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Vermiwash Prepared From Different Agricultural By-products Enhanced the Growth, Yield and Quality of Maize Grown under Reduced Chemical Fertilizer Use

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ABSTRACT

Maize (*Zea mays* L.) is main cereal, which is mainly affected by nutrient scarcity. With the objective to resolve nutrient scarcity in maize through the integration of inorganic fertilizer with organic vermiwash (Vw), an experiment was executed during the spring season of 2019 and 2020, having Randomized Complete Block Design (RCBD) replicating thrice. The treatments involve F_1: 100% recommended chemical fertilizer + No spray (control); F_2: 100% recommended chemical + Positive control (water spray); F_3: 75% recommended chemical fertilizer + alligator weed Vw 15%; F_4: 75% recommended chemical fertilizer + alfalfa Vw 15%; F_5: 75% recommended chemical fertilizer + rice straw Vw 15%; F_6: 75% recommended chemical fertilizer + alligator weed Vw 7.5% + alfalfa Vw 7.5%; F_7: 75% recommended chemical fertilizer + alligator weed Vw 7.5% + rice straw Vw 7.5%; F_8: 75% recommended chemical fertilizer + alfalfa Vw 7.5% + rice straw Vw 7.5%; F_9: 75% recommended chemical fertilizer + alligator weed Vw 5% + alfalfa Vw 5% + rice straw Vw 5%. Foliar spray of Vw was made at 30, 45 and 60 days after sowing. Foliar application of Vw from all sources along with chemical fertilizer improved the maize growth, quality and yield as compared to that of control; however, foliar spray of alligator weed Vw showed the maximum performance concerning morpho-physiological attributes of hybrid maize. The highest crop growth rate (22.93 and 22.95 g m^{-2} day^{-1}), mean net assimilation rate (5.24 and 5.26 g m^{-2} day^{-1}), chlorophyll fluorescence value (0.785 and 0.789), grain protein contents (11.2 and 11.4%), oil contents (3.4 and 3.6%) and grain yield (8.14 and 8.28 t ha^{-1}) during 2019 and 2020, respectively, was noted by applying 75% recommended chemical fertilize + alligator weed Vw 15%.

Keywords: Earthworm, vermicompost, vermiwash, foliar spray, maize, grain yield.

INTRODUCTION

Maize is an important cereal crop followed by wheat and rice, which is a main food for approximately 200 million people (Anwar et al., 2022). It is a chief energy source for humans around the globe, providing feed for poultry birds and also used as feed for domestic animals. Its seed comprises of high value edible oil, starch, minerals, protein and vitamin A. It is cultivated in Pakistan on 1.653 million hectares with per annum production of 10.635 million tons and an average grain yield of 6436 kg ha^{-1}. Its production is boosted by 18.84% to 10.635 million tons as compared to that of previous year's production of 8.949 million tons (GOP 2022).

Maize requires a sufficient amount of nitrogen (N), phosphorus (P) and potassium (K) which are generally gained from synthetic fertilizers to restore N, P and K in soil, ensuring an increase in expenses along with pollution (Sofyan and Sara, 2019). The continuous application of synthetic fertilizers can alter the pH of soil, disrupt the soil

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microbial environments, increase the incidence of pest attacks and also the emission of greenhouse gases. Though, chemical fertilizers are needed for getting more productivity; however, over-dependence on synthetic fertilizers is correlated with the reduction in crop yields and soil properties (Selim, 2020). Too many chemical fertilizers result in the degradation of soil and less nutrient use efficiency by crops that lead to extensive loss of N and environmental pollution (Pahalvi et al., 2021). Maize is a high nutrient requirement crop, and nutrient management plays an important role in enhancing productivity. Energy crises raised the cost of chemical fertilizer and farmers' low acquiring power have forced them to find substitutes.

Earthworms have a momentous position in enhancing the growth as well as productivity of plants. The practice of converting organic waste through earthworms into useful products is called vermitechnology (Sharma and Garg, 2023). Earthworms are very effective in boosting the decomposition of organic wastes. The worms do not prefer to feed on rich food. The dry organic matter that contains 1% N is a good source of nutrition for earthworms. Vermiwash (Vw) is a brown liquid extract collected after passing down water from the various layers of a unit that culture worms. This Vw contains enzymes, secretions of earthworms and essential micro and macronutrients that enhance the productivity of crops. It develops resistance in crops acquiring spray of earthworm wash. Such types of Vw have the nutrients in dissolved form, organic acids and earthworm’s mucus (Sivasubramanian and Ganeshkumar, 2004). Negi et al. (2023) reported that application of Vw on chickpea increased plant height, number of pods per plant, number of seeds per pod, seed yield per plant, 1000 seed weight, seed yield, straw yield, biological yield, net monetary returns. Akazawa et al. (2023) noted that Vw treatment on chickpeas enhanced the plant height, weight of tomato, and sugar contents.

The integrated use of organic and synthetic sources, referred to as integrated nutrient management (INM), is generally a better means of enhancing sustainability (Paramesh et al., 2023). The INM can improve crop yield by giving a better physico-chemical and microbial environment (Patra et al., 2023). It is the perfect solution for enhancing sustainable productivity and retaining soil fertility in maize. The existing capacity of animal waste matter and various crop residues cannot fulfill the requirements for good crop production. Therefore, emphasizes the use of organic sources and integrating it with inorganic fertilizers and biofertilizers seemed to be the better way of enhancing productivity.

Keeping these all in view, the present investigation was carried out with the objective to explore the impact of Vw with synthetic fertilizer on the morpho-physiological parameters of maize.

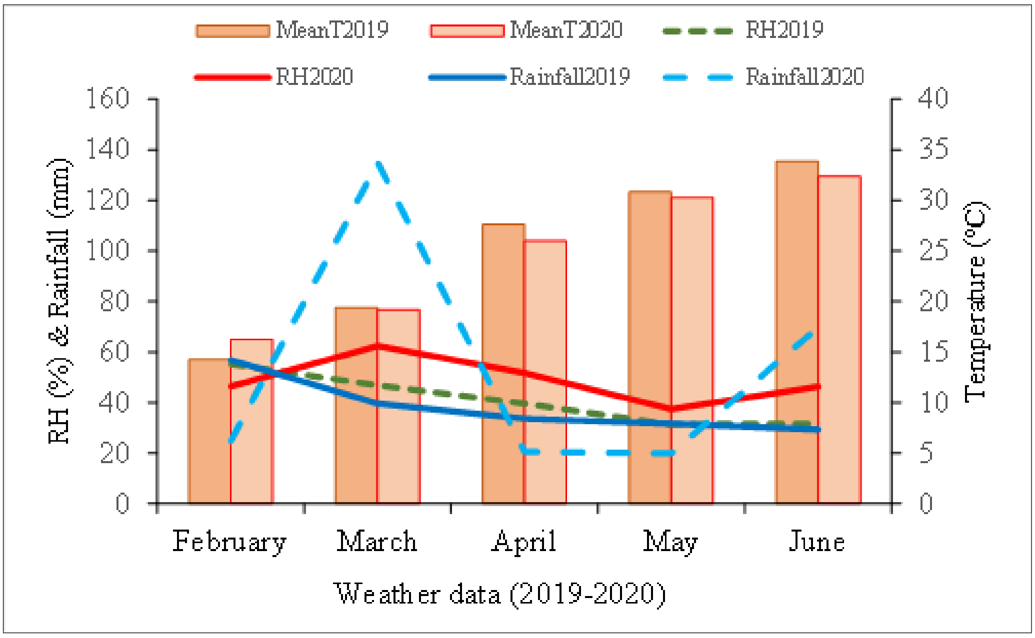
MATERIAL AND METHODS

Meteorological information

Data were noted from the Observatory of Plant Physiology, AARI, Faisalabad, Pakistan. A detailed description is given in Table 1 and Figure 1.

Table 1. Physicochemical properties of soil

Physicochemical properties	Units	Values	
		0-15.0 cm	**16.0-30.0 cm**
Texture	-	Loam	Loam
pH	-	7.39	7.42
Electrical conductivity	dS m^{-1}	0.431	0.361
Organic matter	%	0.972	0.363
Available K	Parts per million	370.0	325.0
Available P	Parts per million	14.10	11.70
Saturation%	%	25.3	25.5



Note: MeanT - mean temperature, RH - relative humidity.

Figure 1. The weather at experimental site during 2019 and 2020

Standard protocol for preparation of Vw from different agricultural by-products

Vw were prepared following the standard protocol by Ismail (1997) with some modification. Three various sources (alligator weed, alfalfa and rice straw) were used for the preparation of Vw. A plastic drum (120 cm length and 22 cm width) with a valve at the bottom was used for the collection of wash. Firstly, it was filled with small gravel (4" size) up to 15 cm, over which a layer of sand (15 cm) was kept and then two kg already partially decayed organic material (alligator weed, alfalfa and rice straw individually for preparation of each earthworm wash) and six kg well rotten cow dung was added. Furthermore, 200 earthworms of local species were added in that drum. Decayed manure was taken from a dairy farm and earthworms of local species (*Allolobophora caliginosa*) were collected from the water channel at Agronomy Farm, University of Agriculture, Faisalabad, Pakistan. The whole materials were kept damp by falling water from the top of the drum. The water has slowly saturated the vermicompost, dissolving the soluble nutrient in casting. After twenty-five days, Vw was collected through a valve fitted at the bottom of the drum. During both years, fresh Vw was collected from the said sources before the start of experiment.

Chemical analysis of vermiwashes

Chemical analysis of vermiwashes are presented in Table 2.

Table 2. Chemical properties of vermiwashes

Ingredients	Alligator weed Vw	Alfalfa Vw	Rice straw Vw	Analysis method
pH	8.16	8.48	8.21	pH meter
EC (ds m^{-1})	1.80	1.48	1.49	Conductivity meter
Total N (%)	0.54	0.51	0.43	Bremner and Mulvaney (1983)
P (ppm)	6.044	5.49	2.75	Olsen (1954)
K (%)	0.418	0.367	0.222	Flame photometery
Zn (ppm)	1.89	0.00	0.02	Rashid (1986)
Mg (ppm)	35.00	28.00	31.00	Flame photometery
Ca (ppm)	240.00	36.50	5.75	Flame photometery
Cu (ppm)	0.09	0.09	0.09	Rashid (1986)

Crop husbandry

The proposed experiment was conducted under field conditions at the Research Area of Plant Physiology, AARI, Faisalabad, Pakistan. Maize hybrid Pioneer-1543 collected from Pioneer Pvt. limited was taken as a test variety. Sowing was done on February 18, 2019 and 2020. Soil was cultivated up to depth of 30 cm and ridge of 75 cm spacing were prepared. Each experimental unit consisted of 5 ridges that were 6 m in length. Each row's first and terminal plant and 1^{st} row and 5^{th} row were taken as buffers. Recommended seed rate was applied at 20 kg ha^{-1}. The treatments comprised of:

F_1: 100% recommended chemical fertilizer + No spray (control);

F_2: 100% recommended chemical fertilizer + Positive control (water spray);

F_3: 75% recommended chemical fertilizer + alligator weed Vw 15%;

F_4: 75% recommended chemical fertilizer + alfalfa Vw 15%;

F_5: 75% recommended chemical fertilizer + rice straw Vw 15%;

F_6: 75% recommended chemical fertilizer + alligator weed Vw 7.5% + alfalfa Vw 7.5%;

F_7: 75% recommended chemical fertilizer + alligator weed Vw 7.5% + rice straw Vw 7.5%;

F_8: 75% recommended chemical fertilizer + alfalfa Vw 7.5% + rice straw Vw 7.5%;

F_9: 75% recommended chemical fertilizer + alligator weed Vw 5% + alfalfa Vw 5% + rice straw Vw 5%.

Recommended chemical fertilizer was applied at the N:P:K ratio of 250:145:90 kg ha^{-1}. One fourth of N and full dose of P_2O_5 and K_2O were applied at the time of seed bed preparation whereas, remaining N was applied in three splits; at the 04, 08 and 12 leaf stages by fertigation. Foliar application of Vw was made at 30, 45 and 60 days after sowing with the help of a hand operated knapsack sprayer. All other management practices were kept constant. Data pertaining to yield, yield attributes, quality parameters were recorded and finally economic analysis was calculated.

Standard procedures used for recording data

Number of leaves per plant was estimated at 120 days after sowing from randomly selected five plants of each treatment. Leaf area was calculated at constant interval (15 days) using a leaf area meter (Model IL 3100, Nebraska, USA). Leaf area index (LAI) was calculated using the formula of Beadle (1987) as follows:

$$LAI = Leaf\ area\ /\ Land\ area$$

Leaf area duration (LAD) was determined using the formula proposed by Hunt (1978) as follow:

$$LAD = [(LAI1 + LAI2)\ x\ (T2 - T1)]\ /\ 2$$

LAI_1 and LAI_2 were the leaf area indices at T_1 and T_2, respectively. Cumulative LAD at terminal harvest was estimated by the addition of all LADs. Crop growth rate (CGR) was calculated by using the formula by Beadle (1987) in g m^{-2} day^{-1}. CGR = (W2-W1)/(T2-T1). W_1 and W_2 were the dry weights (total) harvested at T_1 and T_2, respectively. The mean net assimilation rate (NAR) was computed by the formula proposed by Hunt (1978) as follow:

$$NAR = TDM\ /\ LAD$$

TDM and LAD are the total dry matter and leaf area duration respectively at final produce. Cob measurements, including the number of cobs, grains per cob, and rows per cob, were counted from five random plants, and averages were calculated. Cob diameter and length were measured using a Vernier Caliper and meter rod. The 1000-grain weight was determined by weighing five random samples. At maturity, plants were harvested, sun-dried, and weighed for biological yield, with grains separated and weighed for grain yield. Harvest Index (HI) was calculated using Hunt's (1978) formula. Cell Membrane Stability (CMS) was assessed following Bejandi et al. (2009) method, chlorophyll fluorescence was measured with a chlorophyll fluorometer, and grain protein, starch, and oil contents were analyzed using near-infrared spectroscopy (NIRS) OmegAnalyzer G (Bruins, 2016). Economic analysis was conducted according to CIMMYT's (1988) manual.

Statistical Analysis

The experimental data were analyzed using the statistical package Statistix 8.1 (Analytical Software, USA). To compare the difference among treatment means, Tukey's Honest Significant Difference (HSD) test at a 5% probability level was employed.

RESULTS AND DISCUSSION

Number of leaves per plant

Number of leaves per plant shows the photosynthetic potential of plants that ultimately contribute to achieve a good yield of a crop. It is evident from given data that the number of leaves per plant was significantly affected by the foliar applied Vw with chemical fertilizer at 120 DAS (Table 3). During 2019, more leaves per plant (16.33) were counted at 120 DAS by F_3 as at par with all the treatments except F_1 and F_2. On the contrary, the least leaves per plant (14.67) was documented in F_1 at 120 DAS. Similar trend was observed during 2020.

LAI, LAD, CGR, NAR

The leaf area index shows the crop's photosynthetic capacity or accumulation of dry matter (DM) at a certain growth stage. Results revealed that mean leaf area index, cumulative leaf area duration, mean crop growth rate and net assimilation rate were significantly influenced by the foliar applied Vw with chemical fertilizer during both years of study (2019 and 2020) (Table 3). During 2019, maximum mean LAI (3.83), cumulative LAD (215.70 days), CGR (22.93 g m^{-2} day^{-1}) and NAR (5.24 g m^{-2} day^{-1}) were recorded at F_3 which was statistically at par with all the treatments except F_1 and F_2. Conversely, the minimum LAI (3.01), cumulative LAD (186.73 days), mean CGR (17.32 g m^{-2} day^{-1}) and NAR (4.31 g m^{-2} day^{-1}) was recorded by F_1. A similar trend was observed during 2020.

Chlorophyll fluorescence

The data showed that the value of chlorophyll fluorescence was significantly influenced by the foliar applied Vw with chemical fertilizer during both years of study. During 2019, significantly greater value of chlorophyll fluorescence (0.785) was obtained at F_3 treatment which was statistically remain at par with all the rest of treatments except F_1 and F_2. Conversely, a lower value (0.683) was obtained with application of F_1 treatment which was statistically similar with F_2. A similar trend was also observed during 2020 (Table 3).

CMS

Results revealed that CMS was non-significantly affected by chemical fertilizer during both years. During 2019, maximum CMS (44.73) was recorded for F_3 which was statistically at par with all the treatments excluding F_1. On the contrary, minimum CMS (38.10) was recorded at F_1 which was at par with all treatments excluding F_3 (Table 3).

Number of grains per row

Data pertaining to grains per row revealed foliar applied Vw and chemical fertilizer effect this attribute significantly during 2019 whereas, during 2020 effect was non-significant. Moreover, the maximum number of grains per row (36.07) was recorded at F_3 which was statistically at par with those of the F_4, F_6, F_7 and F_9. Minimum number of grains per row (33.10) was attained at F_1 which was statistically at par with F_2 (Table 4).

Cob diameter and cob length

Data regarding cob diameter and cob length showed that cob diameter and cob length were significantly influenced by the combined use of chemical fertilizer with Vw during both years. During 2019, more cob diameter (46.06 mm) and maximum cob length (23.49 cm) were recorded at F_3 which was statistically similar to those of the F_4, F_6 and F_7 and F_9. However, lesser cob diameter (42.80 mm) and minimum cob length (20.79 cm) were recorded at F_1 (Table 4).

Grain weight per cob

Grain weight per cob is directly linked with grain weight and grains per cob. Table 4 indicated that grain weight was significantly influenced by the combined use of Vw with chemical fertilizer during both years of study.

During 2019, higher 1000-grain weight (326.63 and 326.47 g) was attained F_3 treatment and F_9. Conversely, a lower 1000-grain weight (317.50 g) was recorded at 100% recommended chemical fertilizer with no spray (F1), which was at par with F_2. During 2020, the maximum 1000-grain weight (328.87 g) was recorded at F_3 which was statistically similar with all the treatments except F_1 and F_2. Conversely, minimum 1000-grain weight (319.57 g) was recorded at F_1 which was statistically similar with F_2.

Grain yield

Data depicted in Table 4 revealed that grain yield was significantly affected by the integrated use of Vw and chemical fertilizer during both years of study. During 2019, more grain yield (8.14 t ha^{-1}) was recorded with the application of F_3 which was at par with all the treatments except F_1 and F_2. Conversely, minimum grain yield (7.40 t ha^{-1}) was recorded at F_1 treatment. A similar trend was observed during 2020.

Stover yield

Data regarding stover yield as affected by the foliar-applied Vw and chemical fertilizer are given in Table 4. It is clear from the data that stover yield was significantly affected by the foliar applied Vw with chemical fertilizer during both years of study. During 2019, more stover yield (13.88 t ha^{-1}) was recorded at F_2, which was statistically similar to F_1. Conversely, minimum stover yield (10.11 t ha^{-1}) was obtained F_9. A similar trend was followed in 2020.

Grain protein contents

Data pertaining to grain protein contents as affected by the foliar applied Vw with chemical fertilizer are given in Table 4. Data showed that this attribute was significantly affected by the foliar applied Vw with chemical fertilizer during both years of study. During 2019, maximum protein contents (11.2%) were recorded at F_3 and F_9. On the contrary, lower protein contents (9.9%) were measured at F_1 and F_2. The trend was almost similar during 2020.

Starch contents

Data regarding starch contents as affected by the foliar applied Vw with chemical fertilizer are presented in Table 4. It is clear from the data that starch contents were significantly affected by an application of integrated use of chemical fertilizer with foliar applied Vw during both years of study. During 2019, maximum starch contents (73.0%) were recorded at F_3 followed by treatments F_6 and F_7. Conversely, lower starch contents (71.5%) were recorded at $F_1$and F_2. During 2020, lower starch contents (71.9%) were achieved by F_1 treatment which was statistically similar with F_2. Conversely, higher protein contents (73.0%) were recorded by F_3 and with F_9.

Economic analysis

Maize crop receiving 75% chemical fertilizer with 15% alligator weed Vw (F_3) had the highest benefit cost ratio (BCR) (1.51) and maximum marginal rate of return (MRR) (65.71%), followed by treatments (F_7 and F_9) with a BCR of (1.49 and 1.48) and MRR of (56.71 and 55.42), respectively. On the other hand, treatment with 100% recommended chemical fertilizer with No spray (F_1), had the least BCR (1.31) and MRR (0) (Figure 2 and Figure 3).

Heatmap and correlation matrix

The heatmap matrix during 2019 showed that F1 and F2 treatments showed a strong negative linear relationship with all the studied parameters, while F3 marked a strong positive relationship with all the parameters except the number of leaves and chlorofluorescence. However, all other treatments showed a positive relationship with all the parameters, except stalky. During the year 2020, F1 and F2 showed a negative relationship with all the indicators except stalky, while albeit opposite relationship was observed with other treatments (Figure 4). Moreover, the mental graph showed a positive relationship among all parameters except cob diameter chlorofluorescence and number of leaves during both years (Figure 5).

Table 3. Impact of integrated use of Vw and chemical fertilizer on number of leaves per plant at 120 days after sowing (DAS), mean LAI, cumulative leaf area duration, mean crop growth, net assimilation rate, chlorophyll fluorescence and cell membrane stability during 2019 and 2020

Treatments	Number of leaves per plant at 120 Days after sowing		Mean LAI		Cumulative leaf area duration (days)		Mean crop growth (g m^{-2} day^{-1})		Net assimilation rate (g m^{-2} day^{-1})		Chlorophyll fluorescence (Fv/Fm)		Cell membrane stability	
	2019	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**
F_1	14.67±b	14.67b	3.01b	3.04b	186.73b	189.37b	17.32d	17.68d	4.31c	4.33c	0.683b	0.685b	38.10	38.63
F_2	14.69±b	14.67b	3.02b	3.05b	187.73b	190.03b	17.91cd	17.93cd	4.37bc	4.38bc	0.685b	0.688b	38.97	39.23
F_3	16.33±a	17.33a	3.83a	3.86a	215.70a	218.17a	22.93a	22.95a	5.24a	5.26a	0.785a	0.789a	44.73	44.57
F_4	15.33±ab	15.67ab	3.59a	3.61a	208.73ab	211.67a	20.40a-c	20.42a-c	4.86a-c	4.89a-c	0.754ab	0.752ab	43.83	43.10
F_5	15.33±ab	15.67ab	3.58a	3.60a	209.47ab	212.77a	20.10bc	20.12b-d	4.83a-c	4.85a-c	0.712ab	0.712ab	42.47	41.47
F_6	15.67±ab	15.33b	3.71a	3.73a	212.77a	215.40a	21.07ab	21.09ab	4.93ab	4.96a-c	0.719ab	0.715ab	43.23	42.73
F_7	15.33±ab	15.67ab	3.76a	3.78a	213.80a	216.07a	21.10ab	21.12ab	4.91ab	4.94a-c	0.747ab	0.747ab	43.10	42.53
F_8	15.67±ab	15.33b	3.58a	3.59a	211.47a	214.10a	20.30bc	20.32bc	4.85a-c	4.88a-c	0.731ab	0.732ab	42.87	42.07
F_9	15.33±ab	15.67ab	3.62a	3.64a	214.83a	217.73a	21.43ab	21.45ab	4.96a	4.99ab	0.734ab	0.737ab	43.93	44.93
P value	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.13	0.06
Tukey $HSD_{0.05}$	1.631	1.747	0.479	0.474	22.76	13.65	2.60	2.578	0.568	0.663	0.101	0.091	7.102	6.72

Note: Values with different letters in the same column indicate significant differences in the Tukey HSD test at the 5% significance level. F_1: 100% recommended chemical fertilizer + No spray (control); F_2: 100% recommended chemical fertilizer + Positive control (water spray); F_3: 75% recommended chemical fertilizer + alligator weed Vw 15%; F_4: 75% recommended chemical fertilizer + alfalfa Vw 15%; F_5: 75% recommended chemical fertilizer + rice straw Vw 15%; F_6: 75% recommended chemical fertilizer + alligator weed Vw 7.5% + alfalfa Vw 7.5%; F_7: 75% recommended chemical fertilizer + alligator weed Vw 7.5% + rice straw Vw 7.5%; F_8: 75% recommended chemical fertilizer + alfalfa Vw 7.5% + rice straw Vw 7.5%; F_9: 75% recommended chemical fertilizer + alligator weed Vw 5% + alfalfa Vw 5% + rice straw Vw 5%. This note is also applied for Table 4, Figure 2, Figure 3, Figure 4, and Figure 5.

Table 4. Impact of integrated use of Vw and chemical fertilizer on number of grains per row, cob diameter, cob length, 1000-grain weight, grain yield, stover yield, grain protein content and starch contents during 2019 and 2020

Treatments	Number of grains per cob		Cob diameter (mm)		Cob length (cm)		1000-grain weight (g)		Grain yield (t ha^{-1})		Stover yield (t ha^{-1})		Grain protein content (%)		Starch contents (%)	
	2019	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**
F_1	484.87	487.69	42.80b	43.97c	20.79c	20.80c	317.50b	319.57 b	7.40c	7.50c	13.62a	13.95a	9.9b	10.1b	71.5e	71.9b
F_2	487.53	491.34	43.29b	44.30c	21.05bc	21.57bc	317.87ab	320.00 b	7.48bc	7.58bc	13.88a	14.21a	9.9b	10.1b	71.5e	72.0b
F_3	523.93	515.79	46.06a	47.07a	23.49a	23.93a	326.63a	328.87a	8.14a	8.28a	10.24b	10.54b	11.2a	11.4a	73.0a	73.0a
F_4	520.00	510.61	45.99a	46.77ab	22.56ab	23.07ab	324.60ab	327.83a	7.83a-c	8.05a-c	10.51b	10.71b	11.0a	11.3a	72.1cd	72.8a
F_5	520.13	509.34	44.05ab	45.10bc	22.45a-c	22.63ab	324.70ab	327.93a	7.80a-c	8.03a-c	10.32b	10.52b	11.0a	11.3a	72.1d	72.8a
F_6	521.93	512.23	45.85a	46.77ab	23.02a	23.63a	325.30ab	327.53a	7.93a-c	8.10a-c	10.17b	10.44b	11.1a	11.4a	72.6b	72.9a
F_7	521.60	511.29	45.87a	46.50ab	22.82a	23.60a	325.57ab	327.80a	7.99ab	8.15ab	11.00b	11.27b	11.1a	11.4a	72.6b	72.9a
F_8	520.40	504.46	44.73ab	45.77a-c	22.00a-c	22.63ab	324.73ab	327.63a	7.81a-c	8.00a-c	10.88b	11.12b	11.1a	11.3a	72.1d	72.8a
F_9	521.83	514.44	45.63a	46.80ab	23.15a	24.00a	326.47a	328.37a	7.98ab	8.12ab	10.11b	10.40b	11.2a	11.4a	72.5bc	73.0a
P value	0.83	0.98	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tukey $HSD_{0.05}$	109.98	114.75	2.242	1.945	1.787	1.681	8.773	6.656	0.531	0.605	2.487	2.627	0.451	0.673	0.458	0.559

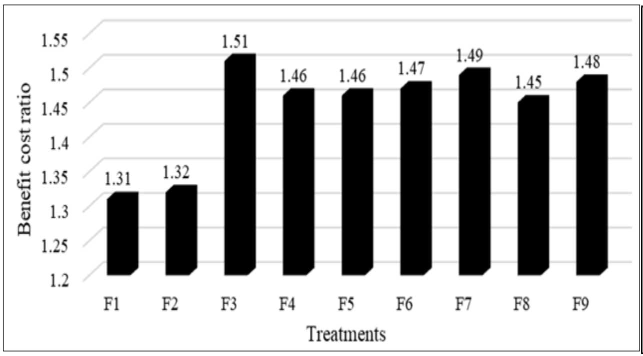


Figure 2. Effects of foliar spray of vermiwash and chemical fertilizer on benefit cost ratio

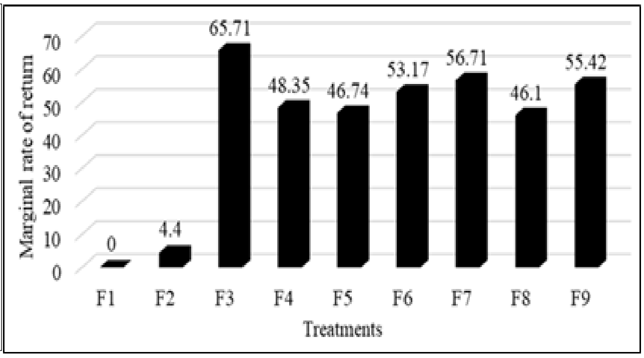


Figure 3. Impacts of foliar spray of vermiwash on marginal rate of return

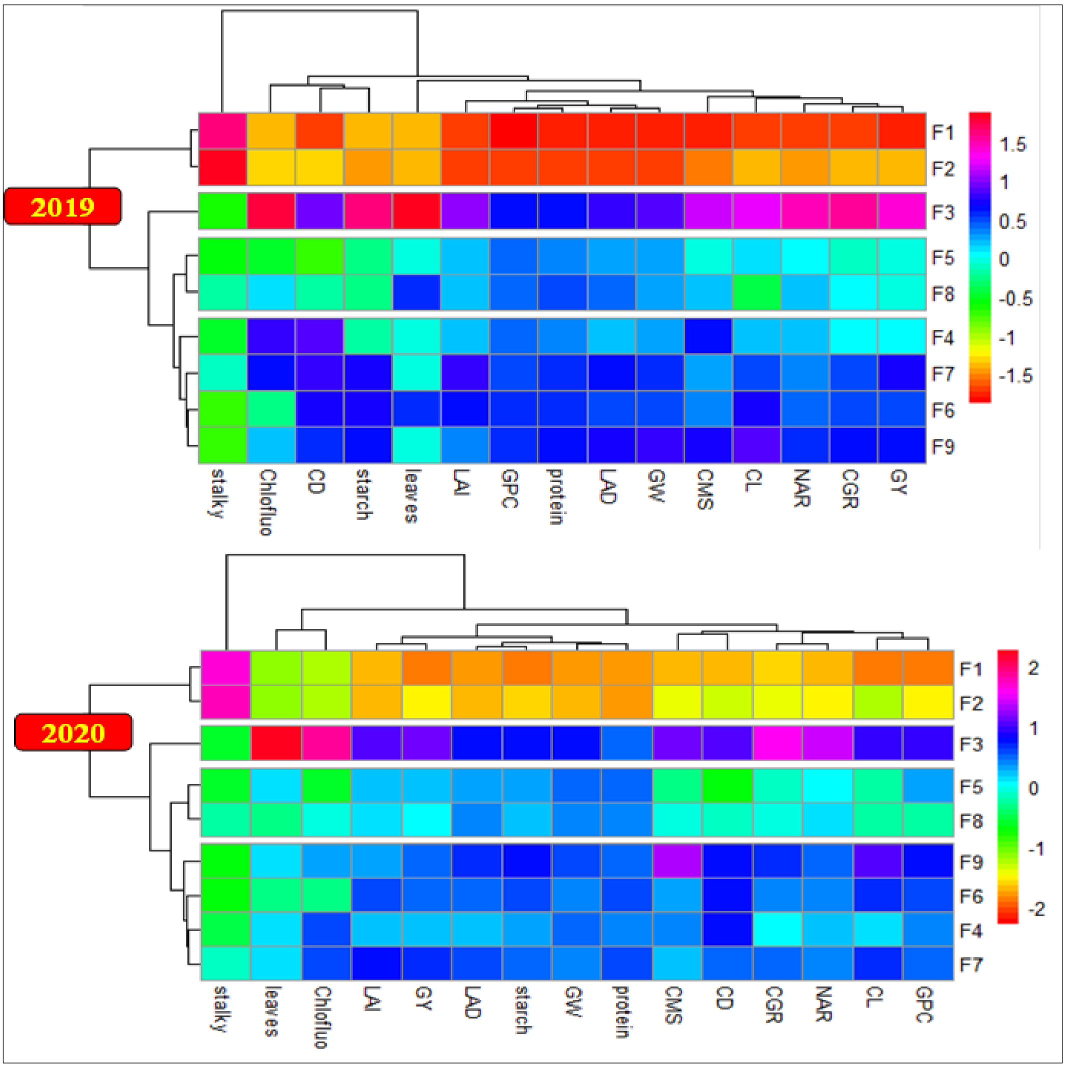


Figure 4. Heatmap matrix of Impact of integrated use of vermiwash and chemical fertilizer on number of leaves per plant at 120 days after sowing (DAS), mean LAI, cumulative leaf area duration (days), mean crop growth (g m^{-2} day^{-1}), net assimilation rate (g m^{-2} day^{-1}), chlorophyll fluorescence (Fv/Fm) and cell membrane stability during 2019 and 2020.

Contemporary agricultural practices often prioritize the heavy utilization of chemical fertilizers, with limited emphasis on organic alternatives (Verma et al., 2020). This overreliance on synthetic fertilizers has resulted in various detrimental effects on water and soil ecosystems, food safety, soil health degradation, and loss of biodiversity (Selim, 2020). High amounts of synthetic sources of nutrients for increasing the production of crops are releasing many detrimental greenhouse gases, diminishing the ozone layer thus exposing the people to damaging ultraviolet rays (Barnes et al., 2022).

Integrated nutrient management assists new lines for achieving yield because it is eco-friendly, socially acceptable and also economically viable. Earthworms and their vermicomposts and Vw serve as a miracle for promoting growth and nutritionally, these are much better as compared to chemical fertilizer and conventional compost (Idrees et al., 2021). Earthworms and their casting and Vw are serving both as growth promoters and as protectors for various crops (Iqbal et al., 2021; Kalika-Singh et al., 2022; Toor et al., 2023).

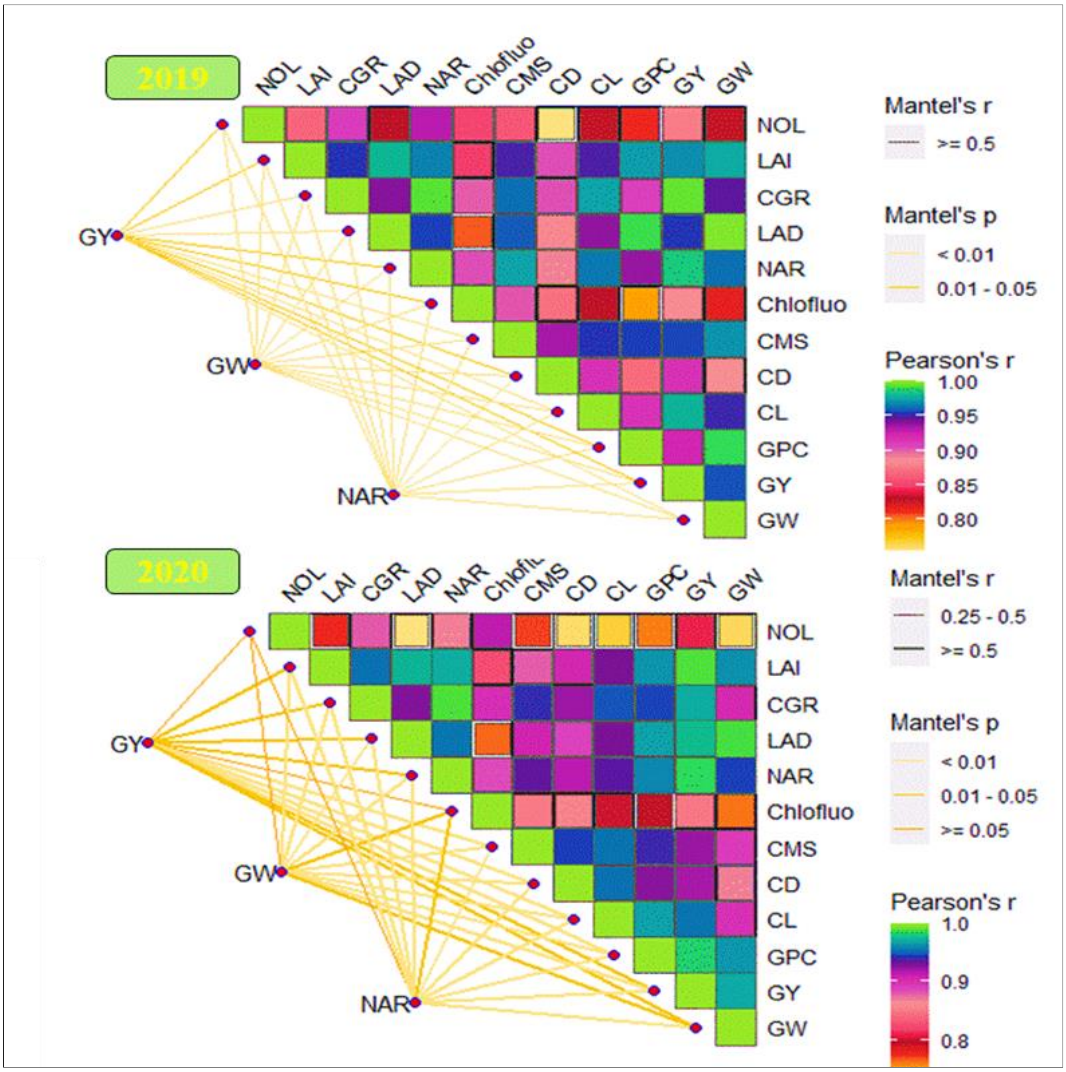


Figure 5. Mental graph matrix of Impact of integrated use of vermiwash and chemical fertilizer on number of leaves per plant at 120 days after sowing (DAS), mean LAI, cumulative leaf area duration (days), mean crop growth (g m^{-2} day^{-1}), net assimilation rate (g m^{-2} day^{-1}), chlorophyll fluorescence (Fv/Fm) and cell membrane stability during 2019 and 2020.

Current study proved that the integrated use of inorganic with organic (Vw extracted from alligator weed, alfalfa and rice straw) positively enhanced leaves per plant at 120 DAS, mean LAI, cumulative LAD, mean CGR, NAR, number of grains per row, cob diameter, cob length, grain weight, grain yield, cell membrane stability and protein concentration. Nevertheless, the number of rows per cob and oil contents was not significantly influenced by the integrated use of chemical fertilizer with Vw (Table 3 and 4).

Leaves per plant are related to capturing photoactive radiation (PAR) that eventually enhances photosynthesis. Current investigation revealed that the foliar-applied Vw and chemical fertilizer significantly improved leaves per plant at 120 days after sowing

(DAS) (Table 3). These findings are in line with those of Samadhiya et al. (2013), who reported that foliar spray of Vw on the tomato plants enhanced the number of leaves. The study also reported that the application of 15% Vw showed growth-enhancing impacts on Abelmoschusesculentus (Elumalai et al., 2013). It was found that humic acid and many other essential nutrients are produced during vermicomposting (Fernández-Gómez et al., 2015). These findings align with those of (Awadhpersad et al., 2021) and (Wang et al., 2021b), who have documented the growth-promoting effects of earthworm wash. Application of Vw on Capsicum frutescens after 30 days resulted in a higher leaf count compared to control plants (Varghese and Prabha, 2014).

Current investigation shows the improvement in crop growth parameters (mean LAI, cumulative LAD, mean CGR and NAR) by the foliar applied alligator weed, alfalfa and rice straw Vw with chemical fertilizer (Table 3). LAI indicates the photosynthetic capability of a crop. The greater the LAI, the more will be the accumulation of total dry matter by the plant. Khatun et al. (2012) reported that N improved the plant height by enhancing the leaves and nodes per plant and ultimately enhanced the LAI. These findings are in accordance with those of Mondal et al. (2017). They reported the improvement in LAI by the application of earthworm wash. Leaf area duration is the time period at which the leaf stays green and shows photosynthetic activities. Improvement in leaf area duration by the foliar applied Vw might be due to the application of N towards plants at the right time and in the right proportion. These are corroborated by the outcomes of different researchers (Mondal et al., 2017). Similarly, more LAD with the integration of organic with inorganic sources was also noted by Khan et al. (2008). CGR is important to check the crops against nutrients applied. It represents the overall weight produced by the plants. It was noted that as the LAI value increases, CGR also increases up to a certain limit. During both years, foliar-applied Vw with chemical fertilizer produced higher mean CGR because of more LAI and LAD. These are also in accordance with Khan et al. (2008) and Mondal et al. (2017). Better NAR was observed from foliar-applied Vw and chemical fertilizer treatments. So, balanced N nutrition might be the reason for more NAR in the treatments that received the foliar spray of Vw and chemical fertilizer. These are in line with Khan et al. (2008). Mujeera and Malathy (2014) found that the use of Vw significantly boosted the growth of vegetable crops. They observed that higher dilutions of Vw had a particularly positive effect on seedling growth parameters. These findings align with previous studies by (Awadhpersad et al., 2021) and (Wang et al., 2021b), who also reported growth-enhancing effects from the application of earthworm wash. Similarly, Sardrood et al. (2013) noted that the application of both chemical and bio-fertilizers led to increased plant growth rates, improved photosynthesis, and higher levels of essential nutrients such as nitrogen, phosphorus, and potassium, resulting in enhanced maize yields.

Foliar applied Vw and chemical fertilizer significantly improved the chlorophyll fluorescence values as compared to control (Table 3). Venkataramana et al. (2009) stated that the foliar applied Vw improved grain yield because of more N in the leaf. Results similar to the current investigation were also testified by Khairnar and Gunjal (2012) on green gram. Quaik et al. (2012) argued that diluted Vw when applied as a source of nutrient for *Plectranthus amboinicus*, boosted chlorophyll content as compared to control.

Foliar applied Vw from all sources with chemical fertilizer significantly enhanced the cell membrane stability (CMS) (Table 3). CMS is very effective for assessing the plants against stress (ElBasyoni et al., 2017). These results are in confirmatory with Kazeminasab et al. (2016). They concluded that vermicompost and Vw enhance the uptake of essential nutrients through improving the CMS.

Grains per cob are a vital attribute and it contributes to the yield of the maize crop. Grains per cob were improved by the foliar applied Vw with chemical fertilizer. It could be due to more cob development due to more N during the growing period (Table 4). These outcomes are in accordance with those reported by different researchers (Ashok and Shiva, 2010). They also noted more grains per cob by the use of both organic with inorganic sources. Liebman et al., (2004) also concluded the comparable effects of applying nitrogenous sources on grains per cob in maize.

Cob diameter and cob length regulates the cob development. Finally, cob length and cob diameter significantly contribute towards the grain yield of maize. Current study revealed that cob length as well as cob diameter was positively affected by the foliar applied Vw with chemical fertilizer (Table 4). Significant results of cob length and cob diameter by the foliar applied Vw were recorded due to sufficient N nutrition (Ayoola and Makinde, 2009). These results are in line with Iqbal (2013), who noted more cob length as well as cob diameter due to the integration of organic and inorganic fertilizers. The application of Vw improved the cob length by enhancing various phytohormones (Yazdani et al., 2009).

Improvement in grain weight was recorded by the foliar-applied Vw with chemical fertilizer in the current investigation (Table 4). The Vw contain appreciable amounts of P which is essential for vigorous root growth and affected the grain weight as P (0 kg ha^{-1}) produced the least grain weight (Hussain et al., 2006). Yazdani et al. (2009) described that the application of Vw improved the 1000-grain weight by enhancing various phytohormones.

In the present investigation, improvement in grain yield was recorded by the foliar-applied Vw and chemical fertilizer. As the Vw extract contains N and P therefore, more grain yield might be owing to the application of more N and P to plants at appropriate times and in the right proportions. These results are in resemble with those stated in the lettuce (Durak et al., 2017), tomato (Wang et al., 2017), sweet corn (Canatoy, 2018), cucumber (Wang et al., 2021a), saffron (Jami et al., 2020) and chicory (Gholami et al., 2018).

Grain protein contents are one of the key quality parameters. A higher concentration of grain protein and starch (Table 4) was found in those treatments that received foliar-applied Vw and chemical fertilizer because combined application of organic with inorganic sources has a potential to supply more nutrients, especially N (Taheri et al., 2018). These results are in line with those reported by Adebifar (2018). Verma (2016) reported that the application of 100% RDF with Vw (100 L ha^{-1}) recorded the highest protein as compared to those of other treatments.

CONCLUSIONS

The foliar spray of vermiwash from different sources and applying at different concentrations showed better growth-stimulating impacts concerning maize morpho-physiological traits than that of the control treatment. Vermiwash of alligator weed proved to be a better source of nutrients than alfalfa and rice straw earthworm wash. Combining application of alligator weed vermiwash 15% with 75% recommended chemical fertilizer (187:110:67 kg of N:P:K ha^{-1}) improved the net assimilation rate (5.24 and 5.26 g m^{-2} day^{-1}), 1000-grain weight (326.63 and 328.87 g), grain yield (8.14 and 8.28 t ha^{-1}) and grain protein content (11.2 and 11.4 %) during 2019 and 2020, respectively.

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