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Release kinetics of Zn from soil and growing media mixtures in a laboratory study

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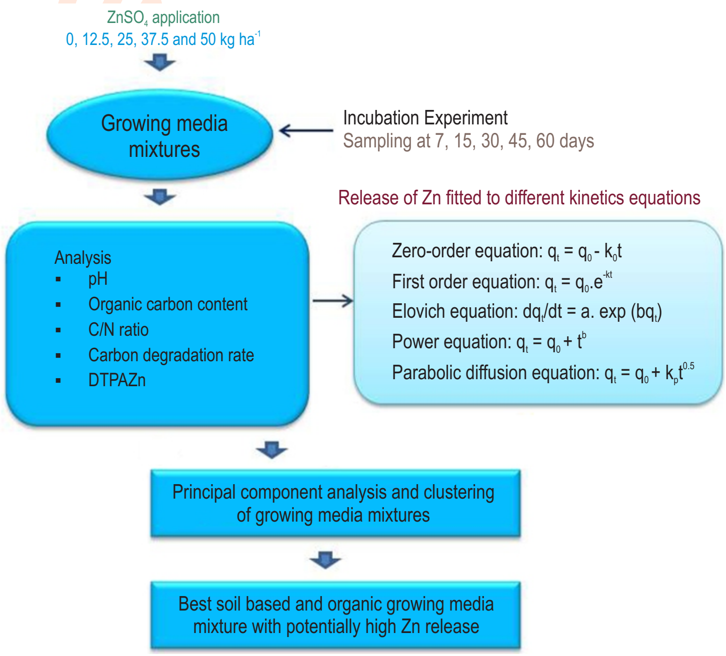
Abstract

Aim: To assess the zinc release from soils and various soilless growing media mixtures comprising different organic manures mixed at various proportions and to understand the kinetic behaviour of Zn release.

Methodology: An incubation study was conducted to examine the time dependent release of zinc from soil and different growing media mixtures of Cocopeat (CP), Vermicompost (VC), Farm Yard Manure (FYM), Pressmud (PM), Vermiculite (VL) and Composted coco peat (CCP) by adding various levels of $ZnSO_4$ (0, 12.5, 25, 37.5 and 50 kg ha^{-1}) for 60 days. The Zn release at required time interval was quantified in soil and growing media mixtures.

Results: Higher zinc release was recorded with growing media mixture of Cocopeat + Vermicompost + Pressmud (1:1:1) as compared to other mixtures. The release was linear up to 30 days and dropped at 45 days then increased. Fitting of various kinetic equations for better understanding of zinc release satisfactorily accounted (R^2, 0.975 to 0.998, at $p \leq 0.05$) by the zero order kinetic equation. Higher half-life time for Zn release ($t_{1/2}$) was noticed with Soil + FYM and Cocopeat + Vermicompost + Pressmud mixtures, which confirmed their suitability. A significant negative correlation between pH, C:N ratio with Zn availability as well as linear decrease in organic carbon content prompted zinc release.



Interpretation: Based on the amount of zinc released and grouping through principal component analysis with hierarchical clustering, a mixture of Cocopeat +Vermicompost +Pressmud at 1:1:1 was the best growing media mixture. Higher initial zinc availability and half-life time ($t_{1/2}$) for zinc release makes it more efficient and best growing media mixture to sustain Zn supply to crops for a longer period of time.

Key words: DTPA Zn availability, Growing media mixture, Kinetic equations, Zn release

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Introduction

Green house cultivation of vegetables is essential to meet the offseason demand and using suitable growing media for achieving increased productivity. Though soil is the most preferred growing media used for crop cultivation, use of organic manures and their mixtures as growing media for cultivating crops under protected cultivation is also gaining momentum. This might be due to better water holding capacity, aeration and optimal physico-chemical properties. Organic substrates that are extensively used in soilless growing media include vermicompost, cocopeat, pressmud, composted cocopeat, farmyard manure, wood-based materials, and biochar. All are commonly mixed with inorganic substrates such as vermiculite, perlite, volcanic tuff, expanded clay granules, pumice, zeolite, and sand, to improve their physico-chemical properties (Raviv *et al.,* 2015; Bar-Tal *et al.,* 2019). Application of fertilizer to soil and soilless growing media had differential impact on the availability of nutrients to crops. In this context, understanding the chemistry of growing media in releasing the applied nutrient will provide a base for efficient utilization of nutrient sources and rationalizing the fertilizer inputs, so as to achieve sustainable crop yield and farm income.

Nutrient management is an art aimed at conserving soil and water for better fertilizer use efficiency, crop productivity, quality and net profit while minimizing the offsite movement of nutrients with less environmental effects. Monitoring the nutrients release and availability is essential for effective fertilizer management in soil less culture, since, all nutrients were applied through fertigation. Hidden hunger of micronutrient particularly zinc in soils limits the crop productivity and nutritional quality of foods, which in turns affects plant-animal-human nutrition and health. Intensive farming with exhaustive high yielding crop varieties under protected cultivation and imbalanced fertilization not only reduces the crop productivity, but also reduces the nutritional quality of crop produce, which consequently contributes to human malnutrition (Kumssa *et al.,* 2016; Van Pamel *et al.,* 2020). Zinc release and bioavailability in soil and growing media is an important process affected by zinc reactivity, which is influenced by zinc speciation, solution composition and nature of growing media (Shi *et al.,* 2008; Peng *et al.,* 2017). Organic matter, metal hydroxides, clay and media particles are the most reactive components responsible for zinc partitioning between media and solution, however organic matter content is considered important for controlling zinc release (Duffner *et al.,* 2014).

Typical growing media characteristics such as dissolved organic matter content, pH, redox condition and presence of competing cations affects the kinetic behaviour of zinc in growing media mixtures (Shi *et al.,* 2013). Zinc adsorption and desorption are rapid processes which controls the short term zinc release kinetics, however it requires comprehensive understanding on the dynamics of zinc in soil and soilless growing media mixtures. Zinc can adsorb heterogeneous metal binding sites, soil/ growing media components, soil organic matter with significant different metal desorption rate (Shi *et al.,* 2016; Tian *et al.,* 2017). So far, soils are though well-researched, for various nutrient availability and release pattern, however, the effect of soil based and soilless growing media mixtures in providing better zinc availability and physical environment appear to lag behind. How coexisting dissolution and dynamics of zinc speciation under different media chemistry affect the kinetic behaviour of zinc is still unknown. Hence, this investigation was carried out to assess the zinc release from soils and various soilless growing media mixtures comprising different organic manures mixed at various proportions and to assess the equation to understand the kinetic behaviour of zinc release.

Materials and Methods

Experimental setup: Soil sample in bulk at a depth of 0 – 15 cm was collected from the farmer's field in Thondamuthur village of Coimbatore district in Tamil Nadu, India. The soil was processed by sieving through 2 mm sieve, air dried and stored for further use. Farmyard manure and vermicompost were collected from the Central farm unit of Tamil Nadu Agricultural University. Pressmud was collected from Bannari Amman Sugars Limited, Sathyamangalam, Tamil Nadu, cocopeat and Composted cocopeat were collected from Vermin Gold Organics, Tirupur, Tamil Nadu and vermiculite (VL) was procured from Essar & Co., Coimbatore. All these materials were mixed in different proportion on weight basis to prepare various mixtures of growing media at two different ratios (1:1 and 1:1:1).

Six growing media mixtures *viz.* Soil + FYM (1:1), Soil + Vermicompost (1:1), Soil + Composted Cocopeat (1:1), Cocopeat + Vermicompost + Pressmud (1:1:1), Cocopeat + Vermicompost + Vermiculite (1:1:1), Cocopeat + Composted Cocopeat + Vermiculite (1:1:1) were prepared. Hundred grams of processed soil and growing media mixtures were weighed separately into the containers and mixed with five levels of $ZnSO_4$ (0, 12.5, 25, 37.5 and 50 kg ha^{-1}). Soil and growing media mixtures were moistened to field capacity and incubated for 60 days. Moisture level was maintained at field capacity by adding double distilled water at alternate days on weight loss basis and continued for 60 days to investigate the effect of various levels of $ZnSO_4$ on the release pattern of zinc from different growing media mixtures and soil.

Sample processing and analyses: Samples drawn at 7, 15, 30, 45 and 60 days after incubation were shade dried, gently powdered with a wooden mallet, sieved through 2 mm sieve and analysed for various physico-chemical properties as per standard procedures. Similarly growing media mixtures samples were also drawn after proper mixing. Soil pH and electrical conductivity was determined by using 1:2.5 soil: water suspension (Jackson, 1973), whereas 1:10 solid: water suspension was used for growing media mixtures. Organic carbon was estimated using wet digestion method (Walkley and Black, 1934). Di-acid (HNO_3: $HClO_4$ at 9:4 v/v) digested samples were analysed calorimetrically for total phosphorous by Colorimetry (Olsen and Sommers, 1982), potassium by flame photometry (Black, 1965), nitrogen by Kjeldahl distillation method (Bremner and Mulvaney, 1982). The DTPA extractable available zinc, Fe, Mn and Cu was quantified as per the standard procedure outlined by Lindsay and Norvell (1978) using atomic absorption spectrophotometry (GBC

Avanta model). The experimental soil was neutral (pH 7.65) in reaction with low salt content (0.08 dS m^{-1}), available nitrogen (175 g kg^{-1}) and available potassium (260 g kg^{-1}). It was medium in Olsen phosphorous (13 g kg^{-1}) and organic carbon content (0.55%) whereas deficient in DTPA zinc content (0.40 mg kg^{-1}). Among the soil based growing media mixtures, higher pH (7.80), organic carbon content (16.8%), C N ratio (31.1), particle density (1.58 g cm^{-3}), pore volume (39.2 cm^3) and field capacity (68.9) was noticed with soil + farm yard manure at 1:1 mixing ratio. However, soil mixed with vermicompost had higher total nitrogen content (1.36%) and bulk density (0.80 g cm^{-3}). High electrical conductivity (3.40 dS m^{-1}) as well as porosity (60%) was found with soil and composted cocopeat mixture at 1:1 mixing ratio.

Among the soilless growing media mixtures cocopeat with vermicompost and pressmud has higher electrical conductivity (3.77 dSm^{-1}), organic carbon (29.6 %), total nitrogen (3.49%), C:N ratio (8.48), bulk density (0.23 g cm^{-3}) and pore volume (17.6 cm^3) whereas, higher pH (7.60), particle density (1.17 g cm^{-3}) and porosity (83.3%) was encountered with cocopeat, vermicompost and vermiculite at 1:1:1 mixing ratio. Higher water content at field capacity was observed with cocopeat, composted cocopeat and vermiculite mixture (166%). The data on zinc release from soil and soilless growing media mixtures with the application of various levels of $ZnSO_4$ at different time intervals were fitted to the kinetic equations given by Almaroai *et al.* (2013). Coefficient of Determination (R^2) and standard Error of Estimate were used to assess the fitness of equation to the experimental data. Relatively higher coefficient of determination (R^2), low standard error of estimate (SE) for computed kinetic parameters characterizes the model best fit for that particular element release.

Statistical analyses: The data obtained on physico-chemical properties, organic carbon and available zinc status in the soil and growing media mixtures were statistically analysed using SPSS software, while the data on nutrient release from different growing media mixtures at varied time intervals were statistically analysed with factorial completely randomized block design in two (growing media and levels of $ZnSO_4$ application) factorial arrangement. Simple correlation and regression analysis were also performed as described by Snedecor and Cochran (1967) with the help of Statistical Tool for Agricultural Research (STAR). The test of significance was conducted at 5% level of significance ($p \leq 0.05$).

Results and Discussion

Zinc release from soil based growing media mixtures increased linearly (Fig 1a), except soil with farm yard manure mixture which showed sharp decline in zinc release on 30^{th} day (13.8 mg kg^{-1}) and increased afterwards up to 60 days (22.4 mg kg^{-1}). The mixture of soil + vermicompost and soil + composted cocopeat mixtures showed decreased zinc release on 45^{th} day (14.2 and 23.1 mg kg^{-1}) and observed rectilinear increase up to 60 days (14.7 and 29.7 mg kg^{-1}). However, soil as growing media did not show any major variation in the zinc release pattern as the decrease was very low at 15 to 30 days after incubation (2.63 and 2.65 mg kg^{-1}). The progressive increase in DTPA extractable zinc with time might be explained due to formation of chelating complexes with organic material and slow mineralization from various growing media mixtures upon decomposition and mineralization (Dhaliwal *et al.,* 2019).

Among all the soil based growing media mixtures, soil + composted cocopeat registered higher zinc release throughout the incubation period. Rendering the potential of zinc release, soil based growing media mixtures can be arranged as: Soil + CCP (23.1 to 29.7 mg kg^{-1}) > Soil + FYM (16.8 to 27.1 mg kg^{-1})> Soil + VC (12.9 to 15.7 mg kg^{-1})>Soil (2.63 to 5.52 mg kg^{-1}). Higher zinc release with mixtures having composted cocopeat and Farmyard manure might be due to higher initial zinc concentration of the organics and improved zinc availability due to multidentate complex formation (Aziz *et al.,* 2017). Addition of highly soluble $ZnSO_4$ improved zinc availability (Fig 1b), and increased zinc content in solution. Higher zinc availability was recorded with 50 kg $ZnSO_4$ ha^{-1} and the higher net change in zinc availability was noted with 37.5 and 50 kg ha^{-1} $ZnSO_4$ application in Soil + CCP (4.24 and 4.50 mg kg^{-1}), Soil + FYM (2.50 and 4.11 mg kg^{-1}), Soil + VC (1.94 and 2.78 mg kg^{-1}) and soil (1.20 and 1.94 mg kg^{-1}). The lowest average zinc availability was noticed in no zinc applied soil (0.52 mg kg^{-1}).

A consistent increase in Zn release was noticed from 7 to 30 days after incubation (Fig. 1a) with different organic growing media mixtures. This might be due to release of organic acids from the organic media composites, labile carbon sources and mineralization which responsible for higher zinc release (Taylor *et al.,* 2009). In spite of this, zinc availability declined on 45 day and increased subsequently up to 60 days. Among all the organic growing media mixtures, the highest zinc release was recorded with cocopeat, vermicompost and pressmud mixture (39.1 mg kg^{-1}) followed by media mixture of cocopeat, vermicompost and vermicullite (36.7mg kg^{-1}) and cocopeat, composted cocopeat and vermiculite (19 mg kg^{-1}). Higher zinc release with Cocopeat + vermicompost and pressmud might be caused by its high initial zinc and organic matter content (Ilker *et al.*, 2016; Rout *et al.*, 2012). Lesser zinc release from growing media mixtures having vermiculite might be due to selective adsorption of zinc on its surface, which significantly affected the release of zinc.

Following zinc release pattern, organic growing media mixtures can be arranged as: CP +VC +PM (26.8 to 42.3 mg kg^{-1}) >CP + CCP + VL (24.6 to 39.1 mg kg^{-1}) > CP + VC + VL (11.3 to 24.1 mg kg^{-1}). However, additional application of $ZnSO_4$ increased Zn release by 36.4, 51, and 46.6% with earlier mentioned organic growing mixtures over control (Fig. 1b). Higher net change in availability was noticed with 37.5 and 50 kg $ZnSO_4$ ha^{-1} in CP +VC +PM (7.12 and 8.81 mg kg^{-1}),CP + VC + VL (9.74 and 7.96 mg kg^{-1}), and CP + CCP + VL (16.9 and 12.5 mg

Table 1: Estimated values of zero-order constants, standard error (SE), coefficient of determination (R^2) and half-life ($t_{1/2}$) for Zn release in different growing media mixtures

Growing media mixtures	Levels of $ZnSO_4$ (kg ha^{-1})	q_0	k_0	SE	R^2	$t_{1/2}$ in day
Soil	0	0.26^{a}	0.039	0.006	0.986	3.3
	10	0.49^{ab}	0.088	0.009	0.977	2.8
	25	1.18^{bc}	0.102	0.012	0.989	5.8
	37.5	0.89^{abc}	0.170	0.007	0.992	2.6
	50	1.56^{c}	0.252	0.000	0.985	3.1
Soil + FYM (1:1)	0	13.4^{i}	1.020	0.259	0.975	7.3
	10	16.2^{k}	1.110	0.167	0.976	6.6
	25	15.9^{k}	1.220	0.333	0.980	6.5
	37.5	16.5^{kl}	1.320	0.229	0.981	6.2
	50	17.3^{m}	1.450	0.010	0.981	6.0
Soil + VC (1:1)	0	7.61^{f}	0.786	0.143	0.989	4.8
	10	7.72^{fg}	0.857	0.012	0.992	4.5
	25	8.45^{gh}	0.958	0.080	0.994	4.4
	37.5	8.59^{h}	1.128	0.000	0.995	3.8
	50	9.03^{h}	1.575	0.196	0.985	2.9
Soil + CCP (1:1)	0	18.8^{n}	1.670	0.443	0.983	5.6
	10	18.7^{n}	1.820	0.390	0.985	5.2
	25	18.6^{n}	1.960	0.312	0.987	4.8
	37.5	18.4^{n}	2.080	0.375	0.990	4.4
	50	19.1^{n}	2.250	0.348	0.991	4.3
CP + VC + PM (1:1:1)	0	26.9^{op}	2.120	0.532	0.982	6.3
	10	26.3^{o}	2.440	0.657	0.983	5.4
	25	27.3^{p}	2.660	0.399	0.981	5.1
	37.5	28.5^{q}	2.860	0.060	0.980	5.0
	50	29.8^{r}	3.020	0.666	0.981	4.9
CP + VC + VL (1:1:1)	0	2.98^{de}	1.190	0.015	0.997	1.3
	10	3.56^{e}	1.260	0.012	0.996	1.4
	25	3.58^{e}	1.330	0.054	0.996	1.3
	37.5	2.70^{d}	1.460	0.045	0.998	0.9
	50	3.24^{de}	1.860	0.015	0.988	0.9
CP + CCP + VL (1:1:1)	0	8.32^{fgh}	1.960	0.083	0.993	2.1
	10	12.1^{i}	2.170	0.158	0.993	2.8
	25	12.3^{i}	2.340	0.083	0.994	2.6
	37.5	12.4^{i}	2.500	0.244	0.995	2.5
	50	17.1^{lm}	2.750	0.098	0.995	3.1

All R^2 values were significant at $p \leq 0.01$. The numerical values for nutrient values in a column followed by dissimilar letters in the superscript are significantly different at ($p \leq 0.05$) by Least significant difference (LSD) test. FYM – Farm yard manure, VC- vermicompost, CCP- Composted cocopeat, PM – Pressmud, CP – Cocopeat, VL – Vermiculite

kg^{-1}).The lowest average Zn availability was noticed for no zinc applied in CP + VC + VL (9.9 mg kg^{-1}).

The purpose of kinetic analysis on zinc release data was to know whether the release of zinc from growing media mixtures under study was independent of their initial concentration (zero order) or it was a concentration-dependent process where a constant proportion of zinc in question was mineralized (first order). Based on the computed values of coefficient of determination (R^2) and standard error of estimate for different growing media mixtures and soil, it was noted that, the zinc release could be satisfactorily accounted (R^2 values varied from 0.975 to 0.995, all significant at $p \leq 0.01$) by zero order kinetic equation. Earlier Ghafoor *et al.* (2011) also showed that, both zero and first-order kinetic equations adequately described potassium release. Dey *et al.,* (2019) also observed that, a micronutrients release pattern from organic amendments upon soil application fitted best to zero-order and power function kinetics equation. In

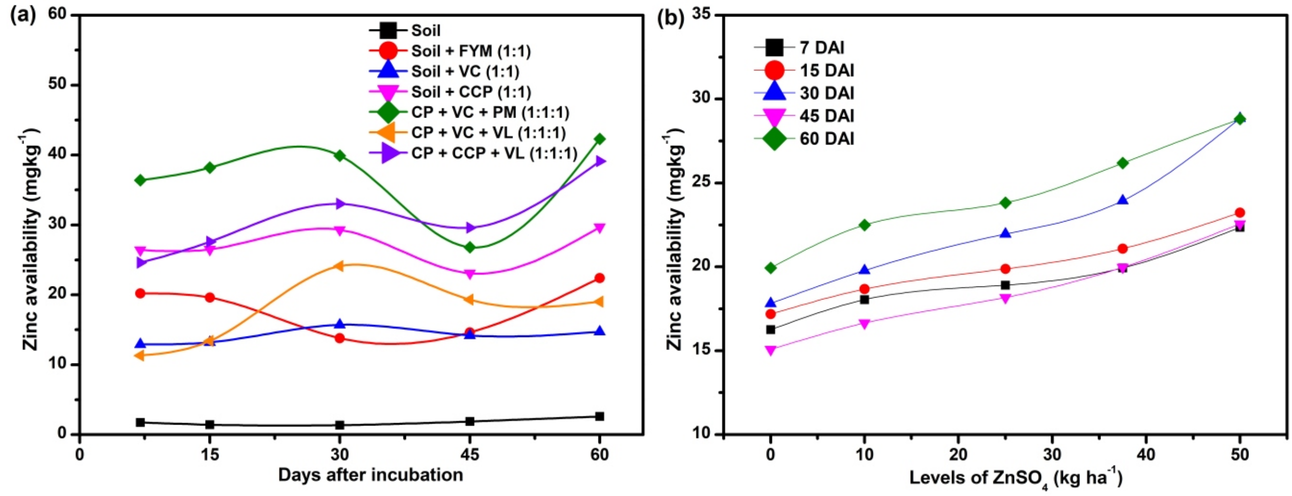

Fig. 1: Changes in DTPA Zn availability (a) in growing media mixtures with incubation time and (b) influenced by levels of $ZnSO_4$ application with time.

the present study, it was noted that zinc release from soil fitted slightly better to first order kinetics equation, whereas, from all other growing media mixtures fitted slightly better to parabolic diffusion and power function kinetic equations. However, considering a satisfactory validity of zero-order kinetics for the release of zinc from soil and growing media mixtures, the computed values of the constants for only zero-order kinetics and half-life ($t_{1/2}$, calculated as $q_0/2k_0$ in days) are presented in Table 1, for rational comparisons. The estimated initial value (q_0) for zinc showed that growing media mixtures and soil could be arranged in the following order of decreasing abundance: CP + VC +PM < Soil +CCP < CP +CCP +VL < Soil + FYM < Soil +VC < CP + VC + VL (Table 1). The highest initial zinc concentration was observed in CP + VC + PM (26.9 mg kg^{-1}) with 50 kg $ZnSO_4$ ha^{-1} whereas the lowest zinc status under no zinc control (0.26 mg kg^{-1}).

As regards to zero order rate constant (k_0), the highest value was observed in CP + VC + PM (3.02 mg kg^{-1} day^{-1}) in comparison to CP + CCP + VL (2.75 mg kg^{-1} day^{-1}) with 50 kg $ZnSO_4$ application. The values for CP + VC + VL (1.19 to 1.96 mg kg^{-1} day^{-1}), Soil + CCP (1.67 to 2.25 mg kg^{-1} day^{-1}), Soil + FYM (1.02 to 1.45 mg kg^{-1} day^{-1}) were not significantly different but having higher release rate than Soil + VC (0.78 to 1.57 mg kg^{-1} day^{-1}) and soil (0.039 to 0.252 mg kg^{-1} day^{-1}). Not only the growing media mixtures but also the levels of $ZnSO_4$ application observed to have contribution towards higher initial concentration but there was no significant difference observed statistically. Over all we can conclude that higher initial zinc release (q_0) and lower zero order rate constant (k_0) of cocopeat + vermicompost + pressmud media contributed higher zinc release for a longer period of time. Half-life ($t_{1/2}$) was calculated as $q_0/2k_0$ in days for all the growing media mixtures. It can predict the potential time taken to release half of initial zinc concentration over the incubation period. However, higher the $t_{1/2}$ values lesser will be the release and vice versa. In other hand, higher will be the time for releasing zinc, it can efficiently release for a longer period instead of increasing availability for a shorter duration, hence making the growing media more efficient one. In most of the growing media mixtures, it was found that, with increased zinc application, $t_{1/2}$ was decreased, whereas, it behaved abruptly in growing media mixtures like soil + FYM, Soil + Composted cocopeat, Cocopeat + Vermicompost + Pressmud and Cocopeat + Vermicompost + Vermiculite. The highest $t_{1/2}$ was observed in Soil + FYM (7.3 days) followed by Cocopeat + Vermicompost + Pressmud (6.6 days) at no Zn control. A linear decrease in pH was noticed with soil and farm yard manure mixture during the incubation period (7.87 to 7.42, Fig. 2a) while soil and soil mixed with composted cocopeat showed a decrease in pH only up to 30 days (7.30 and 7.26) and subsequently increased up to 60 days (7.43 and 7.48).

On the other hand, soil + Farmyard manure behaved dissimilarly than other growing media mixtures, where pH decreased from 7.62 to 7.60 within 15 days and again from 7.65 to 7.62 between 30 to 45 days of incubation. The lowest pH was recorded in soil followed by soil mixed with composted cocopeat. Addition of $ZnSO_4$ decreased the media pH in all the soil based growing media which might be due to the dissolution of sulphate ion that helped in acidifying the media mixtures. Also increasing levels of $ZnSO_4$ in soil, soil + FYM, Soil + VC and Soil + CCP, a net pH of 0.14, 0.10, 0.10, and 0.20 was decreased respectively over control. A rectilinear decrease in pH with incubation period was noticed in organic growing media mixtures, cocopeat, composted cocopeat with vermiculite. Higher (6.89) and lower pH (6.42) was recorded on 7 and 60 days after incubation. However, a slight decline in pH was noticed after 45 days. Among the organic growing media mixtures with higher average pH was associated with CP+ VC + PM (7.25) followed by CP + VC + VL (7.17) and CP + CCP + VL (6.65). From the trend it was clear that growing media mixtures containing vermiculite has lesser pH than other media mixtures, which might

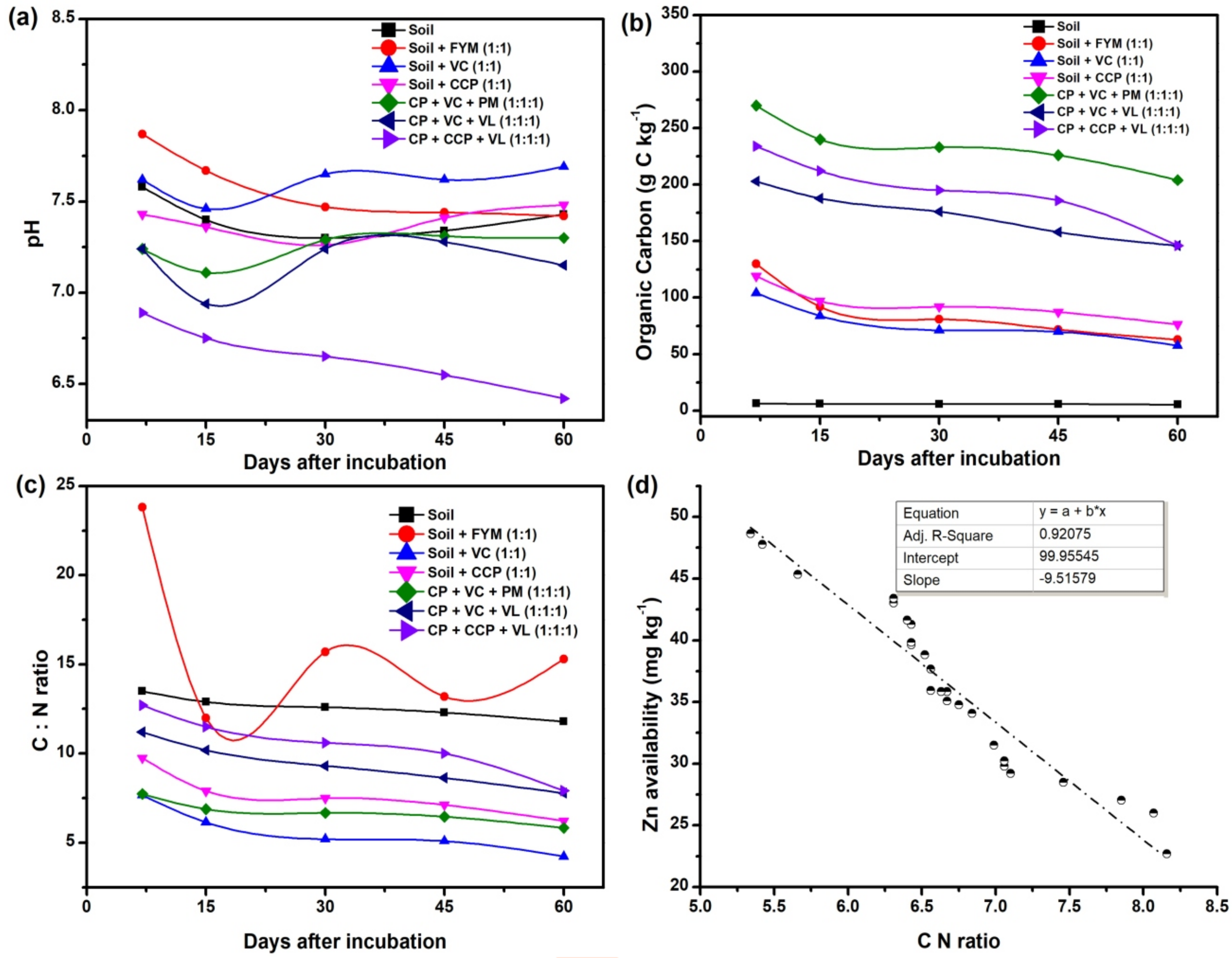

Fig. 2: Changes in (a) pH, (b) organic carbon content, (c) C:N ratio of growing media mixtures with time and (d) relationship between C:N ratio and zinc availability.

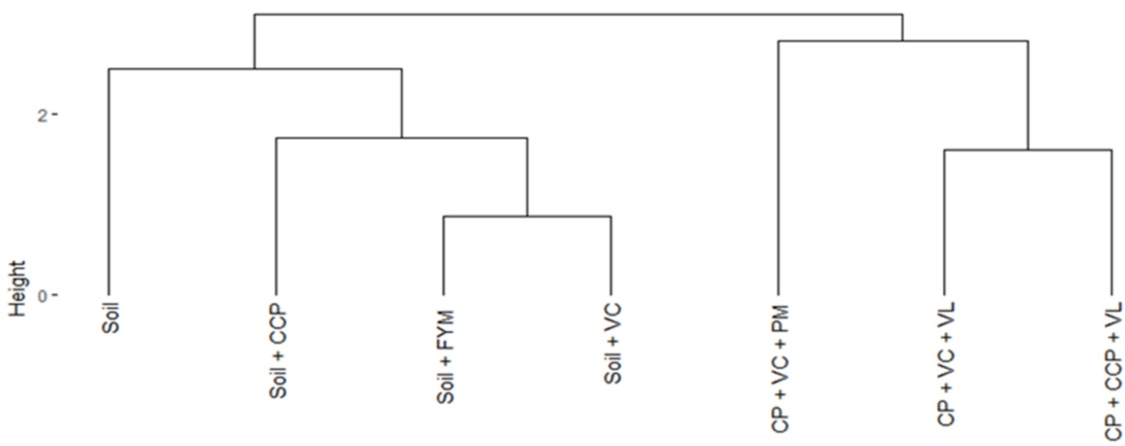

Fig. 3: Hierarchical clustering for grouping of growing media mixtures based on their physico-chemical properties and Zn availability.

be due to transfer of protons from AlOH (or SiOH) groups in the lattice of vermiculite to free OH- ions due to formation of H_2O in suspension (Duman *et al.,* 2008). As discussed above, pH values were significantly influenced by types of media and also levels of $ZnSO_4$ applied during the experiment. Significant reduction in growing media pH with time intervals might be due to the release of organic acids and CO_2 as a result of organic matter decomposition (Hossain *et al*., 2017), facilitated by alkaline pH of growing media and supply of sulphate ions from added $ZnSO_4$ (Dey *et al.,* 2019). A linear decrease in the organic carbon content of soil and growing media mixtures was recorded with the advancement of time and the effect widely differed with nature of growing media mixtures (Fig. 2b). The decrease in organic carbon content resulted in accelerated mineralization with higher rate of carbon degradation up to 30 days but decreased after 30 to 60 days.

The highest average organic carbon content was noted in Soil + CCP (94.4 g C kg^{-1}) followed by Soil + FYM (87.6 g C kg^{-1}), Soil + VC (77.4 g C kg^{-1}) and soil (5.93 g C kg^{-1}). Higher net loss in organic carbon content was observed in Soil + CCP (86.5 g C kg^{-1} at control) followed by Soil +FYM, Soil + VC and soil. Significant decrease in the organic carbon content of growing media mixtures with time might be due to increased decomposition rate of organic manures as all the components of growing media mixtures showed neutral to alkaline pH followed by CO_2 loss (Das *et al.,* 2016). Higher average organic carbon content was observed in CP + VC + PM (234 g C kg^{-1}) in comparison to CP + CCP + VL (195 g C kg^{-1}) and CP + VC + VL (178 g C kg^{-1}). A significant variation in C: N ratio was noticed with increasing time intervals (Fig. 2c), and higher average C:N ratio was noticed in soil (12.6) followed by Soil + CCP (7.69), Soil + VC (5.67) and Soil with FYM (5.57). This might be due to varied organic carbon content in the organic manures and also the major pools of organic matter had dissolved organic carbon which released with passing time and significantly contributed to the nutrient release (Alvarenga *et al.,* 2020). Thus, changing organic carbon content in growing media with increasing time period played a major role in zinc mineralization, and hence contributed to increasing zinc availability (Gupta *et al.,* 2019).

A decreasing trend for C:N ratio was noticed with increasing incubation time in organic growing media mixtures. The lowest average C: N ratio was observed in CP + VC + PM (6.72) which means the higher availability of plant available zinc with growing time. In comparison to CP + VC + PM, CP + CCP + VL (10.5) and CP + VC + VL (9.42) also had higher C:N ratio hence lowered the zinc availability. A statistically significant ($P<0.01$) relationship was found between organic carbon content and zinc availability in different growing media. Zinc availability in the growing media was negatively correlated with pH (R^2 = 0.97) and C: N ratio (R^2 = 0.92, Fig. 2d), while positively correlated with organic matter and organic carbon content of the growing media. This depicted that decrease in pH as well as C: N ratio contributed more towards zinc release. Also higher organic carbon content in the growing media mixtures had better potential for releasing zinc and its availability for longer time. The principal component scatter plots for individuals (growing media mixtures) were studied and it was observed that the individuals lying closer to each other seemed to be similar based on the variables studied.

The Soil + CCP and CP+VC+PM were most distant from the origin in positive coordinates thereby making it most suitable growing media mixtures for increased zinc availability as well as for their better physico-chemical characters. But the Soil + VC and Soil + FYM were observed to possess almost similar behavior and were next in order with lesser variability as compared to former media mixtures. Individuals falling far from the origin and in negative coordinates were less suitable media mixtures such as soil. Conclusively, it can be suggested that, media mixtures which fall under positive quadrants may be considered suitable for higher zinc availability. Further, the cluster analysis based on agglomerative hierarchical clustering and the resultant dendrogram (Fig. 3) were studied for grouping the growing media mixtures based on their behaviours, revealed that, soil + FYM, Soil + VC, Soil + CCP were grouped under one cluster where soil + FYM, Soil + VC behaved similarly.

The mixture *viz.,* CP + VC + VL and CP + CCP + VL fell under one cluster and seemed to have similar effects on Zn availability. From the PC scatter plot and clustering of growing media, CP+VC+PM is most suitable growing media mixtures, which have significantly different contribution towards Zn availability. The study revealed that growing media mixtures vary in their physico-chemical properties and rate of zinc release which can be accounted well by zero-order kinetics. The availability of zinc from different growing media mixtures depends on the nature of organic media used and their decomposition rate. Based on the amount of zinc released from different growing media mixtures, the best source seemed to be the growing media with cocopeat, vermicompost and Pressmud mixed in 1:1:1 ratio, which was positively correlated with reduced pH, narrow C: N ratio and organic carbon content followed by Soil + CCP. Thus, according to the need of the farmer and resource availability, the most suitable soil based growing media or organic growing media mixture can be opted for cultivation and better zinc fertilization practices.

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Add-on Information

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