages such as reduced soil moisture losses due to evaporation, weed control, and favorable temperature for root growth. The attribute of gradual/sustained availability of P as well in the root zone by gradual mobility in soil apart under modulated irrigation at 80% CPE may lead to restricted P losses due to leaching, deep percolation, and precipitation [10,42]. Further, higher P accumulation and bioavailability under fertigation compared to soil applications may be due to the complete solubility of fertilizers. Phosphorus fertigation via drip irrigation facilitates both horizontal and vertical movement of soil phosphorus near the outlet [43], and raises soil phosphorus concentration to a greater extent within the 0–30 cm soil layer rather than at the 30–60 cm layer in pear orchard [44]. Kumar et al. [45] reported that available P was, in general, higher in surface 0–20 cm soil layers; however, it was markedly higher under drip fertigation compared to surface-irrigated apple orchards. Similarly, increasing doses of fertigation improved soil phosphorus and potassium availability have been reported for apricot [46]. The study also revealed that the interactive effect of drip irrigation at 80 percent level with fertigation at 100 percent recommended dose of fertilizers resulted in a higher quantity of soil potassium content (246.37 kg/ha) as compared to the other two combinations. Pramanik et al. [47] also reported significantly higher bioavailability of K under surface irrigation and conventional soil fertilization while taking ratoon crop of banana. This might be due to the adsorption of applied K within the soil surface, thus preventing its movement down into the soil underneath despite a variable load of irrigation water application. Additionally, a raised concentration of K was observed to a greater extent within the 0–30 cm soil layer than at the 30–60 cm layer in pear orchards during K fertigation [44]. Tiwari et al. [8] revealed that the plastic-mulched soil contained more available potassium for the sapota plants as compared to soil without plastic mulch.

However, irrigation and fertigation scheduling for fruit trees such as guava, banana, and plantain in tropical territories have been practiced for many years in an irregular and inefficient manner due to little research or findings of scientifically sound technologies for judicious water management through irrigation practices, fertigation, and soil and water conservation, as shown by the results for commercially important fruit trees [48,49]. The results in tropical areas for fruit trees establish that, through a regular supply of soil moisture with drip irrigation, more roots proliferate laterally and are concentrated near the surface [50,51]; these studies emphasize the importance of soil organic carbon and nutrient status as indicators of soil quality and fertility. Our results establish that irrigation is a determining factor in guava production. The source of available water is deep wells with marked scarcity in the area, a fact that has increased production costs. In general, this crop is irrigated by microsprinkler once a week in some areas of Venezuela, Colombia, and Panama [52,53], for which recommendations have been made for the water sheet when applied, in terms of volume, depending on the percentage of coverage of the plant crown. However, the contributions that have been made in terms of irrigation management in fruit trees in the agroecological conditions of the area have been very scarce [54,55]. Guava production is becoming more expensive, and its availability is scarce in these Latin American countries. Associated with the low production of trees and small fruits of little commercial value, they have forced the abandonment of orchards as they are considered unproductive, reducing the area planted with guava [53,54]. This is why the results of our study represent the initial basis of scientific evidence that raises the need to evaluate technology to optimize irrigation and fertilization water, particularly with respect to climate change and water crisis [56–58].

5. Conclusions

Standardization of fertigation scheduling in guava, especially within the Tarai regions of India or arid or semiarid areas of the world, is the current need to achieve qualitative and quantitative fruit production sustainability. Fertigation standardization not only resulted in nutrient and water savings, but also improved growth. In addition to reducing nutrient losses and improving soil quality and production, plastic mulching and precision irrigation help to decrease the issue of overwatering. Plastic mulching significantly increased the plant spread, canopy volume, and leaf area compared to no mulching. The response of irrigation and fertigation on plant spread, canopy volume, leaf area, and the number of flowers/shoots was recorded as significantly higher under D_2 and F_1. The treatment combination $M_0DI_1F_1$ (nonmulch + 100% CPE + 100% RDF) exhibited maximum organic carbon content (80 g/kg soil), while the minimum (0.75 g/kg soil) was found under MDI_3F_2 and MDI_2F_3. The maximum availability of soil N and P was observed in drip irrigation levels at 80% of CPE with 100% of the recommended dose of fertilizers along with silver-black plastic mulch (MDI_2F_1), which resulted to be superior to the other treatment combinations. Among the interaction combinations, a significant increment was observed under MDI_1F_1, resulting in higher amounts of potassium content. Increased plant growth parameters, viz., plant canopy spared, canopy volume, and flowering, due to management practices (mulching, drip irrigation, and fertigation) presented a higher correlation with fruit yield. Similarly, the soil, viz., nitrogen, phosphorus, potassium availability, and dehydrogenase activity, had a significantly positive linear correlation with fruit yield. Therefore, application of a 100% recommended dose of fertilizer with drip irrigation at 80% in guava orchards is recommended to achieve a targeted yield of better quality. For a sustainable future, farmers belonging to the tropical and subtropical countries can employ this method to conserve natural resources such as water and nutrients.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/hydrology9090151/s1, Figure S1: Weakly meteorological weather data for experimental year (a) 2017 and (b) 2018, Table S1: Physical and chemical attributes of soil before the execution of experiment, Table S2: Data for correlation studies (n = 76).

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References

1. Parvez, G.M.; Shakib, U.; Khokon, M.A.; Sanzia, M. A short review on a nutritional fruit: Guava. *Open Access Toxicol. Res.* **2018**, *1*, 1–8.
2. Vijaya, A.A.; Velayuthaprabhu, S.; Rengarajan, R.L.; Sampathkumar, P.; Radhakrishnan, R. Bioactive Compounds of Guava (*Psidium guajava* L.). In *Bioactive Compounds in Underutilized Fruits and Nuts*; Springer International Publishing: Cham, Switzerland, 2020; pp. 503–527.
3. Saxena, M.; Rathore, R.P.S.; Gupta, R.P.; Bhargav, H.; Thakur, B. Horticultural Statistics at a Glance. Horticulture Statistics division, Department of Agriculture. In Cooperation & Farmers Welfare, Ministry of Agriculture & Farmers Welfare, Government of India. 2018. Available online: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwjLtZyP8dv5AhULv5QKHaSmBroQFnoECAMQAQ&url=https%3A%2F%2Fagricoop.nic.in%2Fsites%2Fdefault%2Ffiles%2FHorticulture%2520Statistics%2520at%2520a%2520Glance-2018.pdf&usg=AOvVaw0zG88g0I6lWc8epxZVGYNB (accessed on 15 June 2022).
4. Singh, H.P.; Singh, G. Nutrient and Water Management in Guava. In I International Guava Symposium; International Society for Horticultural Science. 2005, Volume 735, pp. 389–397. Available online: https://www.ishs.org/ishs-article/735_55 (accessed on 15 June 2022).
5. Crisostomo, L.A.; Naumov, A. Fertilizing for high yield and quality: Tropical fruits of Brazil. In *International Institute Potash*; CHE: Horgen, Switzerland, 2007.
6. Singh, P.; Singh, A.K.; Sahu, K. Irrigation and fertigation of pomegranate cv. Ganesh in Chhattisgarh. *Indian J. Hortic.* **2006**, *63*, 148–151.
7. Pramanik, S.; Patra, S.K. Influence of fertigation on fruit yield, water use and distribution efficiency and economics of guava (*Psidium guajava* L.). *J. Soil Water Conserv.* **2014**, *13*, 164–169.
8. Tiwari, K.N.; Kumar, M.; Santosh, D.T.; Singh, V.K.; Maji, M.K. Influence of Drip Irrigation and Plastic Mulch on Yield of Sapota (Achraszapota) and Soil Nutrients. *Irrig. Drain. Syst. Eng.* **2014**, *3*, 116. [CrossRef]
9. Bisbis, M.B.; Gruda, N.; Blanke, M. Potential impacts of climate change on vegetable production and product quality—A review. *J. Clean. Prod.* **2018**, *170*, 1602–1620. [CrossRef]
10. Raina, J.N. Drip irrigation and fertigation: Prospects and retrospects in temperate fruit production. In *Enhancement of Temperate Fruit Production*; Jindal, K.K., Gautam, D.R., Eds.; Dr. Yashwant Singh Parmar University of Horticulture and Forestry: Solan, India, 2002; pp. 296–301.
11. Veeraputhiram, R.; Kandasamy, O.S.; Singh, S.D.S.; Chinnusamy, C. Influence of drip irrigation and nitrogen fertigation on growth and yield of hybrid cotton. *J. Ecobiol.* **2005**, *17*, 329–335.
12. Badr, M.A.; Abou Hussein, S.D.; El-Tohamy, W.A.; Gruda, N. Efficiency of subsurface drip irrigation for potato production under different dry stress conditions. *Gesunde Pflanz.* **2010**, *62*, 63–70. [CrossRef]
13. Saleh, S.A.; El-Shal, Z.S.; Fawzy, Z.S.; El-Bassiony, A.M. Effect of water amounts on artichoke productivity irrigated with brackish water. *Aust. J. Basic Appl. Sci.* **2012**, *6*, 54–61.

14. Panigrahi, P.; Raychaudhuri, S.; Thakur, A.K.; Nayak, A.K.; Sahu, P.; Ambast, S.K. Automatic drip irrigation scheduling effects on yield and water productivity of banana. *Sci. Hortic.* **2019**, *257*, 108677. [CrossRef]
15. Kumar, S.; Sharma, I.P.; Raina, J.N. Effect of levels and application methods of irrigation and mulch materials on strawberry production in north-west Himalayas. *J. Indian Soc. Soil Sci.* **2005**, *53*, 60–65.
16. Preet, M.S.; Kumar, R.; Singh, V.P.; Kumar, J.; Singh, A.K.; Chand, S. Effect of plastic mulch, drip irrigation and fertigation on vegetative growth and chemical attributes of guava in Tarai region. *Int. J. Chem. Stud.* **2019**, *7*, 214–218. [CrossRef]
17. Preet, M.S.; Kumar, R.; Singh, V.P.; Dongariyal, A.; Srivastava, R. Response of guava to integrated nutrient and water management. *Indian J. Hortic.* **2021**, *78*, 189–197. [CrossRef]
18. Vermeiren, L.; Jobling, G.A. Localized irrigation design, installation, operation, evaluation. *Estud. FAO Irrig. Drain. Pap.* **1984**, *36*, 10–11.
19. Westwood, M.N. *Temperate Zone Pomology, Physiology and Culture*, 3rd ed.; Timber Press, Inc.: Portland, OR, USA, 1993.
20. Walkley, A.; Black, I.A. An examination of the different method for determining organic carbon in soils: Effect of variations in digestion conditions and of inorganic soil constituents. *Soil Sci.* **1934**, *63*, 251–263. [CrossRef]
21. Subbiah, B.V.; Asija, G.L. A rapid procedure for estimation of available nitrogen in soils. *Curr. Sci.* **1956**, *25*, 259–260.
22. Olsen, S.R. *Estimation of Available Phosphorus in Soils by Extraction with Sodium Bicarbonate (No. 939)*; US Department of Agriculture: Washington, DC, USA, 1954.
23. Schollenberger, C.J.; Simon, R.H. Determination of exchange capacity and exchangeable bases in soil—Ammonium acetate method. *Soil Sci.* **1945**, *59*, 13–24. [CrossRef]
24. Casida, L.E.; Klein, D.A.; Santoro, T. Soil Dehydrogenase Activity. *Soil Sci.* **1964**, *98*, 371–376. [CrossRef]
25. Kavino, M.; Kumar, N.; Soorianath Sundaram, K.; Jeyakumar, P. Effect of source of fertilisers for fertigation on yield and quality of banana cv. obusta (AAA). *South Indian Hortic.* **2002**, *50*, 301–307.
26. Mahalakshmi, M.; Kumar, N.; Jeyakumar, P.; Sivapathasundaram, K. Fertigation studies in banana under normal system of planting. *South Indian Hortic.* **2001**, *49*, 80–83.
27. Ramniwas Kaushik Sarolia, D.K.; Pareek, S.; Singh, V. Effect of irrigation and fertigation scheduling on growth and yield of guava (*Psidium guajava* L.) under meadow orcharding. *Afr. J. Agric. Res.* **2012**, *7*, 6350–6356. [CrossRef]
28. Khan, J.N.; Jain, A.K.; Sharda, R.; Singh, N.; Gill, P.S.; Kaur, S. Growth, yield and nutrient uptake of guava (*Psidium guavaja* L.) affected by soil matric potential, fertigation and mulching under drip irrigation. *Agric. Eng. Int. CIGR J.* **2013**, *15*, 17–28.
29. Kumawat, K.L.; Sarolia, D.K.; Kaushik, R.A.; Jodha, A.S. Effect of irrigation and fertigation scheduling on growth, flowering, yield and economics of guava cv. Lalit under ultra-high density planting system. *Hortic. Soc. India* **2017**, *74*, 362–368.
30. Biswas, T.; Bandyopadhyay, P.K.; Nandi, R.; Mukherjee, S.; Kundu, A.; Reddy, P.; Kumar, P. Impact of mulching and nutrients on soil water balance and actual evapotranspiration of irrigated winter cabbage (*Brassica oleracea* var. *capitata* L.). *Agric. Water Manag.* **2022**, *263*, 107456. [CrossRef]
31. Takahashi, H.; Shennan, C.; Huffaker, R.C. Agronomical and physiological studies on zinc deficiency in crop plants. 2. Effect of zinc concentration in nutrient solution and shading on growth, N content and nitrate reductase activity in tomato. *Nettai Nogyo* **1993**, *37*, 22–27.
32. Sarıdaş, M.A.; Kapur, B.; Çeliktopuz, E.; Şahiner, Y.; Kargı, S.P. Land productivity, irrigation water use efficiency and fruit quality under various plastic mulch colors and irrigation regimes of strawberry in the eastern Mediterranean region of Turkey. *Agric. Water Manag.* **2021**, *245*, 106568. [CrossRef]
33. Sharma, U.K.; Meshram, K.S. Evaluate the effect of mulches on soil temperature, soil moisture level and yield of capsicum (Capsicum annuum) under drip irrigation system. *Int. J. Agric. Eng.* **2015**, *8*, 54–59. [CrossRef]
34. Ma, D.; Chen, L.; Qu, H.; Wang, Y.; Misselbrook, T.; Jiang, R. Impacts of plastic film mulching on crop yields, soil water, nitrate, and organic carbon in North-western China: A meta-analysis. *Agric. Water Manag.* **2020**, *202*, 166–173. [CrossRef]
35. Kotur, S.C. Changes in the spatial root activity distribution and placement of superphosphate for maximum absorption as influenced by age of trees of cv. Arka Mridula (*Psidium guajava* L.). *Acta Hortcult.* **2007**, *735*, 413–418. [CrossRef]
36. Liu, J.; Bu, L.; Zhu, L. Optimizing plant density and plastic film mulch to increase maize productivity and water-Use efficiency in semiarid areas. *Agron. J.* **2014**, *106*, 1138–1146. [CrossRef]
37. Tank, R.V.; Patel, N.L. Influence of fertigation on yield and nutrient status in soil and leaf of papaya (Carica papaya L.) var. Madhu Bindu under south Gujarat condition. *Asian J. Hortic.* **2013**, *8*, 170–173.
38. Muñoz, K.; Thiele-Bruhn, S.; Kenngott, K.G.J.; Meyer, M.; Diehl, D.; Steinmetz, Z.; Schaumann, G.E. Effects of Plastic versus Straw Mulching Systems on Soil Microbial Community Structure and Enzymes in Strawberry Cultivation. *Soil Syst.* **2022**, *6*, 21. [CrossRef]
39. Stepniewska, Z.; Wolinska, A. Soil dehydrogenase activity in the presence of chromium (III) and (VI). *Int. Agrophys.* **2005**, *19*, 79–83.
40. Luo, P.; Han, H.; Wang, Y.; Han, M.; Shi, H.; Liu, N.; Bai, H. Influence of long-term fertilization on soil microbial biomass, dehydrogenase activity, and bacterial and fungal community structure in a brown soil of northeast China. *Ann. Microbiol.* **2015**, *65*, 533–542. [CrossRef] [PubMed]
41. Santos, D.V.; Sousa, P.L.; Smith, R.E. Model simulation of water and nitrate movement in a level basin under fertigation treatments. *Agric. Water Manag.* **1997**, *32*, 293–306. [CrossRef]

42. Bangar, A.R.; Chaudhari, B.C. Nutrient mobility in soil, uptake, quality and yield of Suru sugarcane as influenced by drip fertigation in medium vertisols. *J. Indian Soc. Soil Sci.* **2004**, *52*, 164–171.
43. Bacon, P.E.; Davey, B.G. Nutrient availability under trickle irrigation: II. Mineral Nitrogen 1. *Soil Sci. Soc. Am. J.* **1982**, *46*, 987–993. [CrossRef]
44. Klein, I.; Meimon, A.; Skedi, D. Drip nitrogen, phosphorus, and potassium fertigation of 'Spadona' Pear. *J. Plant Nutr.* **1999**, *22*, 489–499. [CrossRef]
45. Kumar, P.; Suman, S.; Spehia, R.S.; Kumar, V.; Kaith, N.S. Studies on method and rate of fertilizer application in apple under mulch in north-western Himalayas. *J. Plant Nutr.* **2016**, *39*, 219–226. [CrossRef]
46. Bindra, M. Effect of Drip Fertigation and Mulch on Soil Nutrient Status and Growth Parameters of Apricot (Prunus Armeniaca) cv. Harcot. Ph.D. Thesis, Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India, 2012.
47. Pramanik, S.; Lai, S.; Ray, R.; Patra, S.K. Effect of drip fertigation on yield, water use efficiency, and nutrients availability in banana in West Bengal, India. *Commun. Soil Sci. Plant Anal.* **2016**, *47*, 1691–1700. [CrossRef]
48. Campos, O.; Paredes, F.; Rey, J.; Lobo, D.; Galvis-Causil, S. The relationship between the normalized difference vegetation index, rainfall, and potential evapotranspiration in a banana plantation of Venezuela. Sains Tanah. *J. Soil Sci. Agroclimatol.* **2021**, *18*, 58–64. [CrossRef]
49. Olivares, B.; Rey, J.C.; Lobo, D.; Navas-Cortés, J.A.; Gómez, J.A.; Landa, B.B. Fusarium Wilt of Bananas: A Review of Agro-Environmental Factors in the Venezuelan Production System Affecting Its Development. *Agronomy* **2021**, *11*, 986. [CrossRef]
50. Araya-Alman, M.; Acevedo-Opazo, C.; Rey, J.C.; Lobo, D.; Navas-Cortés, J.A.; Gómez, J.A.; Landa, B.B.; Orlando, O. Relationship Between Soil Properties and Banana Productivity in the Two Main Cultivation Areas in Venezuela. *J. Soil Sci. Plant Nutr.* **2020**, *20*, 2512–2524. [CrossRef]
51. Calero, J.; Rey, J.C.; Lobo, D.; Landa, B.B.; Gómez, J.A. Correlation of banana productivity levels and soil morphological properties using regularized optimal scaling regression. *Catena* **2022**, *208*, 105718. [CrossRef]
52. Olivares, B.; Hernández, R. Application of multivariate techniques in the agricultural land's aptitude in Carabobo, Venezuela. *Trop. Subtrop. Agroecosyst.* **2020**, *23*, 2. Available online: https://n9.cl/zeedh (accessed on 15 June 2022).
53. Montenegro, E.; Pitti, J.; Orlando, B. Identification of the main subsistence crops of Teribe: A case study based on multivariate techniques. *Idesia* **2021**, *39*, 83–94. [CrossRef]
54. Pitti, J.; Olivares, B.; Montenegro, E. The role of agriculture in the Changuinola District: A case of applied economics in Panama. *Trop. Subtrop. Agroecosyst.* **2021**, *25*, 1–11. Available online: https://n9.cl/quyl2 (accessed on 15 June 2022).
55. Orlando, B.; Pitti, J.; Montenegro, E. Socioeconomic characterization of Bocas del Toro in Panama: An application of multivariate techniques. *Rev. Bras. De Gest. E Desenvolv. Reg.* **2020**, *16*, 59–71. [CrossRef]
56. Valipour, M.; Guzmán, S.M. Identification of the Meteorological Variables Influencing Evapotranspiration Variability Over Florida. *Environ. Model. Assess.* **2022**, *27*, 645–663. [CrossRef]
57. Valipour, M. Calibration of mass transfer-based models to predict reference crop evapotranspiration. *Appl. Water Sci.* **2017**, *7*, 625–635. [CrossRef]
58. Angelakis, A.N.; Valipour, M.; Dietrich, J.; Voudouris, K.; Kumar, R.; Salgot, M.; Mahmoudian, S.A.; Rontogianni, A.; Tsoutsos, T. Sustainable and Regenerative Development of Water Mills as an Example of Agricultural Technologies for Small Farms. *Water* **2022**, *14*, 1621. [CrossRef]