

Synergistic effects of engineered Biochar and organic fertilizers on the plant growth, yield, and fruit quality of bell pepper and tomato in a tropical laterite soil



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Presented

by

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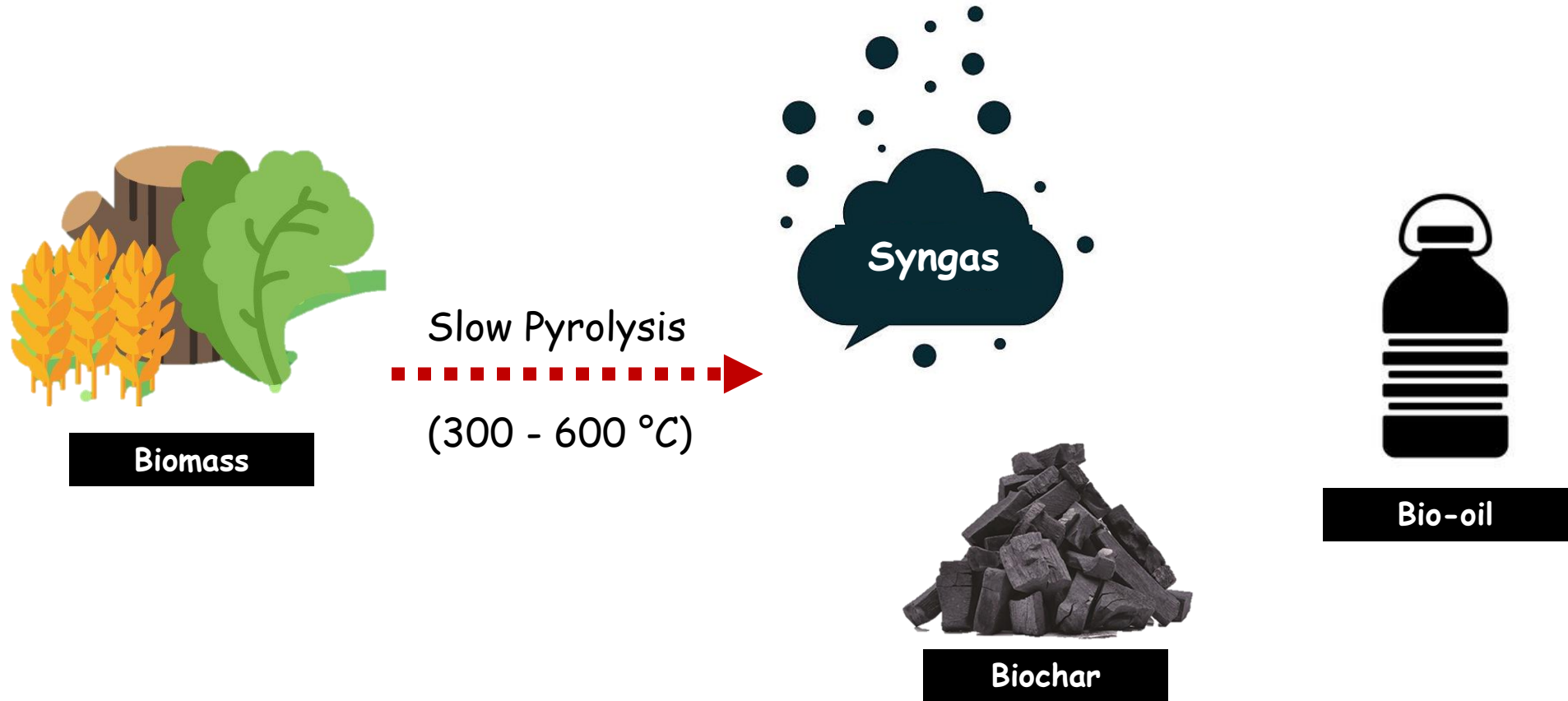


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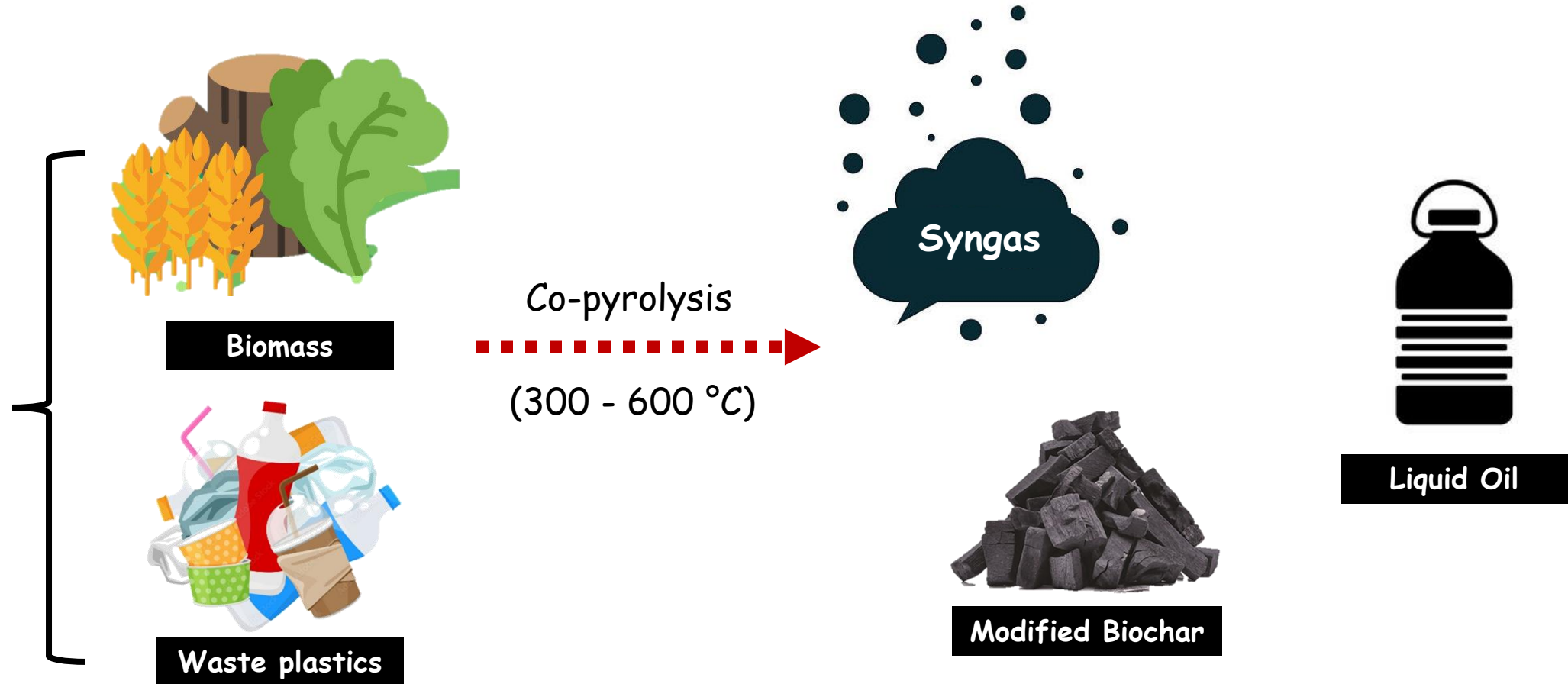


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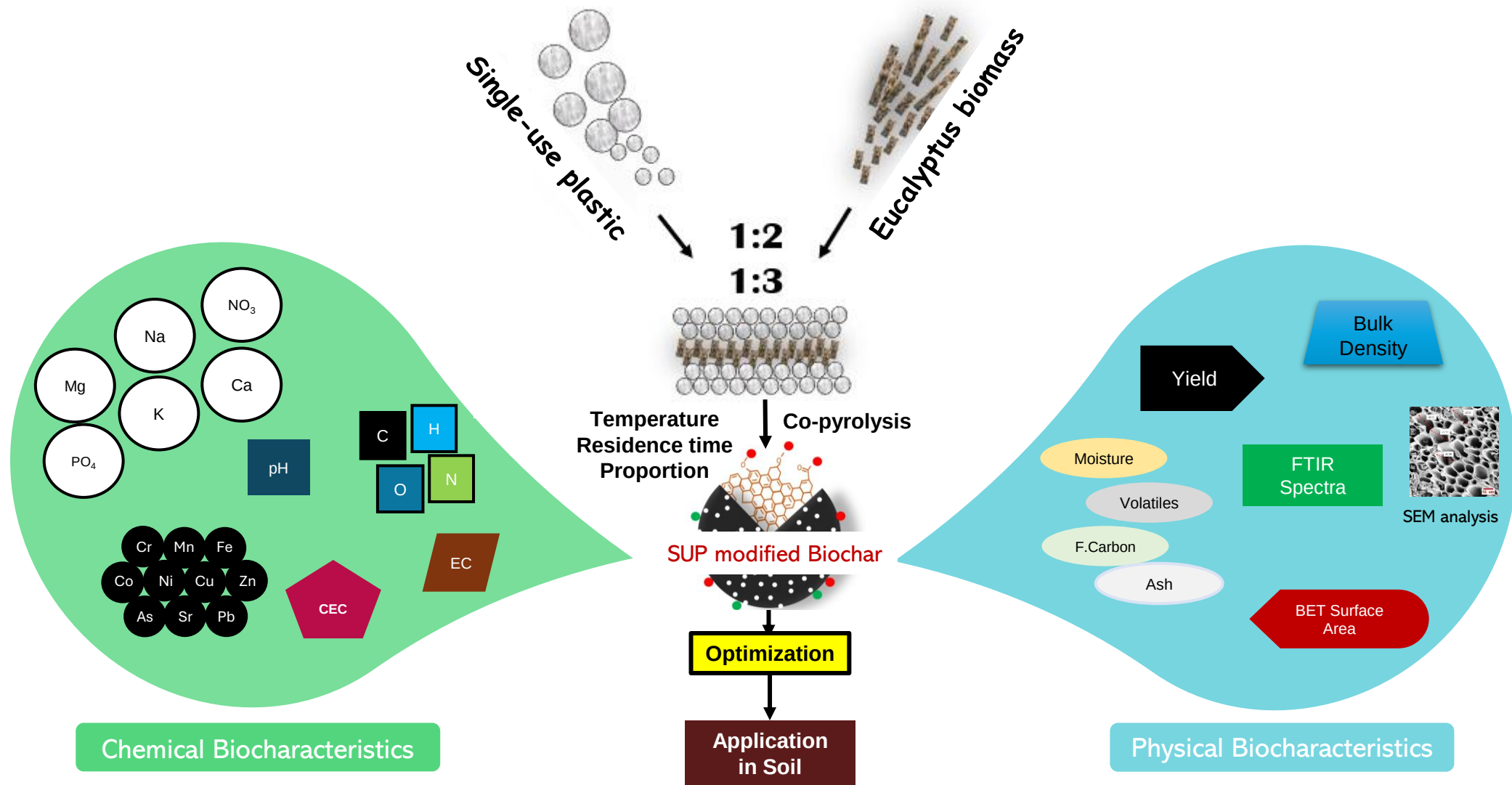
Pyrolysis and Biochar Production



Co-pyrolysis



Production of SUP modified Biochar

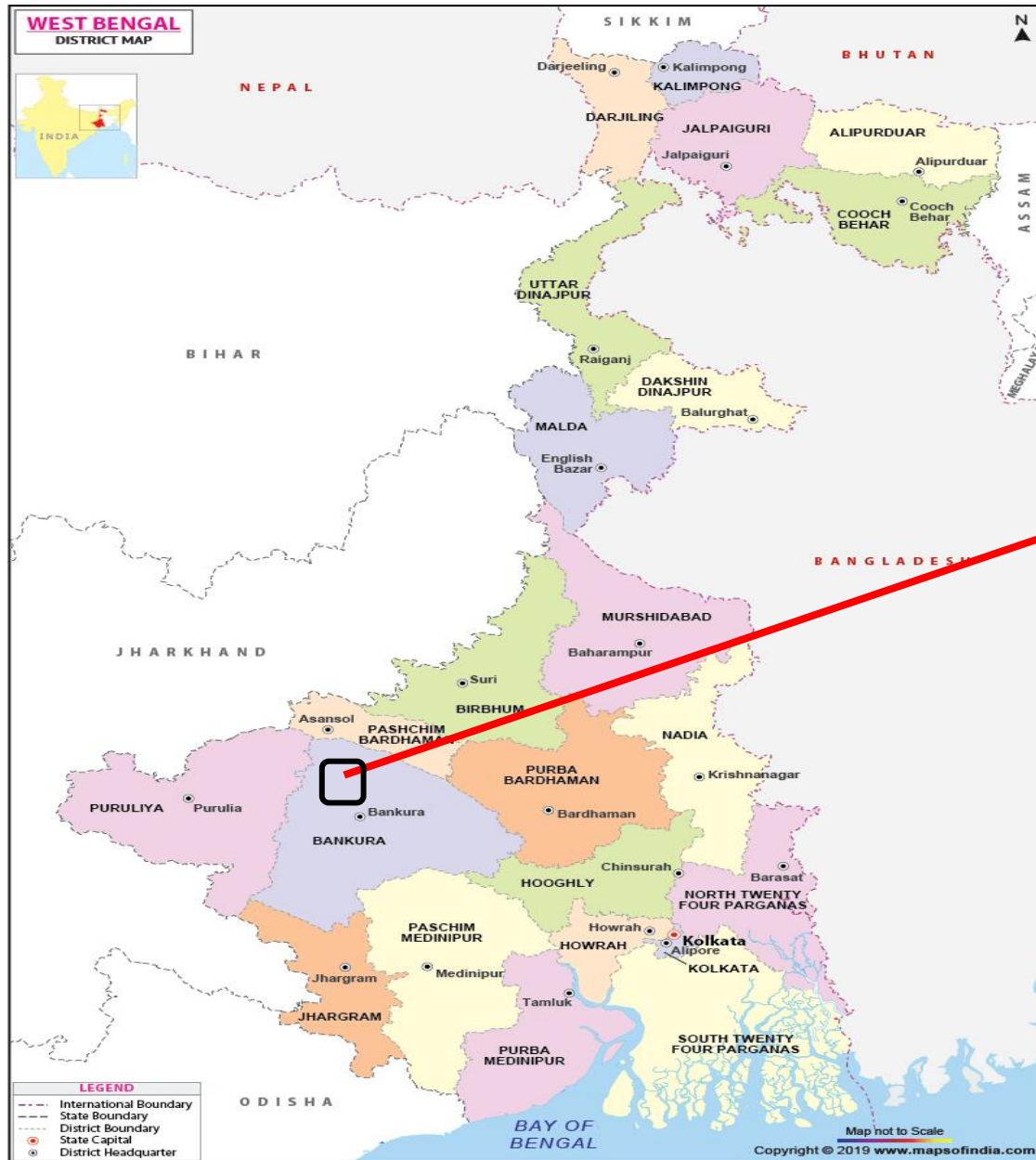


Characteristics of soil and organic supplements used in the study						
Parameter	BC	BP	BL	V. Compost	Manure	Soil
Pyrolysis temperature (°C)	450	400	500	-	-	-
Texture	-	-	-	-	-	Loamy sand
Total Carbon mass fraction (%)	68.97 (3.21)	72.32 (3.51)	73.61 (2.84)	21.18 (1.03)	24.16 (1.12)	0.895 (0.04)
Total Nitrogen mass fraction (%)	3.67 (0.12)	5.22 (0.27)	4.51 (0.29)	1.75 (0.06)	3.86 (0.15)	-
C/N ratio	18.79	14.05	16.32	12.1	6.26	-
Organic matter (g kg ⁻¹)	-	-	-	30.47 (1.52)	34.15 (1.7)	1.871 (0.09)
Water holding capacity	135.5 (7.06)	142.6 (7.3)	164.2 (6.77)	122.1 (6.25)	102 (5.32)	35.4 (1.81)
Bulk density (g cm ⁻³)	0.342 (0.013)	0.255 (0.012)	0.24 (0.013)	0.76 (0.034)	0.71 (0.027)	1.39 (0.06)
pH	9.35 (0.13)	9.57 (0.12)	9.92 (0.15)	6.5 (0.09)	8.47 (0.06)	6.92 (0.1)
Electrical conductivity (dS m ⁻¹)	4.45 (0.21)	5.42 (0.27)	4.73 (0.24)	6.88 (0.34)	5.22 (0.25)	0.52 (0.03)
Cation exchange capacity (Cmol kg ⁻¹)	47.32 (2.29)	53.56 (2.06)	51.54 (2.5)	12 (0.461)	23 (1.11)	9.91 (0.38)
Available major nutrients (g kg ⁻¹)	Available nutrients (g kg ⁻¹)					
Na	0.61 (0.025)	0.578 (0.023)	0.233 (0.01)	0.212 (0.008)	0.624 (0.023)	0.015 (0.001)
K	25.79 (0.94)	21.51 (0.74)	26.79 (0.98)	6.23 (0.22)	3.43 (0.74)	0.105 (0.004)
Ca	6.73 (0.28)	8.3 (0.39)	8.79 (0.36)	11.42 (0.54)	2.34 (0.39)	0.074 (0.003)
Mg	7.29 (0.25)	6.94 (0.24)	6.07 (0.21)	3.63 (0.16)	4.18 (0.24)	0.029 (0.001)
NO ₃ -N	0.081 (0.004)	0.094 (0.004)	0.117 (0.005)	8.14 (0.338)	9.36 (0.004)	0.018 (0.001)
NH ₄ -N	n.d	n.d	n.d	4.63 (0.25)	11.2 (0.69)	n.d
P	1.5 (0.081)	1.56 (0.082)	1.15 (0.062)	5.63 (0.295)	3.22 (0.082)	0.023 (0.001)
Available minor nutrients (mg kg ⁻¹)	Available minor nutrients (mg kg ⁻¹)					
Mn	3.07 (0.15)	3.75 (0.16)	2.4 (0.11)	212 (9.28)	129 (4.6)	32.5 (1.54)
Fe	6.55 (0.34)	9.83 (0.5)	3.28 (0.17)	1230 (64)	112.2 (4.5)	10.74 (0.55)
Cu	0.4 (0.02)	0.46 (0.02)	0.33 (0.01)	18 (0.87)	3.8 (0.02)	8.73 (0.39)
Zn	23.2 (0.87)	24.2 (0.84)	22.2 (0.83)	53 (3.84)	18 (1.84)	28.2 (1.06)

Nomenclature of different treatments used in the study

	Control	Polystyrene modified Biochar (BP)			LDPE modified Biochar (BL)			Conventional Biochar (BC)		
	0 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha
Biochar (C)	C ₀	P ₁	P ₂	P ₃	L ₁	L ₂	L ₃	B ₁	B ₂	B ₃
Vermicompost + Biochar (VC)	VC ₀	VP ₁	VP ₂	VP ₃	VL ₁	VL ₂	VL ₃	VB ₁	VB ₂	VB ₃
Manure + Biochar (MC)	MC ₀	MP ₁	MP ₂	MP ₃	ML ₁	ML ₂	ML ₃	MB ₁	MB ₂	MB ₃
Vermicompost + Manure + Biochar (VMC)	VMC ₀	VMP ₁	VMP ₂	VMP ₃	VML ₁	VML ₂	VML ₃	VMB ₁	VMB ₂	VMB ₃

Study area of commercial organic olericulture



Study area of commercial organic olericulture



Phenological stages of the bell pepper and tomato species



Transplantation (Day 1)



Vegetative growth (Day 15)



First flowering (Day 30)



Fruit development (Day 53)



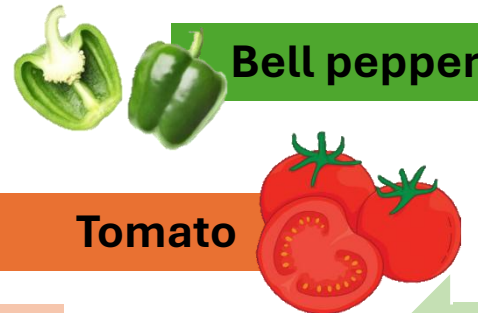
Fruit maturity & harvest (Day 69)



Vegetative growth (Day 28)



Transplantation (Day 1)



Fruit harvest (Day 120)



Fruit harvest (Day 97)



First flowering (Day 56)



Fruit development (Day 71)



Fruit maturity & harvest (Day 97)



Fruit harvest (Day 117)

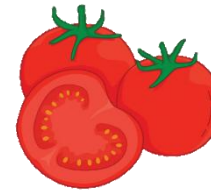
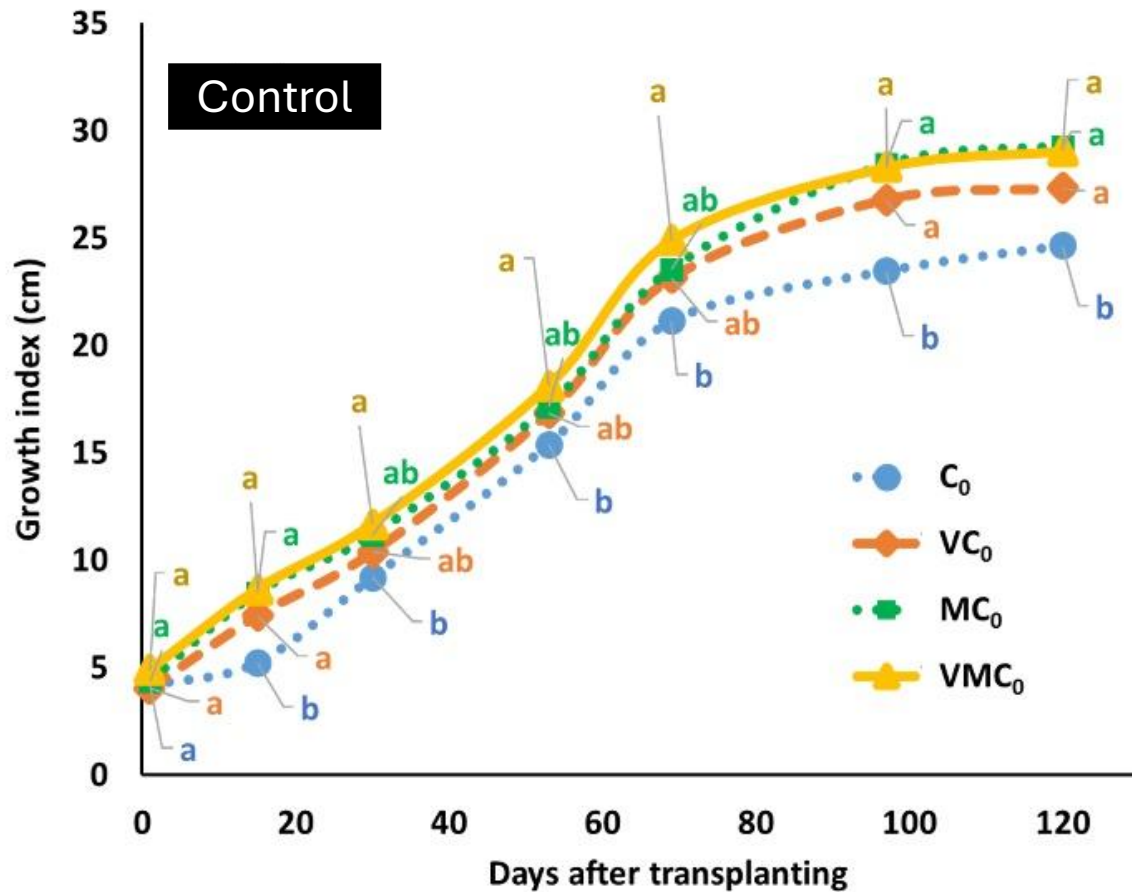


Fruit harvest (Day 134)

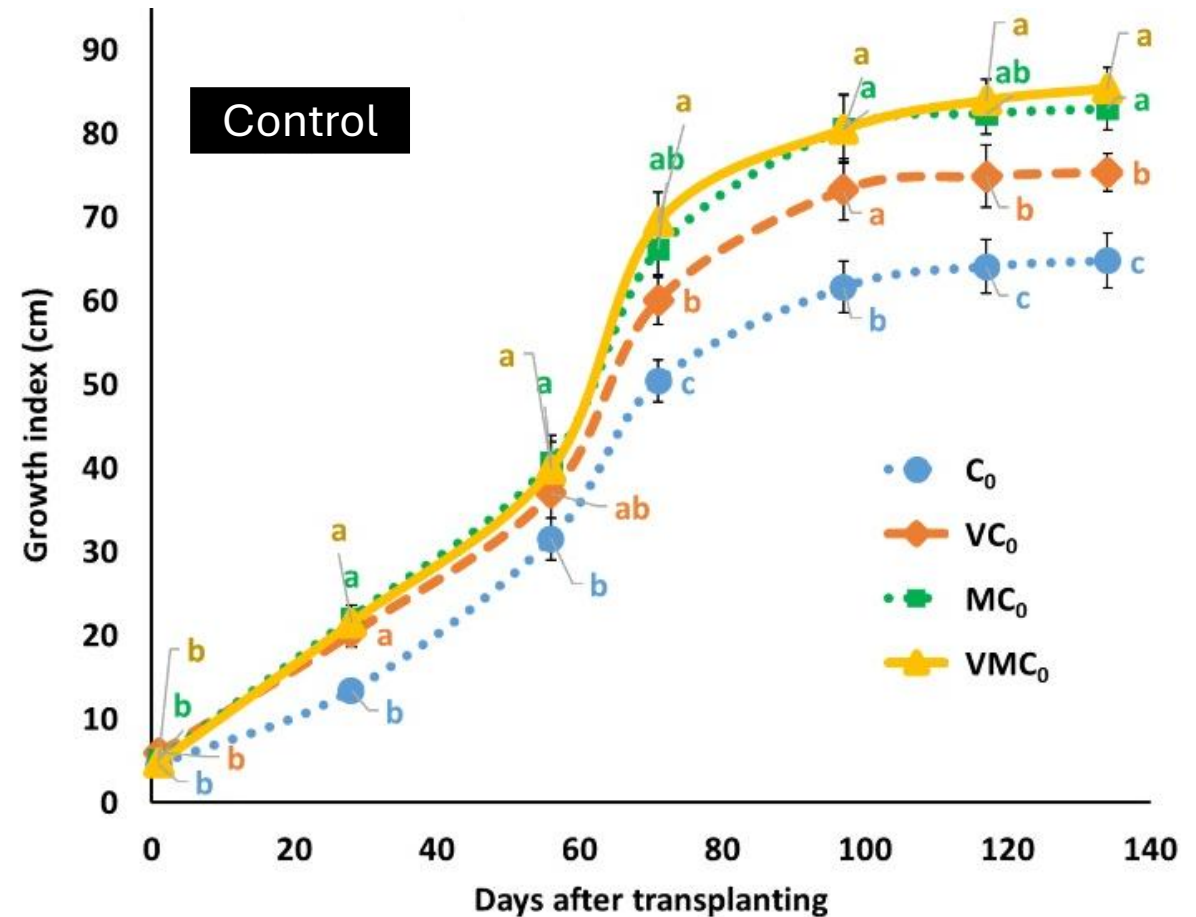
Effect of Biochars on plant growth index (Control group)



Bell pepper



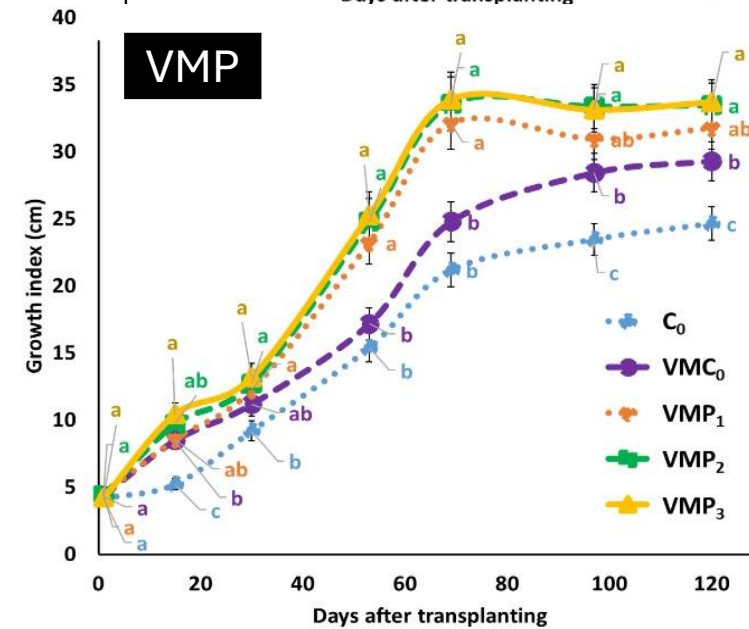
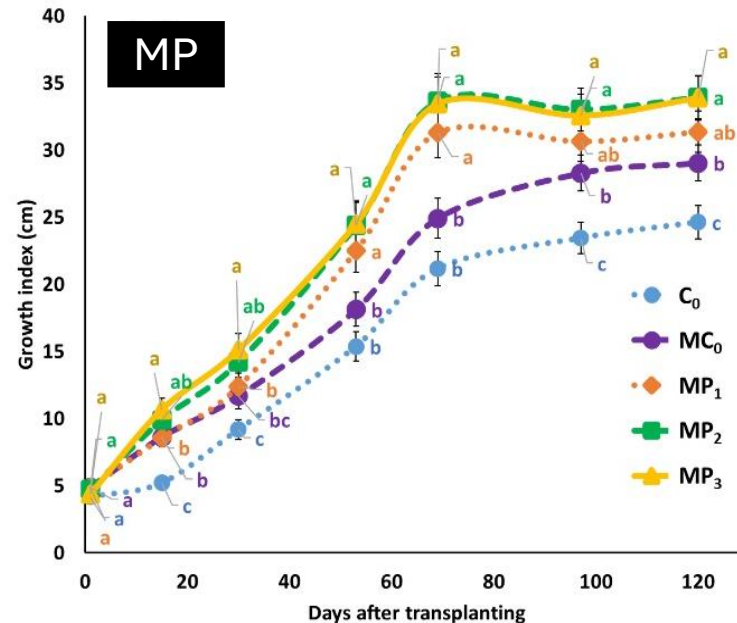
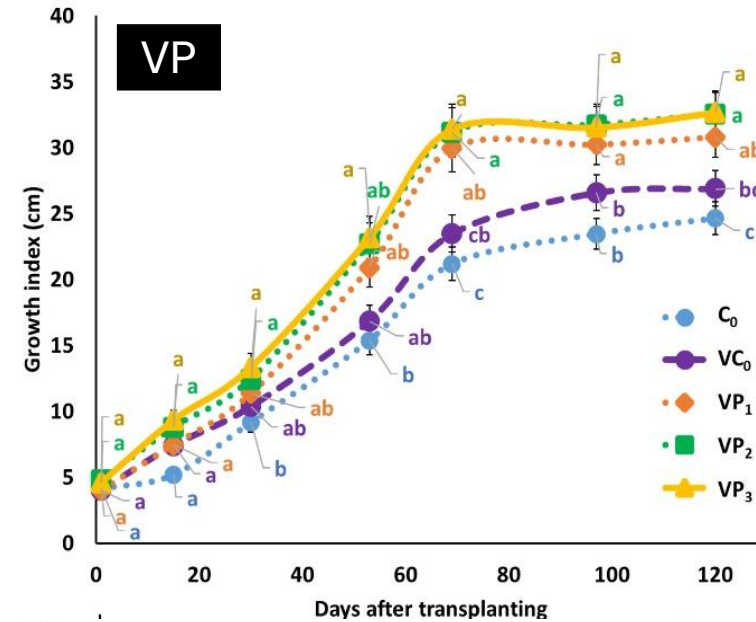
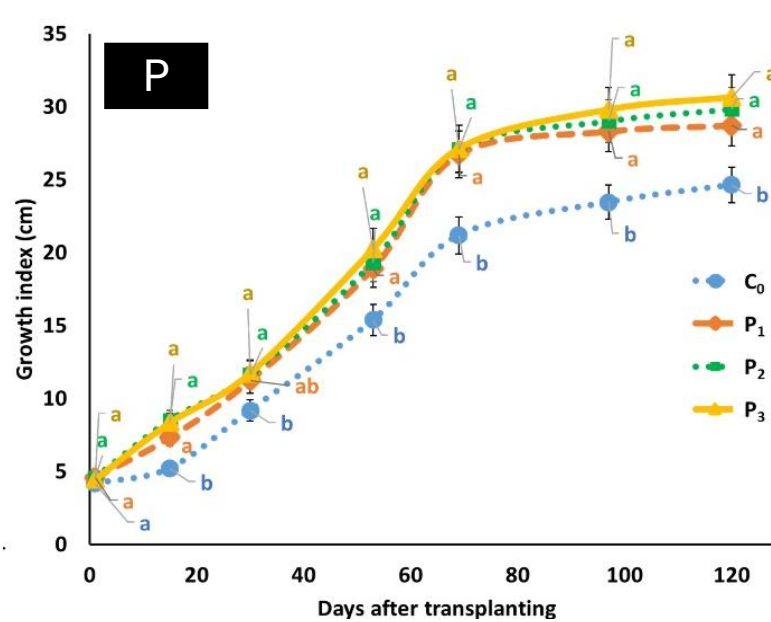
Tomato



Effect of Biochars on plant growth index (BP)

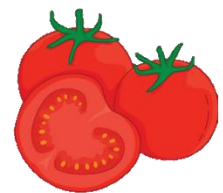


Bell pepper

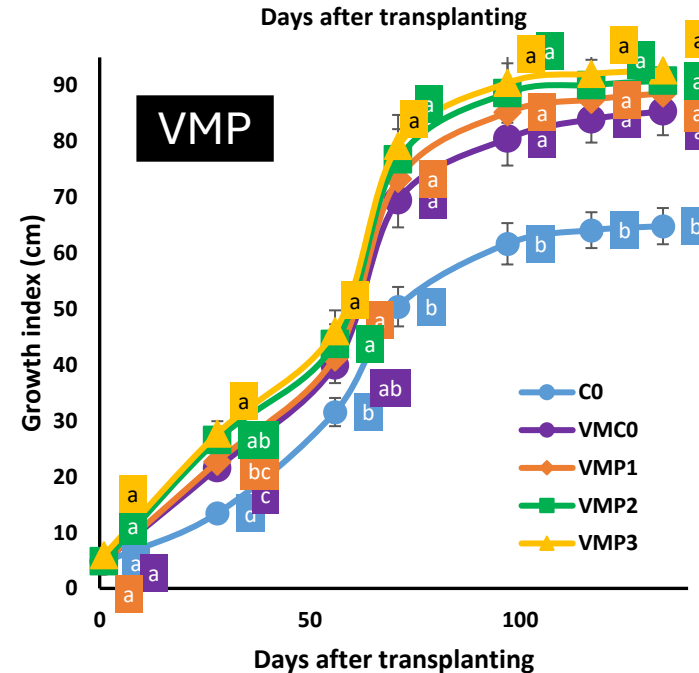
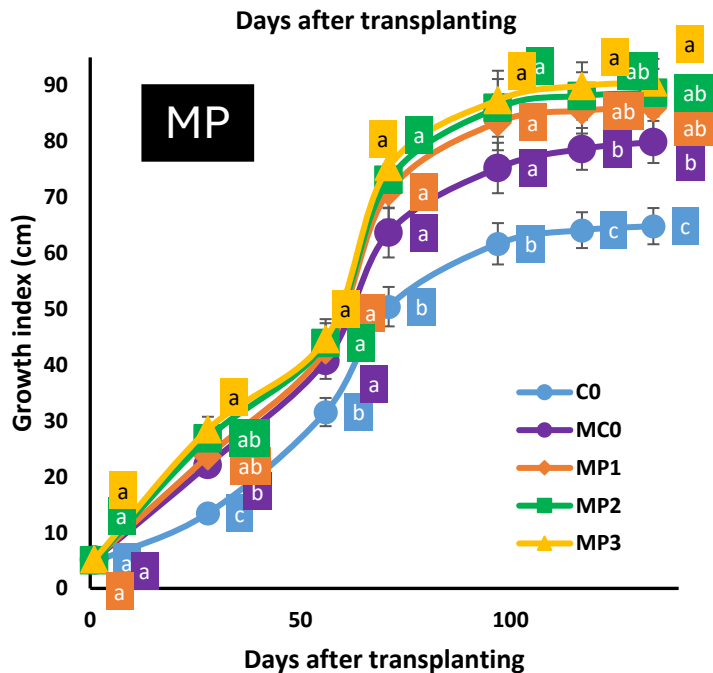
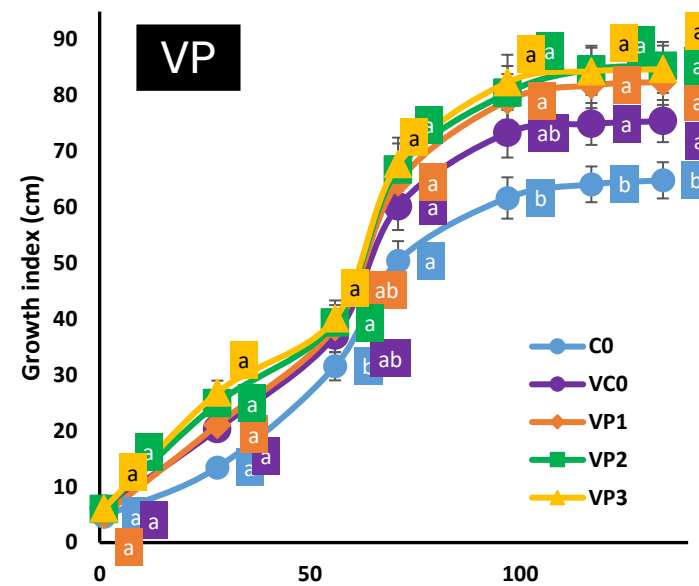
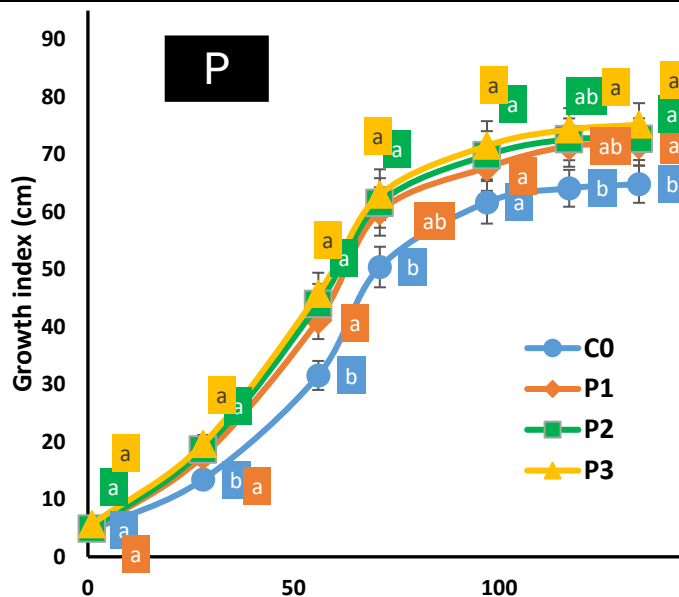


Means followed by the same letter are not significantly different at $p < 0.05$ according to Tukey's test.

Effect of chars on plant growth index (BP)



Tomato

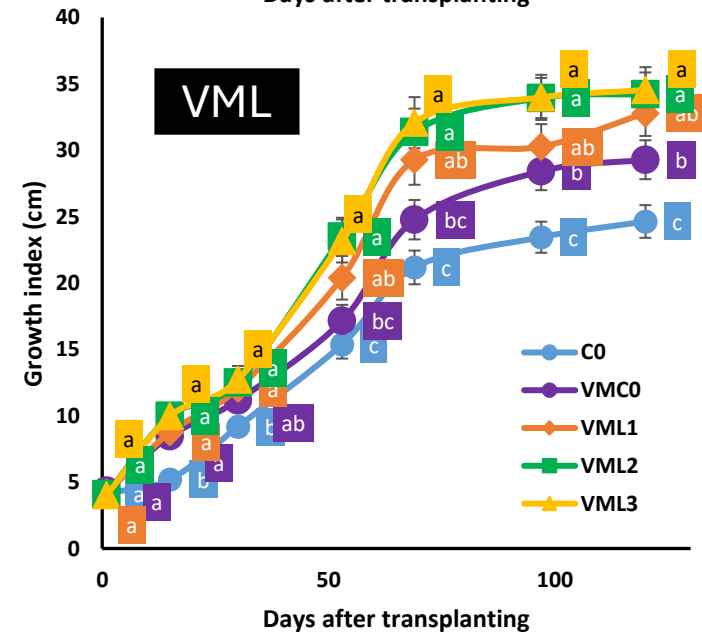
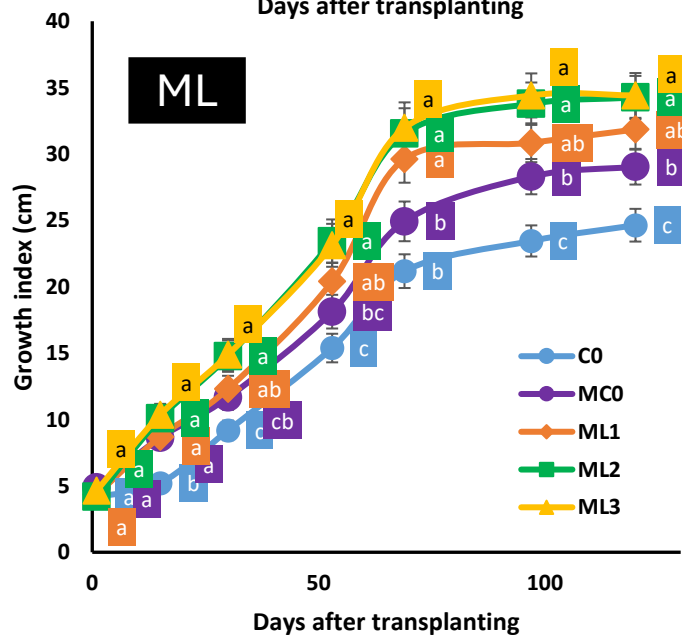
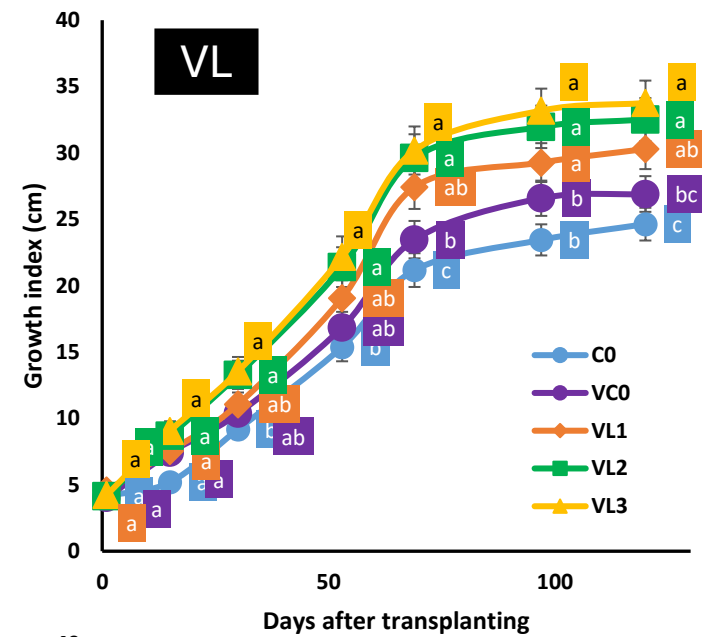
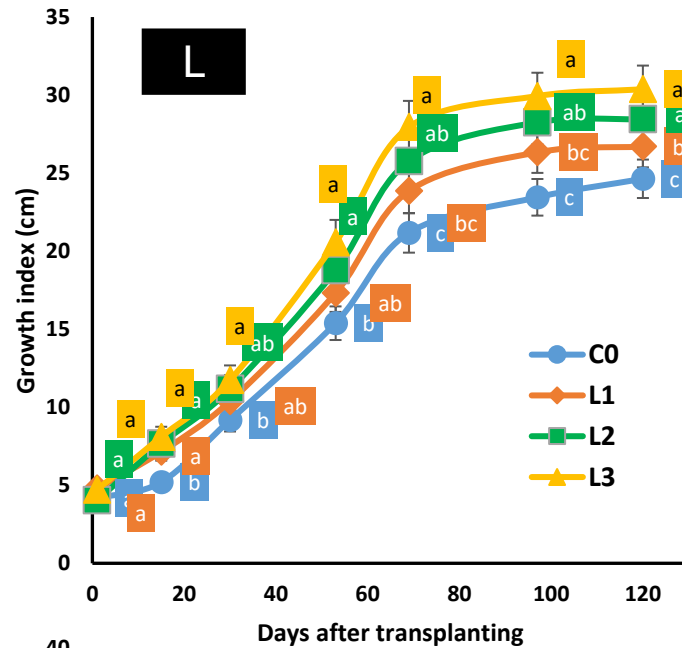


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Effect of chars on plant growth index (BL)

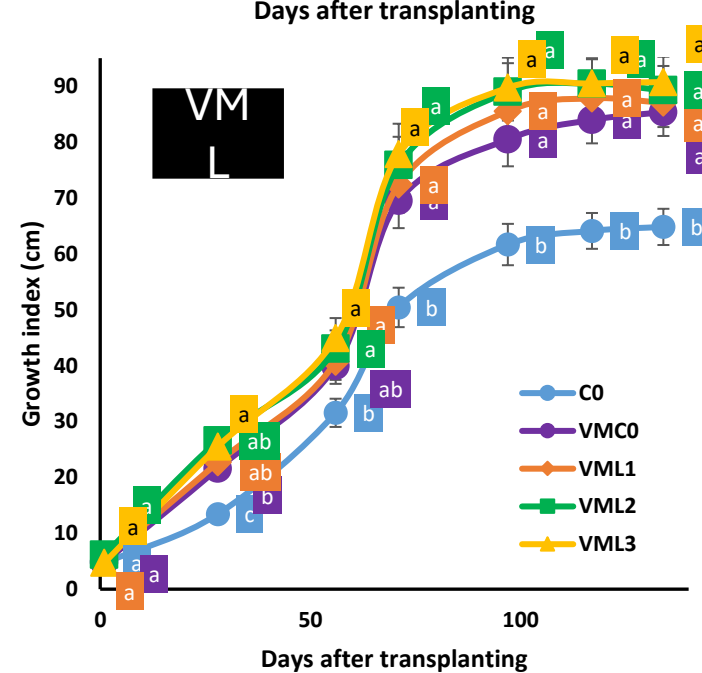
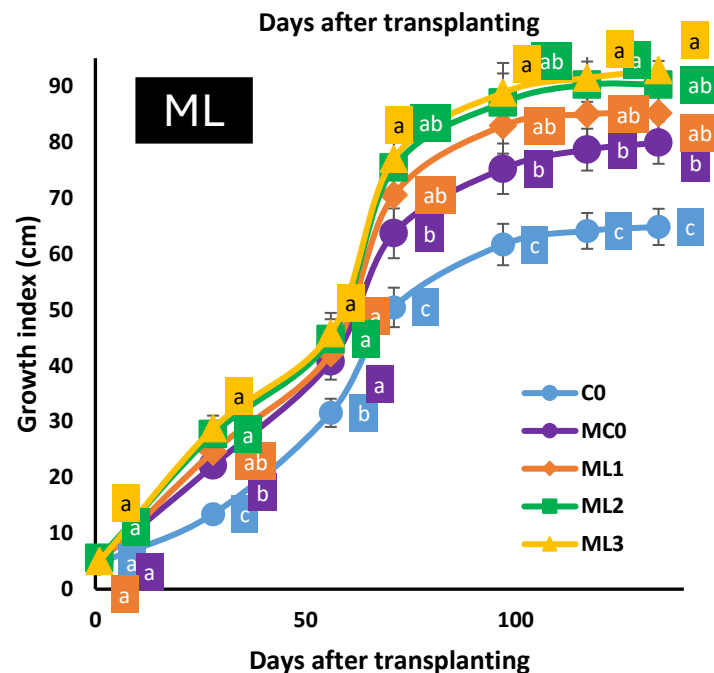
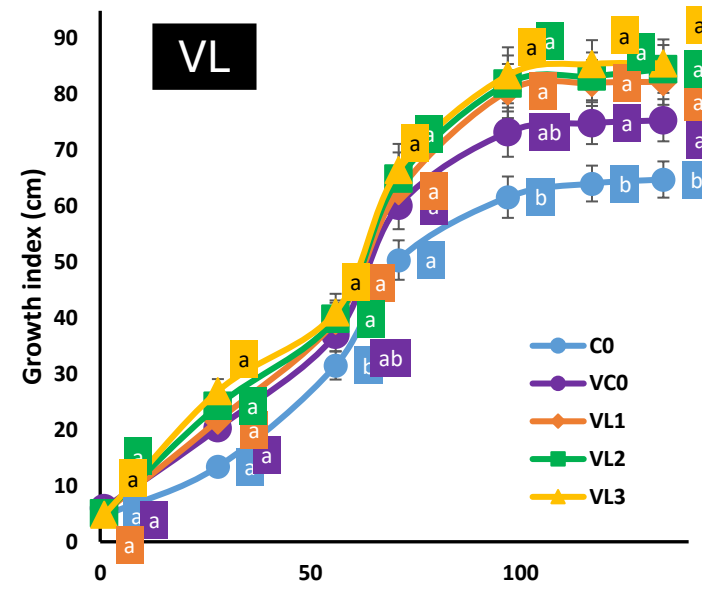
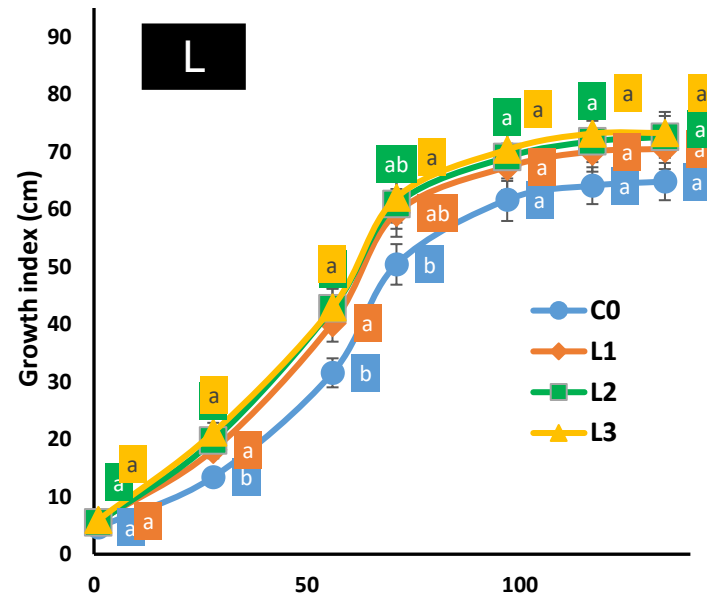


Bell pepper



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Effect of chars on plant growth index (BL)

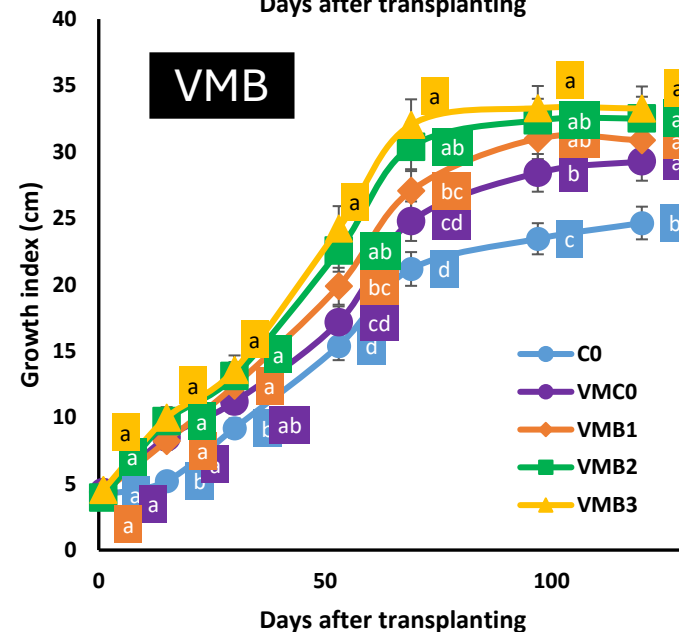
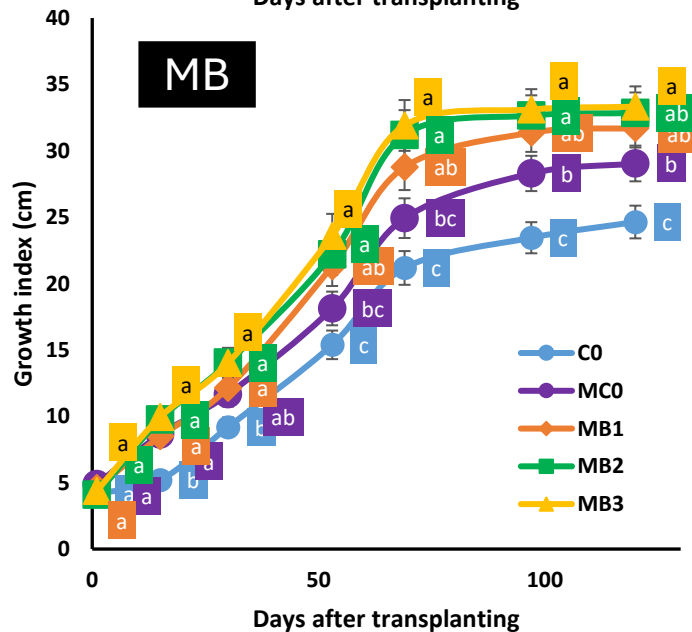
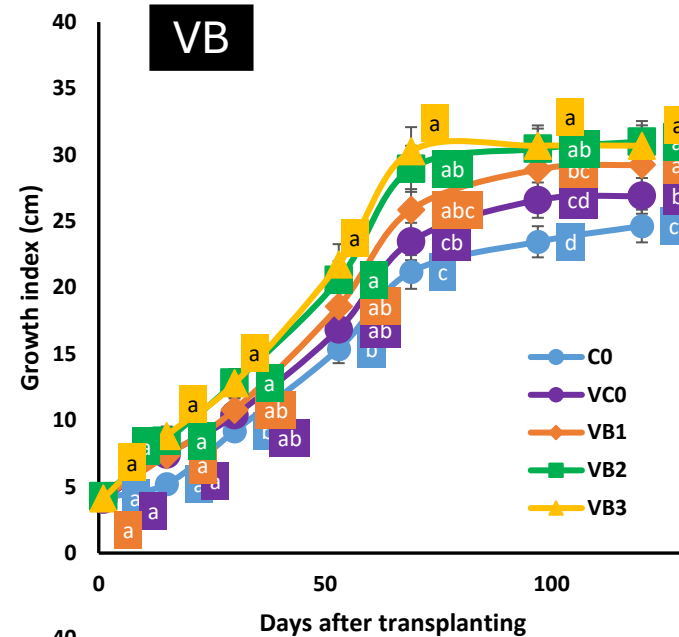
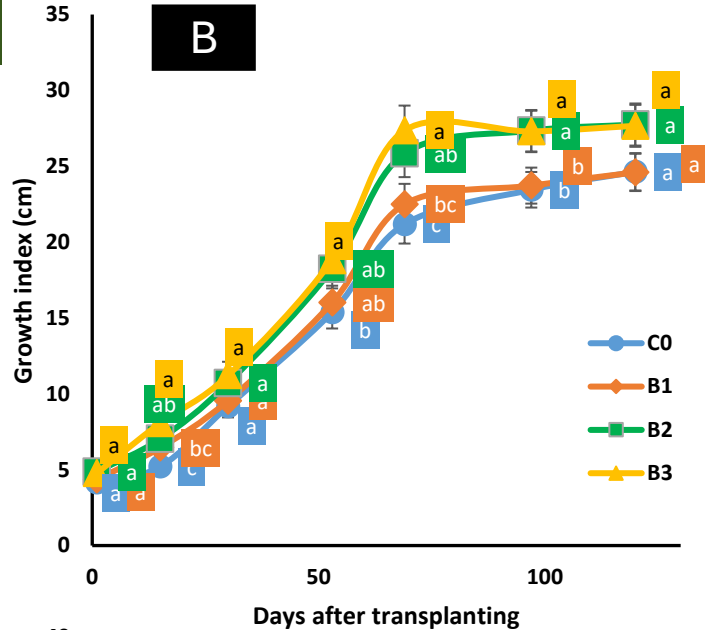


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Effect of chars on plant growth index (BC)

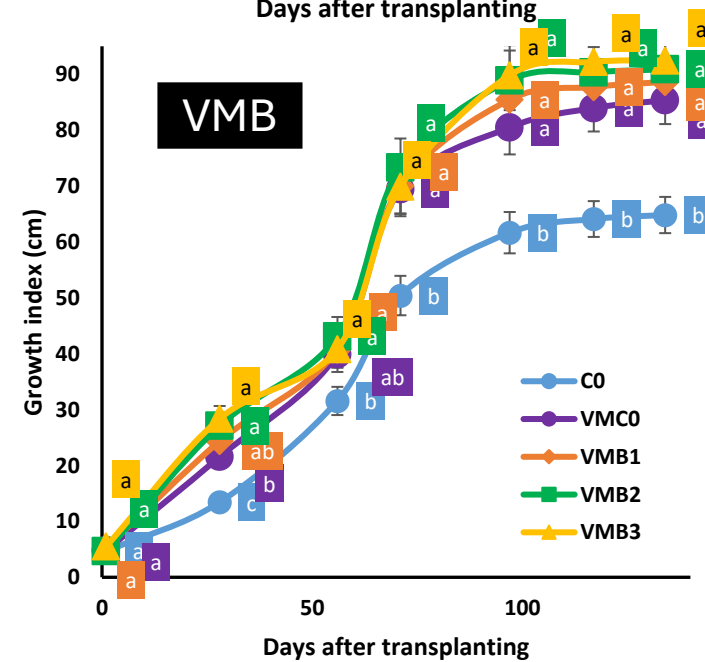
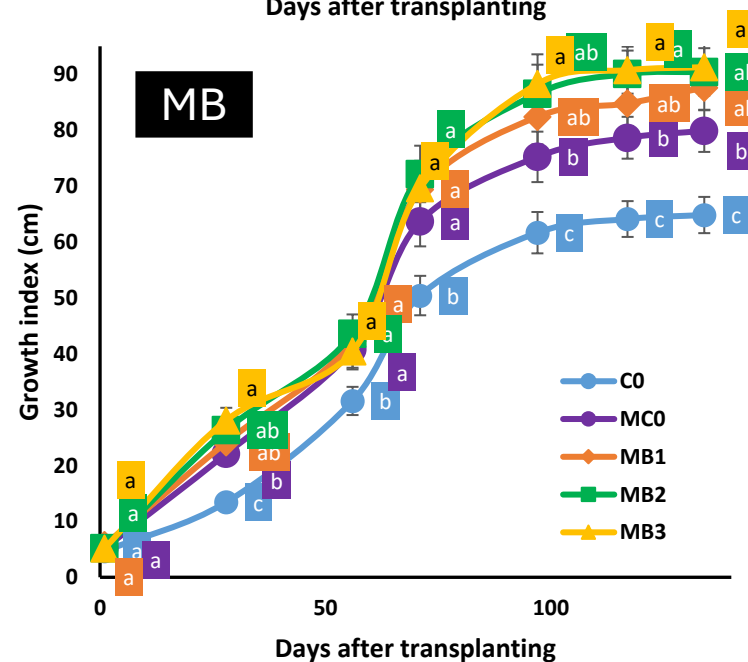
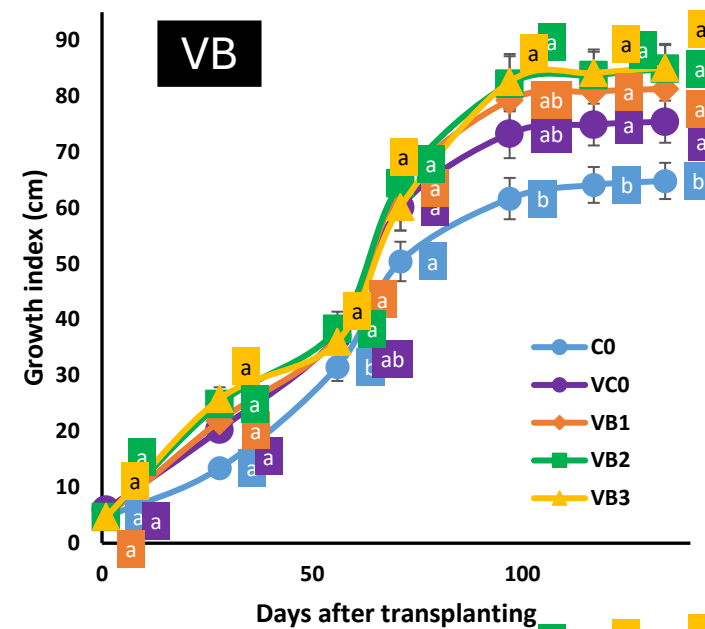
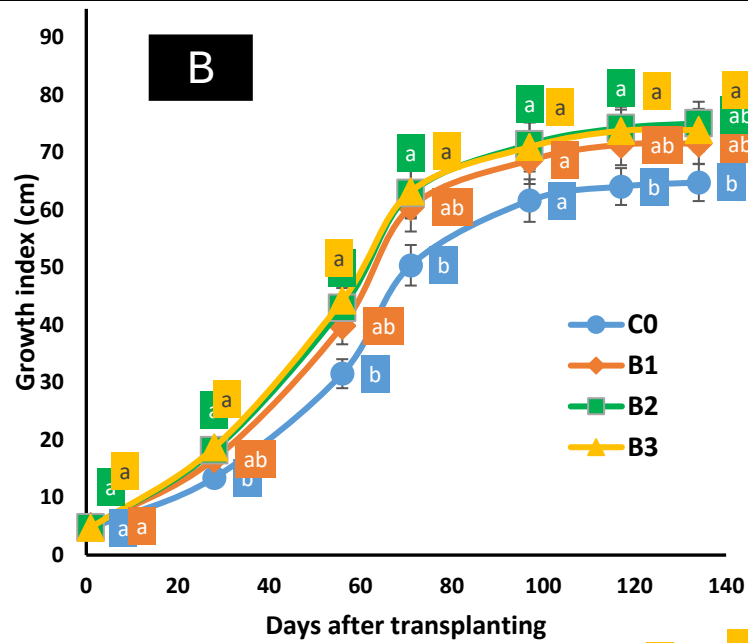


Bell pepper



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Effect of chars on plant growth index (BC)

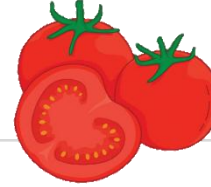
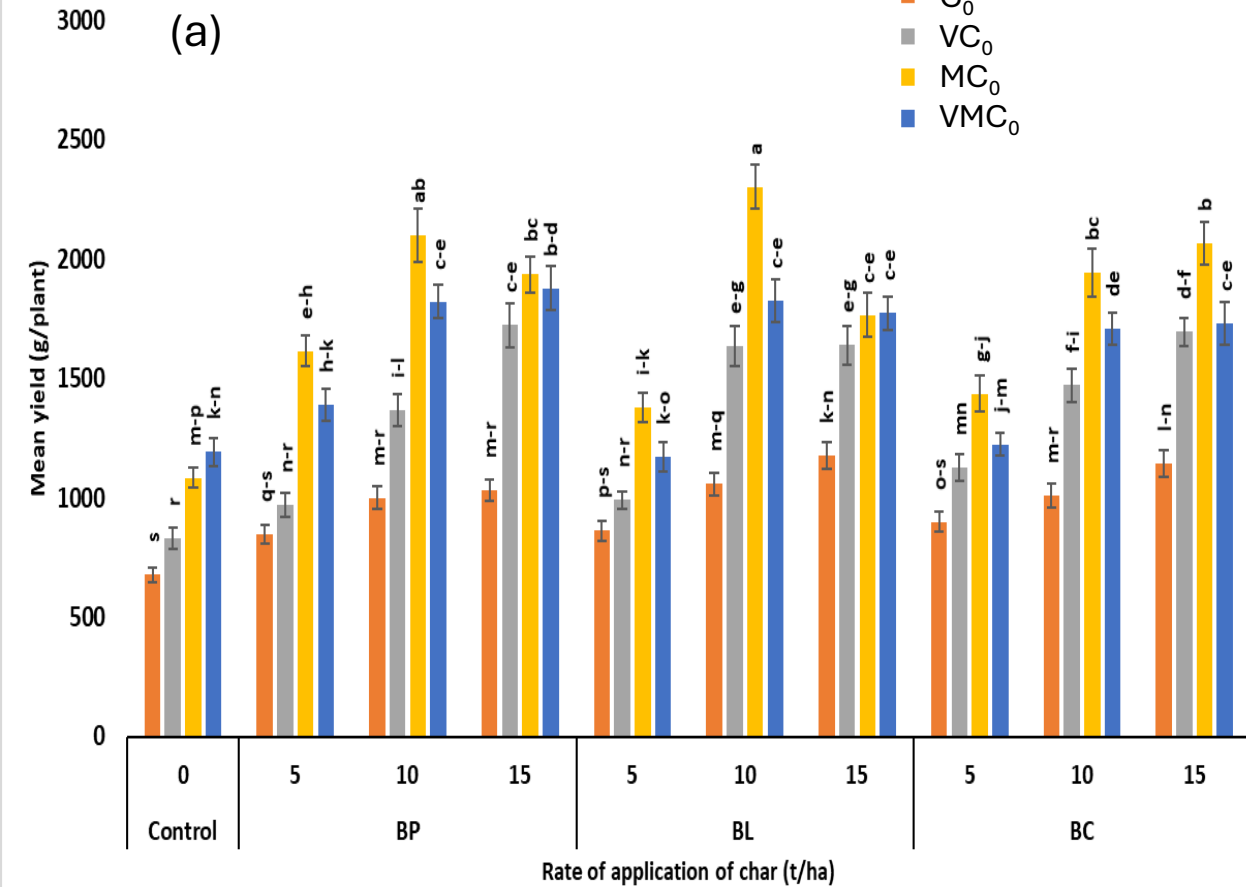


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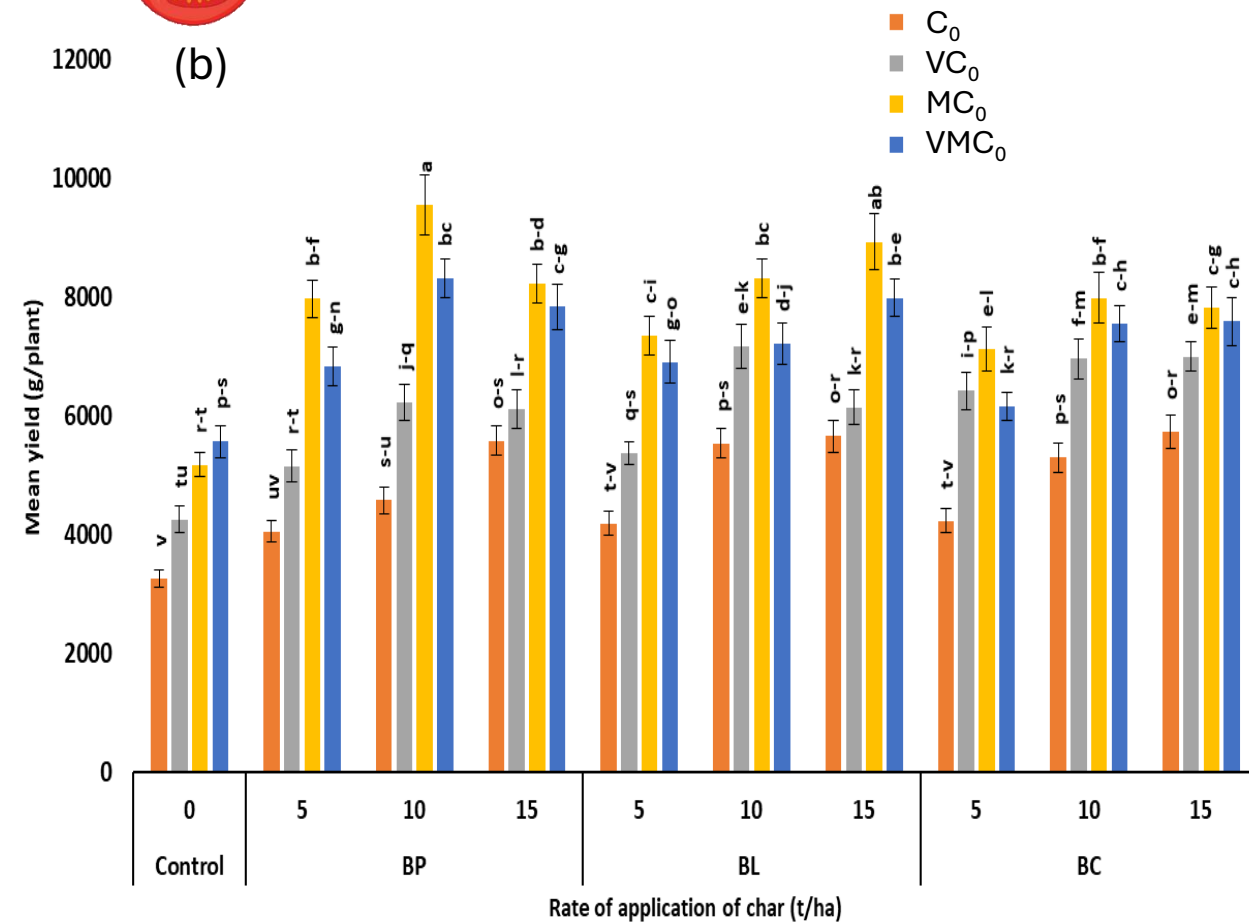
Effect of Biochars on fruit yield



Bell pepper



Tomato

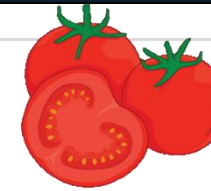
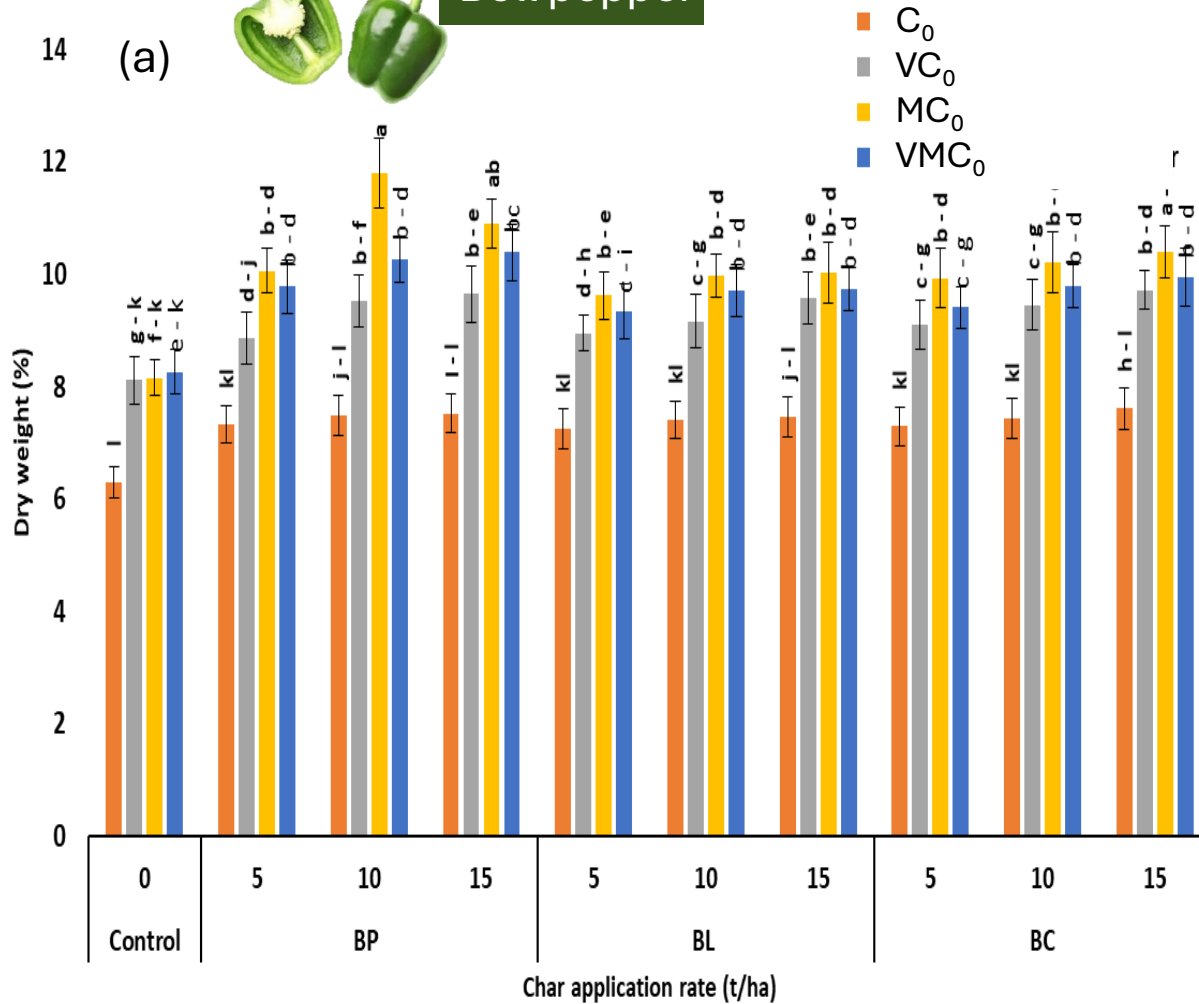


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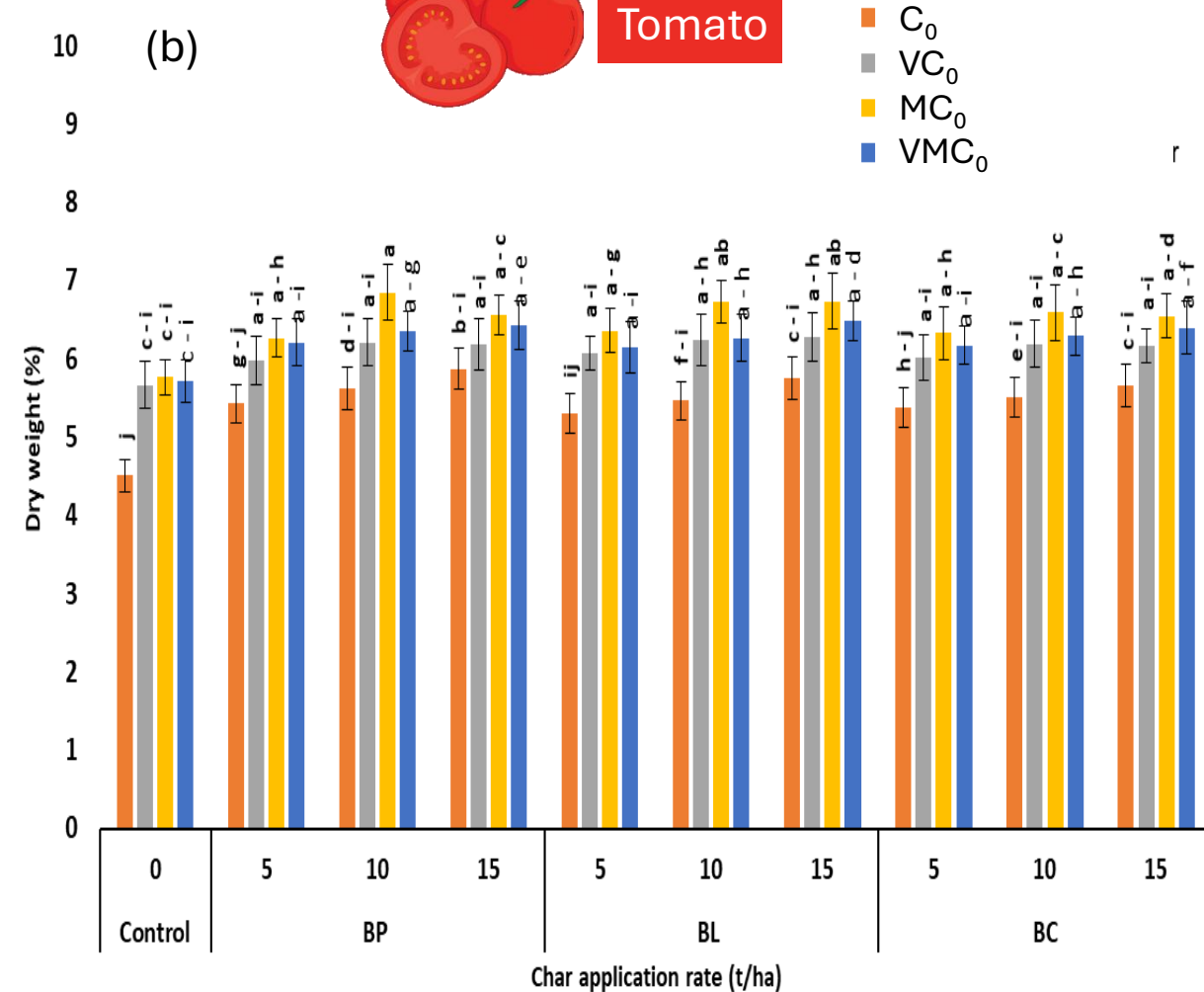
Effect of chars on fruit dry weight



Bell pepper



Tomato



Means followed by the same letter are not significantly different at $p < 0.05$ according to Tukey's test.

Effect of Biochars on fruit quality parameters



Bell pepper

	Control	BP			BL			BC		
	0 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha
Total soluble solids (TSS) (% Brix)										
Biochar	4.1 (p)	4.8 (mn)	5.3 (j - l)	5.2 (k - m)	4.9 (l - n)	5.2 (f - i)	5.2 (e - h)	4.7 (k - m)	5.4 (f - i)	5.3 (e - h)
Vermicompost+ Biochar	4.7 (no)	5.1 (l - n)	5.9 (e - h)	5.7 (g - j)	5.4 (g - k)	5.8 (ab)	6 (a)	5.2 (h - k)	5.8 (b - d)	5.9 (ab)
Manure+ Biochar	4.8 (mn)	5.6 (h - k)	6.7 (bc)	6.8 (ab)	5.8 (g - j)	6.9 (c - e)	7.2 (b - d)	5.6 (i - l)	6.5 (d - g)	6.9 (f - i)
Vermicompost + Manure + Biochar	4.8 (mn)	5.4 (i - l)	6.2 (d - f)	6.3 (c - e)	5.5 (k - n)	6.3 (k - m)	6.5 (no)	5.4 (i - l)	6.1 (j - l)	5.8 (op)
	Control	BP			BL			BC		
	0 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha
Titrateable acidity (TA) (% citric acid)										
Biochar	0.208 (l)	0.238 (j - l)	0.247 (h - l)	0.248 (h - l)	0.251 (f - k)	0.265 (e - k)	0.269 (e - k)	0.243 (i - l)	0.252 (f - k)	0.257 (e - k)
Vermicompost + Biochar	0.228 (kl)	0.27 (e - j)	0.278 (b - j)	0.288 (a - h)	0.272 (d - j)	0.283 (b - i)	0.275 (c - j)	0.254 (e - k)	0.278 (b - j)	0.281 (b - i)
Manure + Biochar	0.249 (g - l)	0.279 (b - j)	0.327 (a)	0.318 (ab)	0.294 (a - e)	0.314 (a - c)	0.313 (a - d)	0.276 (c - j)	0.286 (a - h)	0.295 (a - e)
Vermicompost+ Manure + Biochar	0.249 (g - l)	0.266 (e - k)	0.286 (a - h)	0.283 (b - i)	0.273 (e - k)	0.286 (a - h)	0.292 (a - f)	0.267 (e - k)	0.29 (a - g)	0.287 (a - h)
	Control	BP			BL			BC		
	0 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha
Vitamin C (mg/100g)										
Biochar	143.6 (n)	151.2 (mn)	156.3 (f - m)	155.1 (h - m)	153.1 (k - m)	155 (h - m)	156.1 (f - m)	153.6 (j - m)	154.5 (i - m)	155.9 (f - m)
Vermicompost + Biochar	152.6 (lm)	156.2 (f - m)	162.7 (b - l)	163.9 (b - j)	159.1 (d - m)	165.9 (a - g)	163.8 (b - k)	157.2 (e - m)	159.2 (d - m)	162.4 (c - l)
Manure + Biochar	154.7 (h - m)	161.6 (c - m)	170.4 (a - c)	168.3 (a - d)	166.4 (a - f)	173.4 (ab)	175.7 (a)	164.8 (b - i)	169.3 (a - d)	171.5 (a - c)
Vermicompost + Manure + Biochar	155.2 (g - m)	159.5 (d - m)	167.8 (a - e)	165.1 (a - i)	163.3 (b - m)	167.1 (a - e)	168.4 (a - d)	161.5 (c - m)	165.3 (a - g)	167.9 (a - e)

Means followed by the same letter are not significantly different at $p < 0.05$ according to Tukey's test.

Effect of chars on fruit nutrients



Tomato

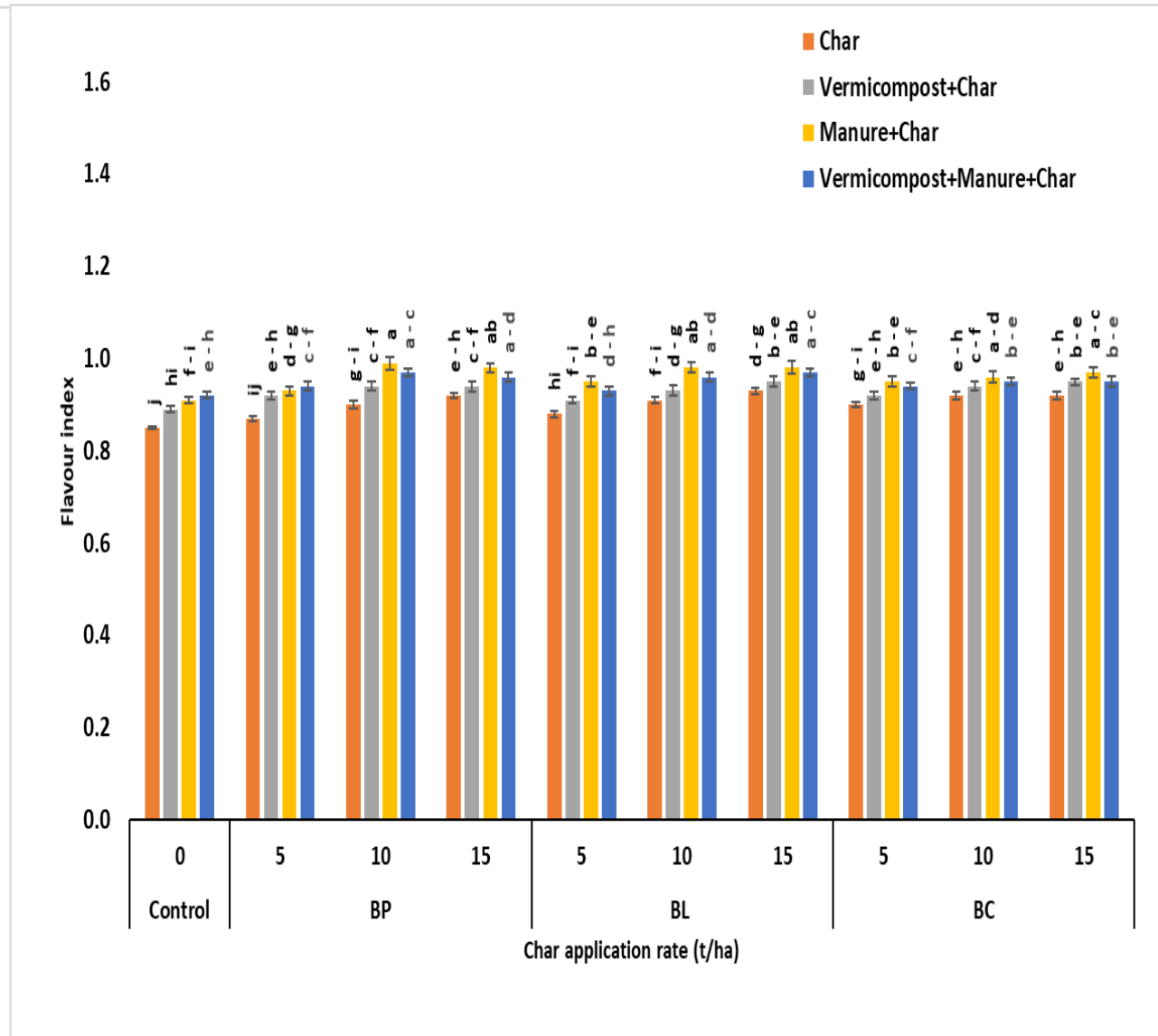
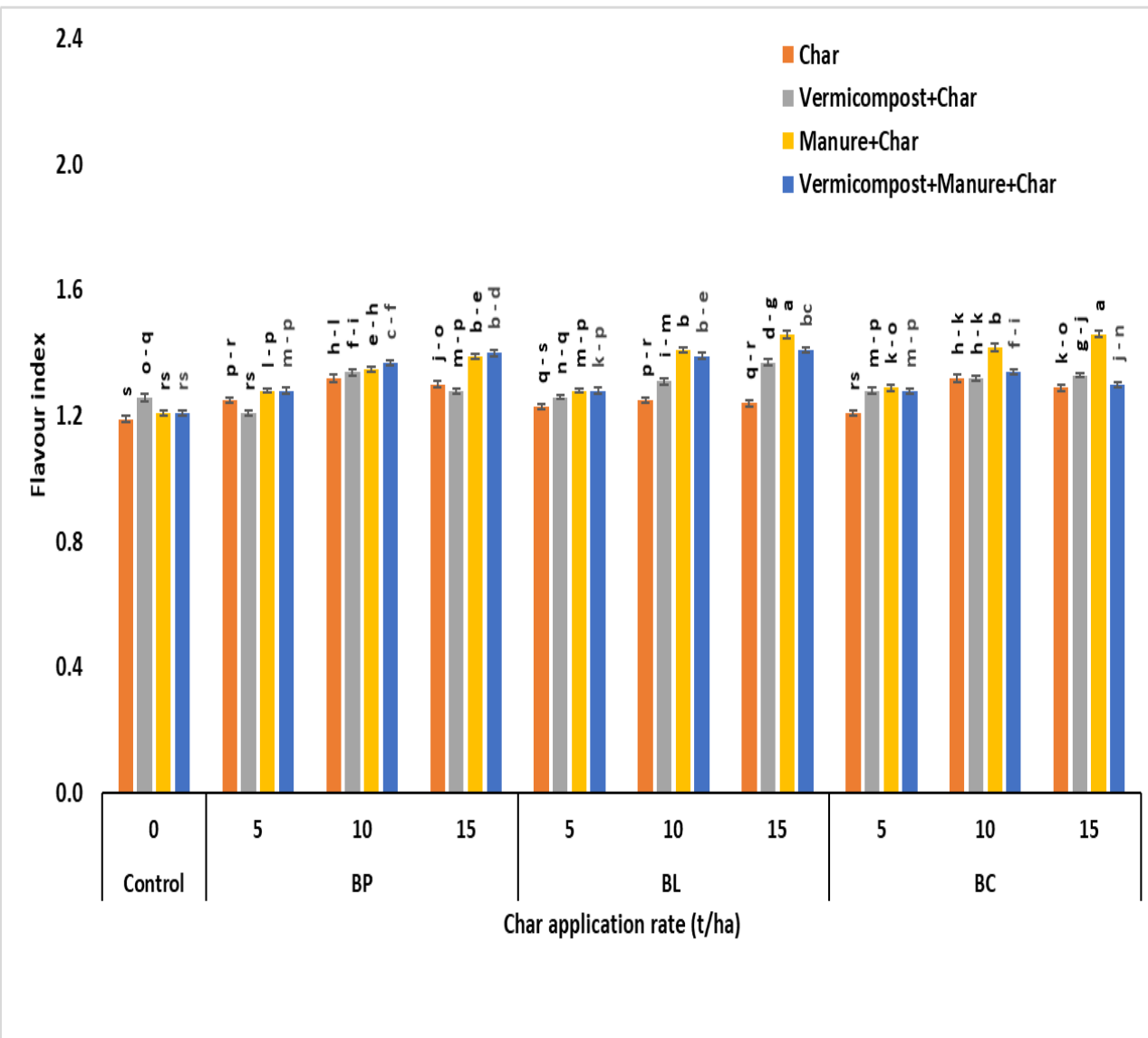
Total soluble solids (TSS) (% Brix)	Control	BP			BL			BC		
	0 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha
Char	3.4 (l)	3.8 (jk)	4 (g - j)	4.2 (e - i)	3.9 (h - k)	4.1 (d - h)	4.3 (b - e)	4 (e - i)	4.2 (c - f)	4.2 (b - e)
Vermicompost + Char	3.9 (i - k)	4.2 (e - i)	4.4 (c - f)	4.4 (c - f)	4.1 (c - g)	4.3 (a - c)	4.5 (ab)	4.2 (b - e)	4.4 (a - d)	4.5 (a - c)
Manure + Char	4.1 (j - l)	4.3 (d - h)	4.9 (a)	4.8 (ab)	4.5 (b - f)	4.7 (a - d)	4.8 (a - c)	4.5 (c - f)	4.6 (b - e)	4.7 (b - e)
Vermicompost+ Manure + Char	4.2 (e - i)	4.4 (c - f)	4.7 (a - c)	4.6 (a - d)	4.3 (f - j)	4.6 (d - h)	4.7 (g - j)	4.4 (e - i)	4.5 (e - i)	4.5 (kl)

Titratable acidity (TA) (% citric acid)	Control	BP			BL			BC		
	0 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha
Char	0.329 (o)	0.408 (mn)	0.428 (g - n)	0.426 (h - n)	0.418 (j - n)	0.435 (g - n)	0.433 (g - n)	0.409 (l - n)	0.439 (f - n)	0.446 (e - n)
Vermicompost + Char	0.402 (n)	0.446 (e - n)	0.471 (b - n)	0.482 (a - k)	0.451 (d - n)	0.488 (a - k)	0.494 (a - i)	0.445 (e - n)	0.476 (b - m)	0.486 (a - k)
Manure + Char	0.416 (k - n)	0.492 (a - i)	0.54 (ab)	0.531 (a - c)	0.517 (a - e)	0.553 (a)	0.542 (ab)	0.485 (a - k)	0.513 (a - e)	0.522 (a - d)
Vermicompost+ Manure + Char	0.422 (l - n)	0.481 (a - l)	0.498 (a - h)	0.487 (a - k)	0.476 (b - n)	0.499 (a - g)	0.508 (a - f)	0.466 (c - n)	0.489 (a - j)	0.493 (a - i)

Vitamin C (mg/100g)	Control	BP			BL			BC		
	0 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha
Char	15.01 (l)	17.03 (l - k)	17.67 (f - k)	18.14 (b - i)	16.49 (k)	17.21 (h - k)	17.67 (f - k)	16.84 (jk)	17.79 (e - j)	17.83 (e - j)
Vermicompost + Char	16.83 (jk)	17.87 (d - j)	18.06 (c - i)	18.23 (b - i)	17.76 (e - j)	18.37 (b - h)	18.29 (b - h)	18.13 (b - i)	18.33 (b - h)	18.52 (a - g)
Manure + Char	17.23 (h - k)	19.09 (a - d)	19.69 (a)	19.31 (ab)	18.7 (a - f)	18.97 (a - e)	18.9 (a - f)	18.44 (b - h)	18.89 (a - f)	19.13 (a - c)
Vermicompost+ Manure + Char	17.39 (g - k)	18.41 (b - h)	18.88 (a - f)	18.98 (a - e)	18.07 (b - j)	18.52 (a - f)	18.41 (b - h)	17.99 (c - j)	18.59 (a - f)	18.69 (a - f)

Means followed by the same letter are not significantly different at $p < 0.05$ according to Tukey's test.

Effect of chars on fruit flavour index



Means followed by the same letter are not significantly different at $p < 0.05$ according to Tukey's test.

Effect of Biochars on fruit physical characteristics



Bell pepper

Length (cm)

	Control	BP			BL			BC		
	0 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha
Biochar	7.8 (f)	9.1 (d - f)	9.6 (a - e)	9.8 (a - e)	9.2 (c - f)	9.5 (a - e)	9.6 (a - e)	8.8 (ef)	9.3 (b - f)	9.8 (a - e)
Vermicompost + Biochar	9.2 (c - f)	9.7 (a - e)	10 (a - e)	10.2 (a - e)	9.7 (a - e)	10.1 (a - e)	10.2 (a - e)	9.5 (a - e)	9.8 (a - e)	10.1 (a - e)
Manure + Biochar	9.6 (a - e)	10.1 (a - e)	10.9 (a)	10.6 (a - d)	10.2 (a - e)	10.7 (a - c)	10.8 (ab)	10 (a - e)	10.5 (a - d)	10.4 (a - d)
Vermicompost+ Manure + Biochar	9.7 (a - e)	10 (a - e)	10.7 (a - c)	10.8 (ab)	10.2 (a - e)	10.4 (a - d)	10.7 (a - c)	10.2 (a - e)	10.5 (a - d)	10.6 (a - d)

Width (cm)

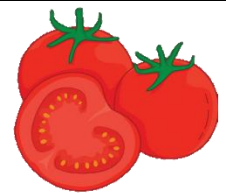
	Control	BP			BL			BC		
	0 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha
Biochar	4.6 (f)	5.7 (d - f)	5.9 (bc)	6 (d - f)	5.6 (d - f)	6 (d - f)	6 (d - f)	5.4 (d - f)	5.7 (d - f)	5.9 (d - f)
Vermicompost + Biochar	5.2 (ef)	6.1 (d - f)	6.3 (ab)	6.4 (de)	6 (d - f)	6.3 (de)	6.5 (de)	5.8 (d - f)	6.2 (d - f)	6.3 (de)
Manure + Biochar	5.6 (d - f)	6.3 (de)	6.7 (ab)	6.8 (de)	6.3 (de)	6.9 (cd)	6.7 (de)	6.1 (d - f)	6.6 (de)	6.7 (de)
Vermicompost+ Manure + Biochar	5.8 (d - f)	6.4 (de)	6.6 (a)	6.8 (de)	6.2 (d - f)	6.6 (de)	6.8 (de)	6.2 (d - f)	6.5 (de)	6.7 (de)

wall thickness (mm)

	Control	BP			BL			BC		
	0 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha
Biochar	3.5 (j)	4.8 (e - i)	4.8 (e - i)	4.9 (d - i)	4.6 (g - i)	4.7 (f - i)	4.9 (d - i)	4.4 (h - i)	4.7 (f - i)	4.7 (f - i)
Vermicompost + Biochar	4.3 (ij)	5.1 (b - i)	5.3 (a - g)	5.4 (a - g)	5 (c - i)	5.3 (a - g)	5.5 (a - f)	4.9 (d - i)	5.1 (b - i)	5.2 (a - h)
Manure + Biochar	4.4 (h - i)	5.7 (a - d)	5.8 (a - c)	5.8 (a - c)	5.5 (a - f)	5.9 (ab)	6 (a)	5.4 (a - g)	5.6 (a - e)	5.7 (a - d)
Vermicompost+ Manure + Biochar	4.4 (h - i)	5.5 (a - f)	5.7 (a - d)	5.9 (ab)	5.5 (a - g)	5.7 (a - d)	5.9 (ab)	5.4 (a - g)	5.5 (a - f)	5.7 (a - d)

Means followed by the same letter are not significantly different at $p < 0.05$ according to Tukey's test.

Effect of chars on fruit physical characteristics



Tomato

Polar diameter

	Control	BP			BL			BC		
	0 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha
Char	4.9 (e)	5.4 (de)	5.6 (b - e)	5.7 (a - e)	5.5 (c - e)	5.7 (a - e)	5.7 (a - e)	5.4 (de)	5.5 (c - e)	5.6 (b - e)
Vermicompost + Char	5.5 (c - e)	6 (a - d)	6.2 (a - d)	6.2 (a - d)	5.9 (a - d)	6.2 (a - d)	6.1 (a - d)	5.8 (a - e)	6 (a - d)	6.1 (a - d)
Manure + Char	5.6 (b - e)	6.3 (a - d)	6.5 (ab)	6.4 (a - c)	6.3 (a - d)	6.6 (ab)	6.6 (a)	6.1 (a - d)	6.3 (a - d)	6.4 (a - c)
Vermicompost+ Manure + Char	5.8 (a - e)	6.1 (a - d)	6.2 (a - d)	6.4 (a - c)	6.2 (a - d)	6.4 (a - c)	6.5 (ab)	6.1 (a - d)	6.2 (a - d)	6.3 (a - d)

Equitorial diameter

	Control	BP			BL			BC		
	0 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha
Char	5.2 (g)	5.8 (e - g)	6 (c - g)	6.1 (b - g)	5.7 (fg)	6 (c - g)	6 (c - g)	5.8 (e - g)	5.9 (d - g)	6.1 (b - g)
Vermicompost + Char	5.8 (e - g)	6.3 (a - f)	6.5 (a - f)	6.6 (a - f)	6.4 (a - f)	6.6 (a - f)	6.5 (a - f)	6.2 (a - f)	6.4 (a - f)	6.6 (a - f)
Manure + Char	6 (c - g)	6.7 (a - e)	7 (ab)	6.9 (a - c)	6.8 (a - d)	7.1 (a)	7 (ab)	6.6 (a - f)	6.8 (a - d)	6.9 (a - c)
Vermicompost+ Manure + Char	6.2 (a - f)	6.6 (a - f)	6.7 (a - e)	6.8 (a - d)	6.8 (a - f)	6.9 (a - c)	7 (ab)	6.6 (a - f)	6.7 (a - e)	6.8 (a - d)

Means followed by the same letter are not significantly different at $p < 0.05$ according to Tukey's test.



Bell pepper

Effect of Biochars on fruit nutrients

Sodium (mg/100g)

Means followed by the same letter are not significantly different at $p < 0.05$ according to Tukey's test.

	Control	BP			BL			BC		
	0 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha
Biochar	73.55(g)	89.86(d - f)	93.8(a - f)	95.77(a - f)	90.85(c - f)	93.81(a - f)	94.8(a - f)	86.9(e - f)	91.83(b - f)	96.77(a - e)
Vermicompost + Biochar	81.73(fg)	95.78(a - f)	98.75(a - e)	100.7(a - e)	94.25(a - f)	98.14(a - e)	99.61(a - e)	93.81(a - f)	96.77(a - e)	99.73(a - e)
Manure + Biochar	91.94(b - f)	99.73(a - e)	104.6(a - d)	107.7(a)	100.7(a - e)	105.7(a - c)	106.6(ab)	98.75(a - e)	103.7(a - d)	102.7(a - d)
Vermicompost+ Manure + Biochar	94.05(a - f)	98.7(a - e)	103.7(a - d)	105.6(a - c)	100.7(a - f)	102.7(a - d)	105.7(a - c)	100.7(a - e)	103.7(a - d)	104.7(a - d)

Potassium (mg/100g)

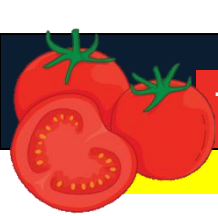
	Control	BP			BL			BC		
	0 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha
Biochar	2143(q)	2596(o - q)	2817(n - p)	3192(j - n)	2676(n - q)	2987(m - o)	3153(j - o)	2369(pq)	2953(m - o)	3129(j - o)
Vermicompost + Biochar	2967(m - o)	3038(k - o)	3607(h - k)	3827(f - i)	3169(j - o)	3576(h - l)	3963(e - i)	3010(l - o)	3465(i - m)	3976(d - i)
Manure + Biochar	3701(g - j)	3909(e - i)	4627(ab)	4771(a)	4109(b - h)	4653(ab)	4541(a - d)	3821(f - i)	4463(a - e)	4588(a - c)
Vermicompost+ Manure + Biochar	3821(f - i)	3967(d - i)	4289(a - f)	4683(ab)	4082(c - i)	4364(a - f)	4594(a - c)	4045(c - h)	4262(a - g)	4706(a)

Calcium (mg/100g)

	Control	BP			BL			BC		
	0 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha
Biochar	23.92(m)	30.86(k - m)	32.14(kl)	33.54(kl)	29.95(lm)	31.43(k - m)	32.04(kl)	30.58(lm)	32.19(kl)	32.58(kl)
Vermicompost + Biochar	38.4(k)	48.07(ij)	49.82(g - j)	51.57(g - j)	49.61(h - j)	51.45(g - j)	52.64(f - j)	47.2(j)	48.07(ij)	49.82(g - j)
Manure + Biochar	56.01(c - h)	61.56(a - d)	63.83(ab)	64.78(a)	60.67(a - e)	62.23(a - c)	64.58(a)	59.28(a - f)	61.29(a - e)	62.56(a - c)
Vermicompost+ Manure + Biochar	47.71(ij)	53.88(e - j)	56.23(b - h)	57.28(a - g)	52.94(f - j)	55.26(c - i)	56.21(b - h)	51.5(g - j)	54.36(d - j)	54.48(d - j)

Magnesium (mg/100g)

	Control	BP			BL			BC		
	0 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha
Biochar	80.61(h)	88.84(f - h)	90.48(c - h)	92.13(a - h)	86.84(gh)	90.13(d - h)	91.77(a - h)	89.48(e - h)	91.46(b - h)	92.72(a - h)
Vermicompost + Biochar	95.42(a - h)	100.4(a - g)	102.6(a - f)	104.3(a - e)	103.6(a - f)	104.9(a - d)	105.3(a - c)	103.6(a - f)	105.6(ab)	106.6(a)
Manure + Biochar	90.48(c - h)	95.42(a - h)	98.71(a - g)	100.4(a - g)	96.06(a - g)	99.66(a - g)	101.4(a - g)	97.71(a - g)	100.7(a - g)	102(a - f)
Vermicompost+ Manure + Biochar	92.13(a - h)	100.1(a - g)	102(a - f)	103.6(a - f)	100.4(a - g)	102.8(a - f)	104.9(a - d)	101.7(a - g)	103.9(a - f)	104.6(a - d)



Tomato

Effect of chars on fruit nutrients

Sodium (mg/100g)		Means followed by the same letter are not significantly different at p<0.05 according to Tukey's test.											
	Control	BP			BL			BC					
	0 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha
Char	198(i)	218.2(hi)	225.1(f - i)	228.9(d - i)	220.6(g - i)	227.7(e - i)	230.1(c - i)	218(hi)	224(f - i)	226.9(e - i)			
Vermicompost + Char	227.6(e - i)	239.9(a - h)	247.3(a - h)	252.3(a - h)	241.5(a - h)	249.8(a - h)	252.3(a - h)	235(b - i)	242.4(a - h)	249.8(a - h)			
Manure + Char	243.7(a - h)	256.4(a - g)	264(a - e)	274.7(a)	261.9(a - f)	270.6(ab)	273.1(a)	253.8(a - h)	266.5(a - d)	264(a - e)			
Vermicompost+ Manure + Char	246.2(a - h)	253.8(a - h)	270.6(ab)	273.1(a)	258.9(a - h)	264(a - e)	269.6(ab)	256.7(a - g)	264.3(a - e)	267(a - c)			
Potassium (mg/100g)													
	Control	BP			BL			BC					
	0 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha
Char	3361(k)	3834(jk)	4035(h - k)	4169(g - j)	3983(i - k)	4013(i - k)	4039(h - k)	3881(jk)	4109(g - k)	4224(g - j)			
Vermicompost + Char	4055(h - k)	4786(e - h)	4865(d - g)	5034(c - f)	4524(f - j)	4713(f - i)	4869(d - g)	4534(f - j)	4657(f - i)	4750(e - i)			
Manure + Char	4436(f - j)	5804(a - c)	6056(ab)	6110(a)	5729(a - c)	5952(ab)	6030(ab)	5568(a - d)	5991(ab)	5866(ab)			
Vermicompost+ Manure + Char	4579(f - i)	5574(a - d)	5687(a - c)	5724(a - c)	5351(b - f)	5802(a - c)	5975(ab)	5487(a - e)	5737(a - c)	5832(ab)			
Calcium (mg/100g)													
	Control	BP			BL			BC					
	0 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha
Char	82.38(j)	88.77(ij)	90.01(h - j)	91.71(f - j)	86.26(ij)	88.14(ij)	90.89(g - j)	85.51(j)	87.88(ij)	89.32(h - j)			
Vermicompost + Char	101.1(e - i)	105.3(c - g)	107.5(a - e)	108.5(a - e)	104(d - g)	106.4(a - f)	107.1(a - e)	103.9(d - g)	105.6(b - g)	107.5(a - e)			
Manure + Char	115.4(a - e)	117.7(a - d)	119.4(a - c)	121.3(a)	116.5(a - d)	118.8(a - d)	120.5(ab)	116.2(a - d)	118.6(a - d)	119.4(a - c)			
Vermicompost+ Manure + Char	108.7(a - e)	112(a - e)	113.4(a - e)	114.2(a - e)	113.1(a - e)	114.6(a - e)	115.4(a - e)	111.1(a - e)	112.5(a - e)	113.3(a - e)			
Magnesium (mg/100g)													
	Control	BP			BL			BC					
	0 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha
Char	172.2(h)	183.6(gh)	190.4(d - h)	192.2(c - h)	185.1(f - h)	187(e - h)	190.4(d - h)	187(e - h)	191.6(c - h)	193.8(b - h)			
Vermicompost + Char	201.9(a - h)	214.4(a - g)	217.9(a - e)	225(ab)	213.9(a - g)	218.2(a - e)	222.4(a - c)	217.9(a - e)	225(ab)	228.5(a)			
Manure + Char	193.3(b - h)	203.9(a - h)	210.9(a - g)	214.4(a - g)	207.4(a - g)	211.9(a - g)	215.4(a - g)	210.9(a - g)	214.9(a - g)	217.9(a - e)			
Vermicompost+ Manure + Char	196.8(a - h)	211.3(a - g)	216(a - f)	218.7(a - e)	210.7(a - h)	215.9(a - f)	219.8(a - d)	212.2(a - g)	218.2(a - e)	220.5(a - d)			

Effect of chars on fruit nutrients

Means followed by the same letter are not significantly different at $p < 0.05$ according to Tukey's test.

Bell pepper

	Control	BP			BL			BC		
Nitrogen (%)	0 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha
Char	2.31(k)	2.45(k)	2.62(k)	2.64(k)	2.6(k)	2.67(k)	2.34(k)	2.34(k)	2.45(k)	2.56(k)
Vermicompost + Char	3.47(j)	4.29(e-g)	4.66(ef)	4.85(f-i)	3.92(e-h)	4.59(ef)	4.84(h-j)	3.83(f-i)	4.31(f-i)	4.35(ij)
Manure + Char	4.89(ef)	5.87(a)	6.49(ab)	6.36(a-c)	5.66(a-c)	6.34(a-c)	6.22(cd)	5.7(a-c)	6.13(a-c)	6.04(b-d)
Vermicompost+ Manure + Char	4.05g-j	4.51ef	4.93e-g	4.71e-i	4.32ef	4.92de	5.15f-j	4.37ef	4.88de	5.08f-i

	Control	BP			BL			BC		
Phosphorus (mg/100g)	0 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha
Control	207.1(k)	222.5(jk)	234.2(i - k)	241.6(g - k)	228.5(i - k)	235.2(h - k)	241.4(g - k)	232.4(i - k)	244.9(f - k)	252.1(d - j)
Compost (5 t ha ⁻¹)	226.2(i - k)	259.8(c - j)	276.3(a - h)	281.5(a - g)	255.8(d - j)	278.7(a - g)	283.1(a - g)	263.5(a - j)	283.2(a - g)	283.6(a - f)
Manure (5 t ha ⁻¹)	248.1(e - k)	286.6(a - f)	302.7(a)	300.6(a - c)	283.7(a - f)	301.2(a - c)	301.6(ab)	284.6(a - f)	304.6(a)	300.8(a - c)
Compost + Manure (1:1) (5 t ha ⁻¹)	260.6(b - j)	289.5(a - e)	299.7(a - c)	301.1(a - c)	279.4(a - i)	300.3(a - c)	297.8(a - c)	293.9(a - d)	297.8(a - c)	302(ab)

Tomato

	Control	BP			BL			BC		
Nitrogen (%)	0 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha
Char	3.27(i)	3.16(i)	3.81(hi)	3.58(hi)	3.24(i)	3.69(hi)	3.78(hi)	3.17(i)	3.41(i)	3.42(i)
Vermicompost + Char	4.33(gh)	5.05(d-g)	5.39(d-f)	5.68(d-f)	5.17(d-f)	5.27(d-f)	5.09(d-g)	4.93(e-g)	5.07(d-g)	5.14(d-g)
Manure + Char	5.87(d)	7.39(a-c)	7.67(ab)	7.86(a)	6.83(c)	7.46(a-c)	7.8(a)	6.91(bc)	7.25(a-c)	7.52(a-c)
Vermicompost+ Manure + Char	4.86fg	5.29d-f	5.53d-f	5.75d-e	5.2d-g	5.41d-f	5.47d-f	5.01e-g	5.43d-f	5.39d-f

	Control	BP			BL			BC		
Phosphorus (mg/100g)	0 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha
Control	332.2(g)	368.4(d - g)	376.2(b - g)	380.1(a - g)	355(fg)	370(d - g)	379.5(a - g)	371.1(d - g)	379.7(a - g)	385.4(a - g)
Compost (5 t ha ⁻¹)	355(fg)	379.9(a - g)	386.1(a - g)	390.1(a - g)	371(d - g)	383.8(a - g)	384.2(a - g)	382.5(a - g)	393.3(a - f)	395.4(a - f)
Manure (5 t ha ⁻¹)	366.7(e - g)	398.6(a - f)	435.4(ab)	433(a - c)	400.5(a - f)	425(a - e)	425.7(a - e)	405.4(a - f)	435.9(ab)	438.7(a)
Compost + Manure (1:1) (5 t ha ⁻¹)	373(c - g)	408.8(a - f)	421(a - e)	427.2(a - e)	396.8(a - g)	409.1(a - f)	418.3(a - e)	403.8(a - f)	428.2(a - d)	434.7(ab)



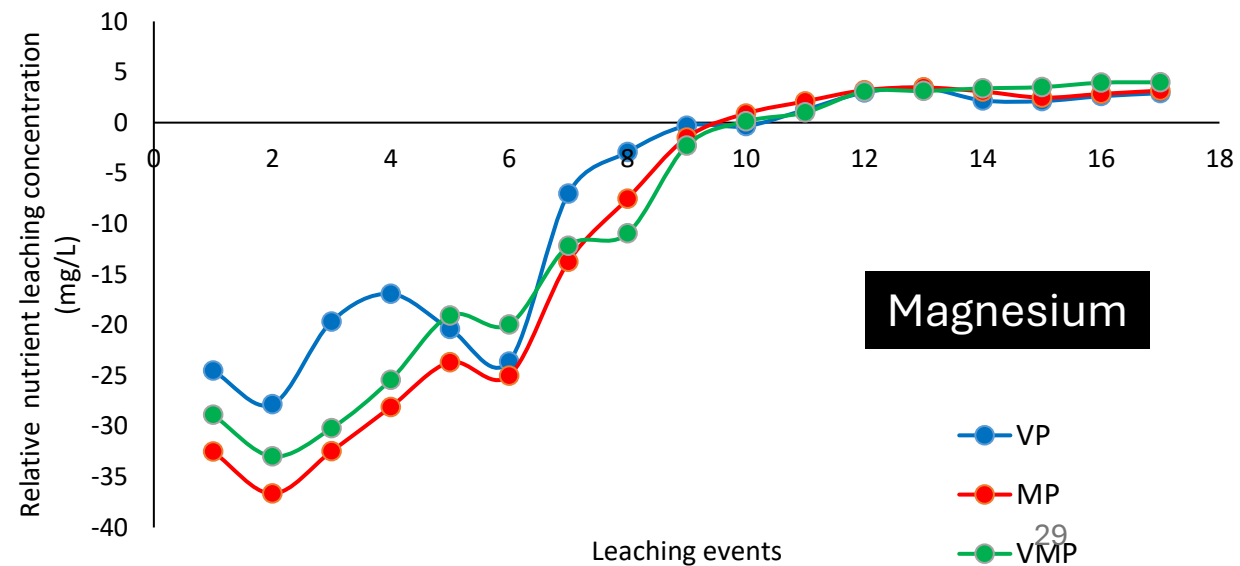
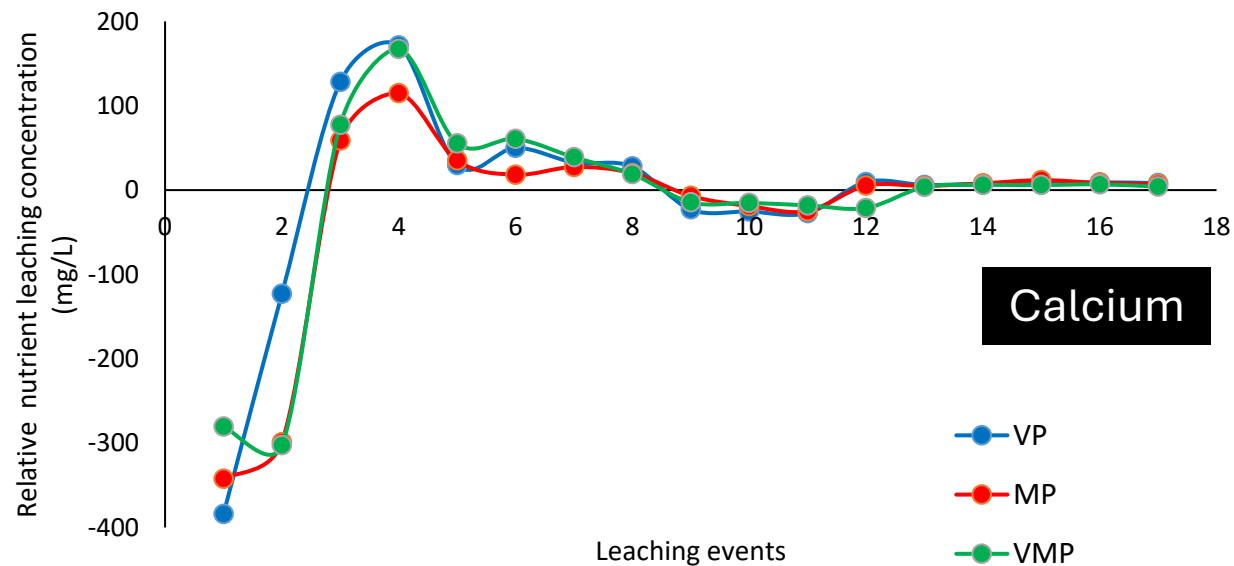
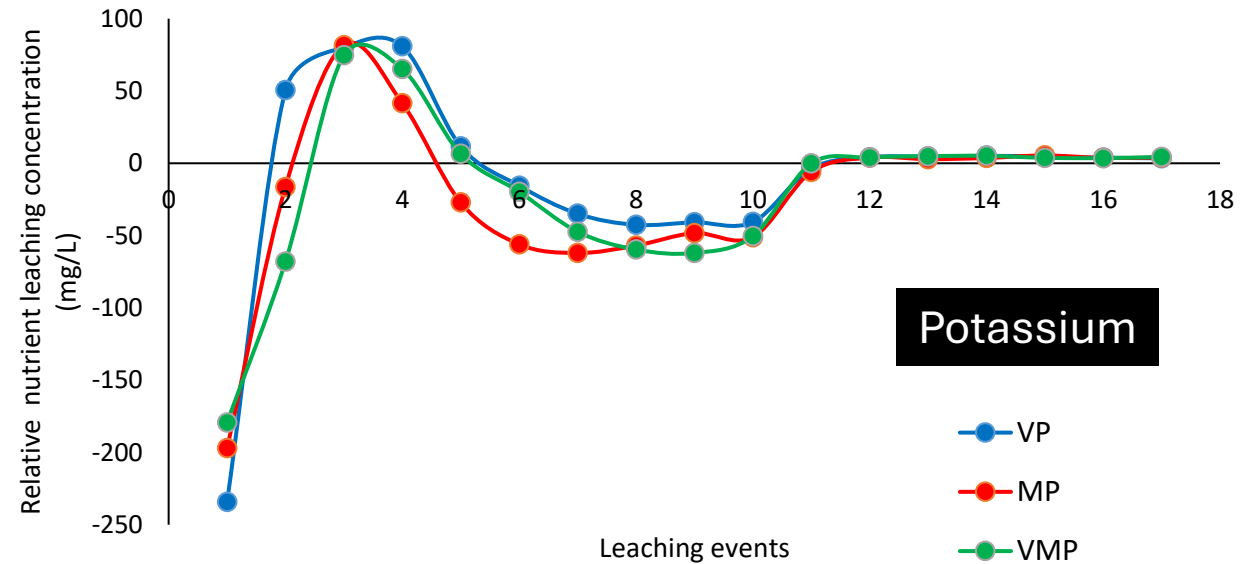
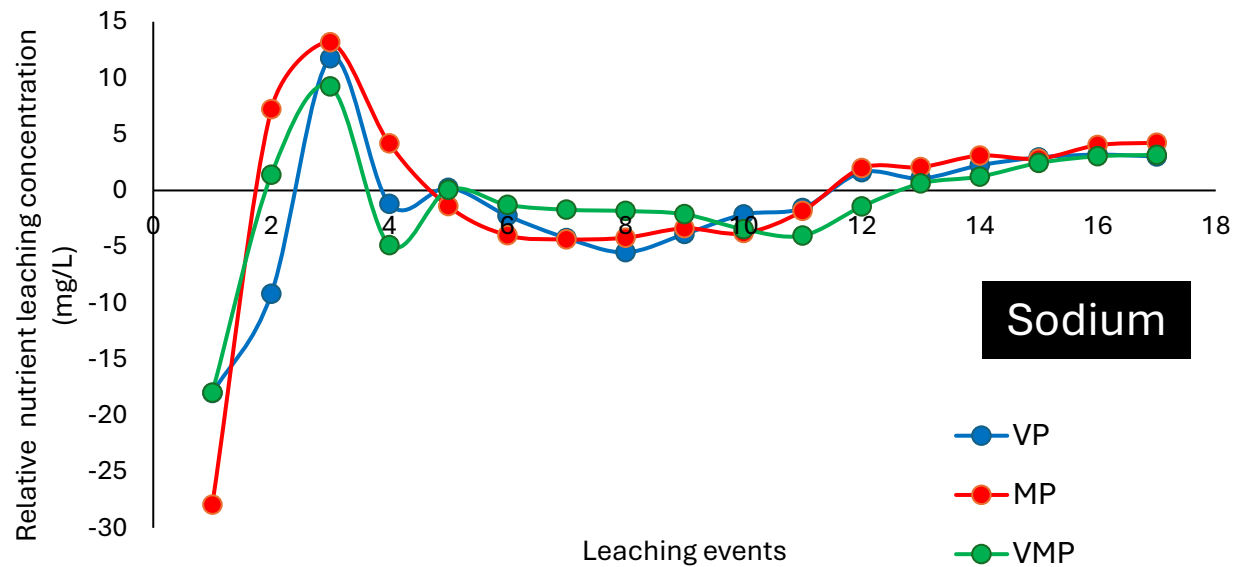
Bell pepper

Effect of chars on fruit micronutrients

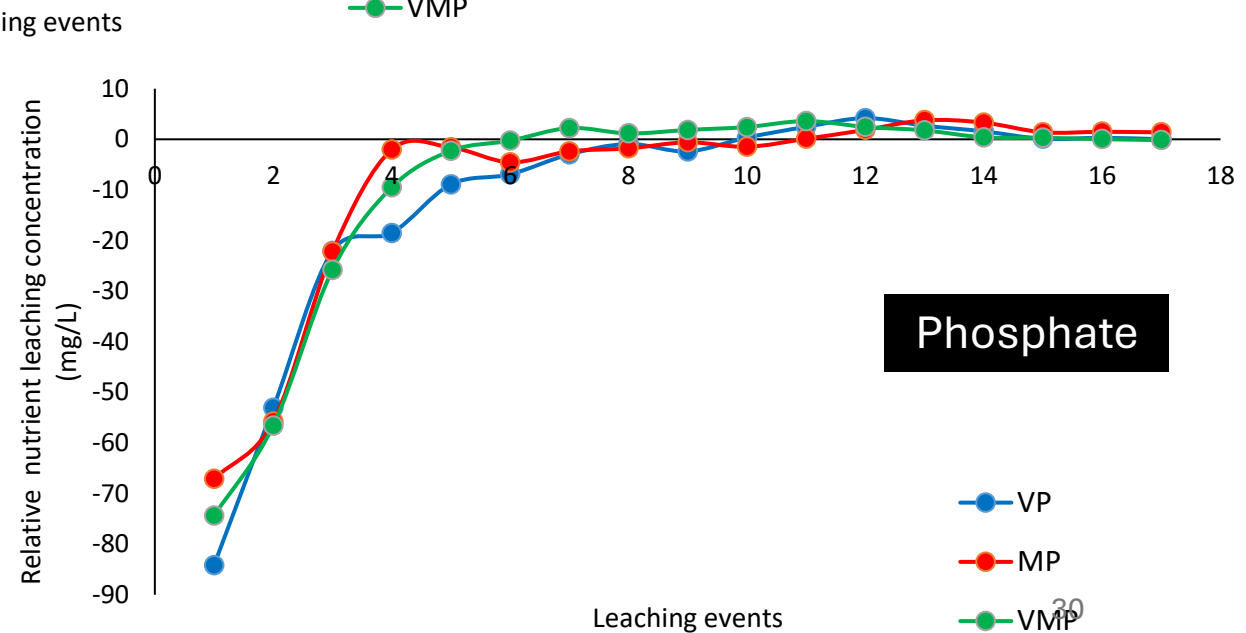
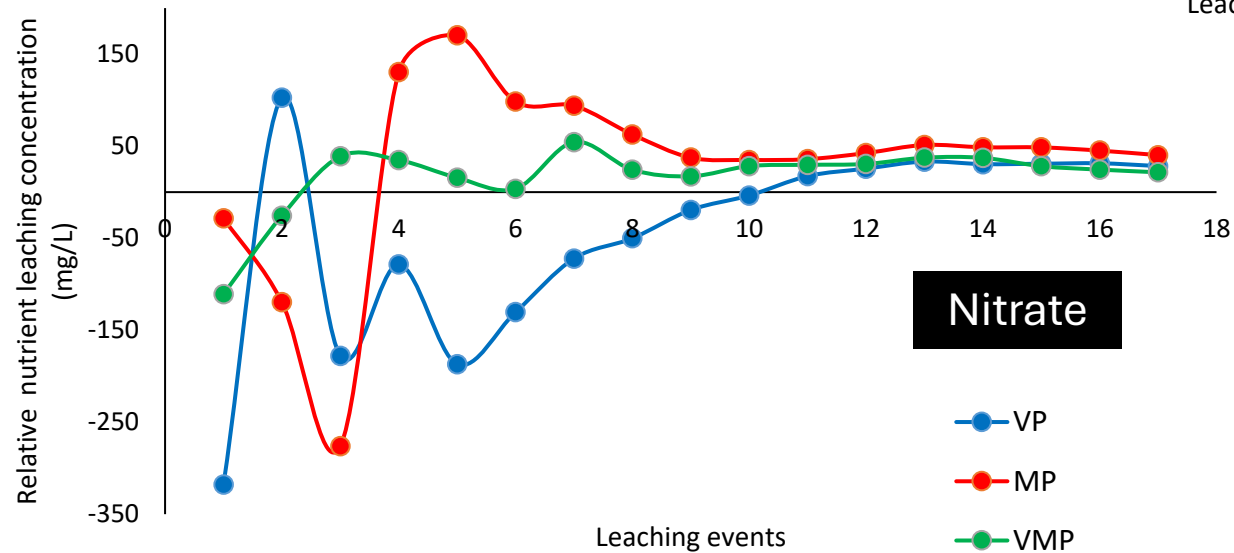
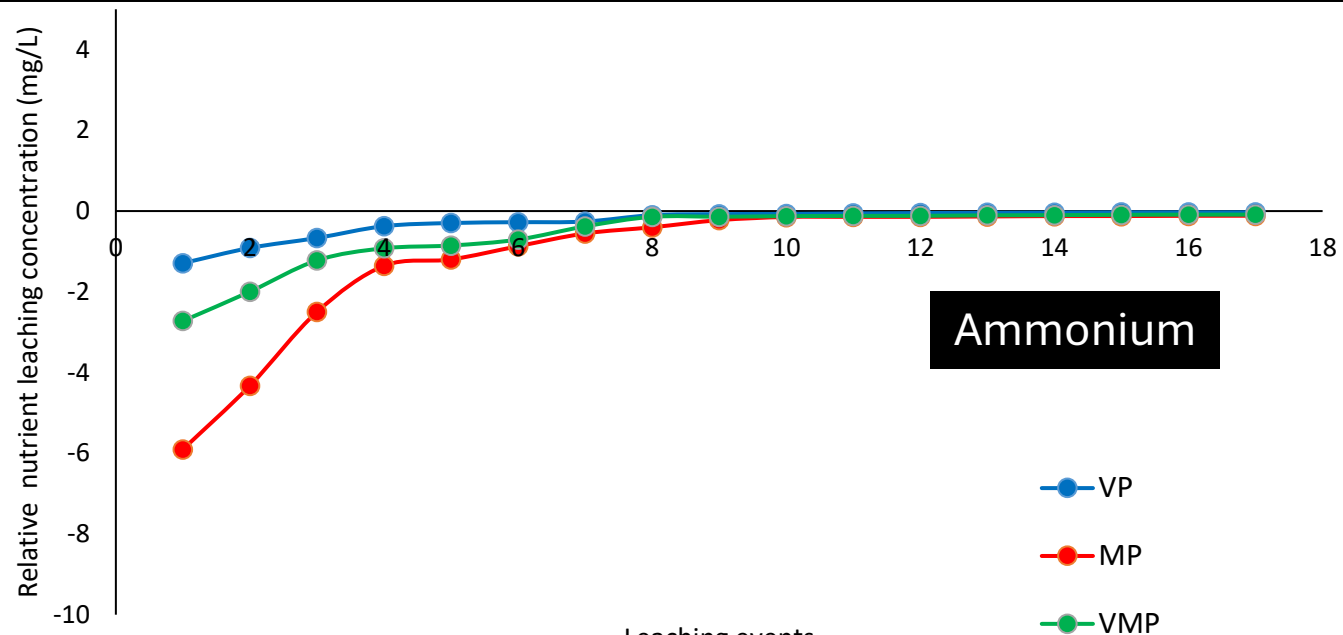
Iron (ug/100g)		Means followed by the same letter are not significantly different at p<0.05 according to Tukey's test.									
	Control	BP			BL			BC			
	0 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	
Char	2801(m)	3459(lm)	3619(j - l)	3576(k - l)	3232(lm)	3580(k - l)	3449(lm)	3111(lm)	3385(lm)	3512(k - m)	
Vermicompost + Char	5273(a - e)	5137(b - f)	5326(a - e)	5248(a - e)	5038(b - h)	5642(ab)	5673(ab)	5158(b - f)	5951(a)	5537(a - c)	
Manure + Char	4192(i - k)	4331(h - j)	4850(c - i)	4829(c - i)	4502(f - i)	4977(b - h)	4835(c - i)	4373(g - i)	4612(e - i)	4776(d - i)	
Vermicompost+ Manure + Char	4846(c - i)	5078(b - g)	5116(b - f)	5220(b - f)	4933(c - i)	5069(b - g)	5224(b - e)	4920(c - h)	5227(b - e)	5346(a - d)	
Copper (ug/100g)		BP			BL			BC			
	Control	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	
	0 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	
Char	208.5(o)	323(n)	375.3(k - n)	381.1(j - n)	334.1(n)	368.7(l - n)	372.5(k - n)	352.4(mn)	377.5(k - n)	384.9(i - n)	
Vermicompost + Char	555.5(cd)	666.2(a)	687.1(a)	696.7(a)	654.7(ab)	705(a)	712(a)	654.7(ab)	686.6(a)	694.1(a)	
Manure + Char	356.3(mn)	448.4(h - k)	458.6(g - j)	471.5(e - h)	428.4(h - m)	461.2(g - i)	472.7(e - h)	445.7(h - l)	468.1(f - h)	476.9(d - h)	
Vermicompost+ Manure + Char	417.8(h - m)	549(c - e)	569.9(c)	572.3(c)	552.9(c - g)	579.8(bc)	579.4(bc)	543.8(c - f)	562.6(c)	580.6(bc)	
Zinc (ug/100g)		BP			BL			BC			
	Control	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	
	0 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	
Char	484.8(i)	525.3(hi)	550.2(g - i)	583.2(g - i)	548.6(g - i)	573.1(g - i)	598.5(g - i)	538.8(g - i)	546.9(g - i)	586.9(g - i)	
Vermicompost + Char	588.3(g - i)	596.8(g - i)	626.4(gh)	643.8(gh)	607.2(g - i)	636.9(gh)	652.3(gh)	602.3(g - i)	647.7(gh)	660.4(g)	
Manure + Char	964.4(d - f)	1079(b - d)	1150(a - c)	1148(a - c)	1031(c - e)	1165(ab)	1176(ab)	1085(b - d)	1200(ab)	1218(a)	
Vermicompost+ Manure + Char	856.8(f)	882.2(f)	925.5(ef)	942.8(ef)	877(f)	913.9(ef)	929(ef)	884.4(f)	903.9(ef)	936.7(ef)	
Manganese (ug/100g)		BP			BL			BC			
	Control	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	
	0 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	
Char	546.3(n)	607.3(mn)	624.6(l - n)	648.2(j - n)	614.7(mn)	630(k - n)	653.2(i - n)	599.1(mn)	617.4(mn)	647.4(j - n)	
Vermicompost + Char	715(h - m)	760.5(f - j)	794(d - h)	825.6(c - h)	749.1(f - k)	779.6(e - h)	802.8(d - h)	740(g - l)	773.2(f - i)	789.3(d - h)	
Manure + Char	845(b - g)	910.2(a - d)	946.1(a - c)	972.6(a)	901.5(a - d)	939.2(a - c)	975.8(a)	896.2(a - e)	933.4(a - c)	966(ab)	
Vermicompost+ Manure + Char	776.9(e - h)	793.6(d - h)	839.9(c - g)	856.1(a - g)	807(d - i)	846(b - g)	869.2(a - f)	801.6(d - h)	831.5(c - h)	861.4(a - g)	

 Tomato Effect of chars on fruit micronutrients												
Iron (ug/100g)				Means followed by the same letter are not significantly different at p<0.05 according to Tukey's test.								
	Control	BP			BL			BC				
	0 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha		
Char	3460(j)	4611(i)	5031(hi)	5072(hi)	4924(i)	5006(hi)	5139(hi)	4716(i)	4842(i)	5031(hi)		
Vermicompost + Char	7031(a - f)	7471(a - d)	7790(ab)	7801(a)	7385(a - e)	7789(ab)	7908(a)	7570(a - c)	7785(ab)	7893(a)		
Manure + Char	5924(gh)	6591(c - g)	6696(c - g)	6677(c - g)	6354(fg)	6505(d - g)	6570(d - g)	6247(fg)	6462(e - g)	6570(d - g)		
Vermicompost+ Manure + Char	6447(e - g)	6524(d - g)	6677(c - g)	6803(b - g)	6677(c - g)	6715(c - g)	6801(b - g)	6570(d - g)	6677(c - g)	6785(c - g)		
Copper (ug/100g)												
	Control	BP			BL			BC				
	0 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha		
Char	380.4(s)	418.2(rs)	436.5(rs)	458.7(rs)	424.3(rs)	443.9(rs)	445.9(rs)	431.5(rs)	448.8(rs)	471.6(o - s)		
Vermicompost + Char	827.8(h - k)	1190(cd)	1218(b - d)	1254(a - c)	1031(ef)	1212(b - d)	1307(a - c)	1123(de)	1315(ab)	1354(a)		
Manure + Char	465.7(p - s)	522.9(n - r)	589.2(n - p)	615.5(mn)	531.2(n - r)	578.7(n - q)	595.3(no)	540.3(n - r)	594.3(no)	621.2(l - n)		
Vermicompost+ Manure + Char	538.1(n - r)	732.7(k - m)	870.9(g - j)	898.1(g - i)	775.7(j - l)	854(g - k)	880.7(g - j)	790.6(l - k)	946.4(f - h)	976(fg)		
Zinc (ug/100g)												
	Control	BP			BL			BC				
	0 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha		
Char	792.9(i)	842.2(i)	868.4(i)	908.9(i)	830.6(i)	854.7(i)	889.8(i)	842(i)	865.7(i)	898.7(i)		
Vermicompost + Char	1406(h)	1541(h)	1582(gh)	1595(gh)	1558(h)	1574(h)	1589(gh)	1562(h)	1587(gh)	1602(gh)		
Manure + Char	2150(c - e)	2339(a - d)	2433(ab)	2475(ab)	2211(b - e)	2368(a - c)	2403(a - c)	2393(a - c)	2463(ab)	2498(a)		
Vermicompost+ Manure + Char	1845(fg)	1978(ef)	1998(ef)	2094(def)	1970(ef)	1987(ef)	1991(ef)	1981(ef)	1993(ef)	2027(ef)		
Manganese (ug/100g)												
	Control	BP			BL			BC				
	0 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha	5 t/ha	10 t/ha	15 t/ha		
Char	268(m)	311.7(k - m)	355.6(f - l)	363(e - l)	340.7(h - l)	348.1(g - l)	363(e - l)	325.9(i - m)	348.1(g - l)	348.1(g - l)		
Vermicompost + Char	303.5(lm)	357.4(f - l)	392.6(b - h)	400.5(b - h)	366.4(d - k)	383.6(c - i)	403.4(b - g)	363(e - l)	379.8(c - j)	393.2(b - h)		
Manure + Char	449.5(b)	574.6(a)	599.6(a)	626.6(a)	577.4(a)	607(a)	614.4(a)	570(a)	591.8(a)	607.2(a)		
Vermicompost+ Manure + Char	319.8(j - m)	376.3(c - j)	412.2(b - f)	437(bc)	379.4(c - k)	407.2(b - g)	428(b - d)	369.1(d - k)	402.4(b - h)	422.2(b - e)		

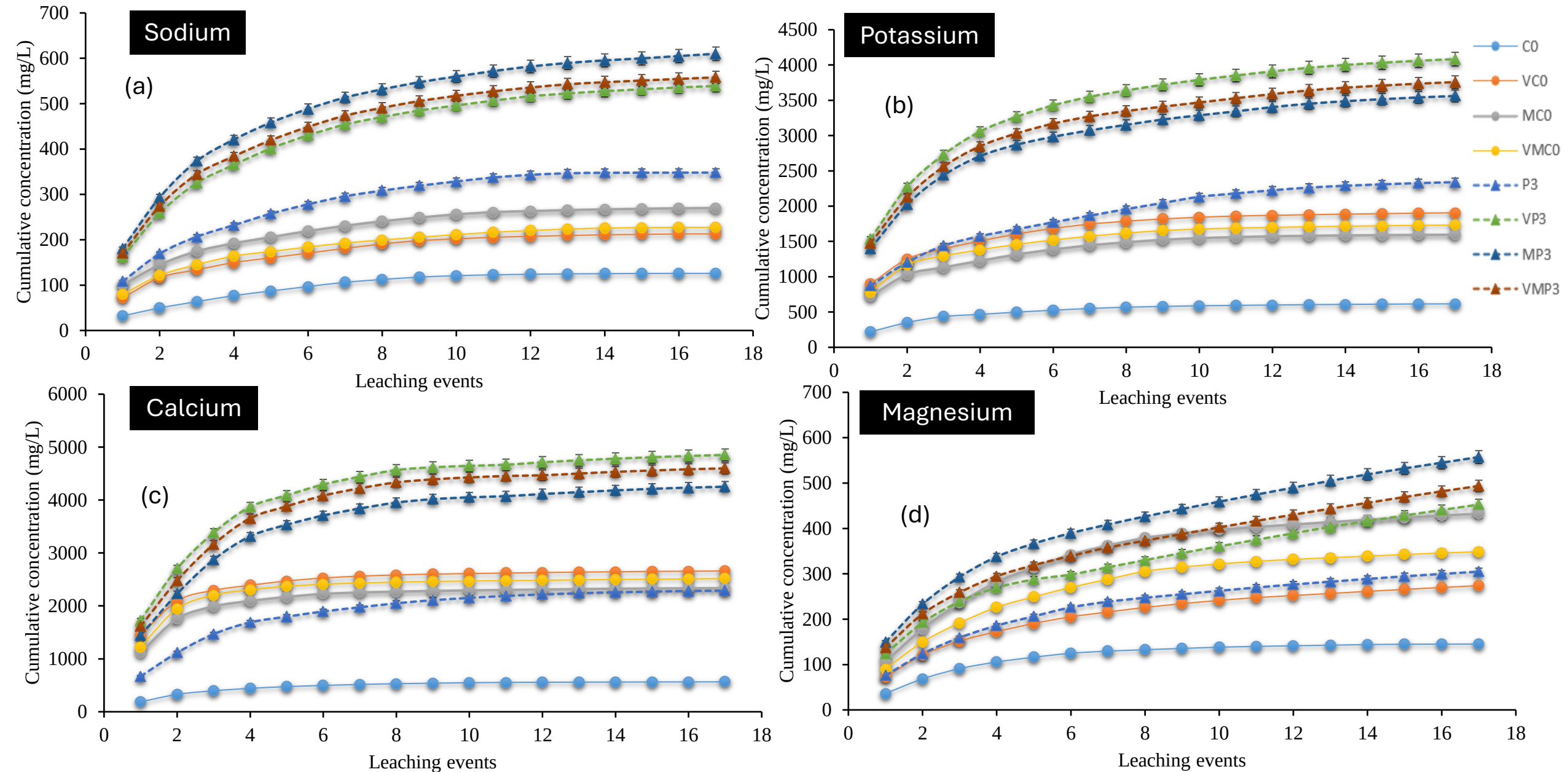
Leaching column test



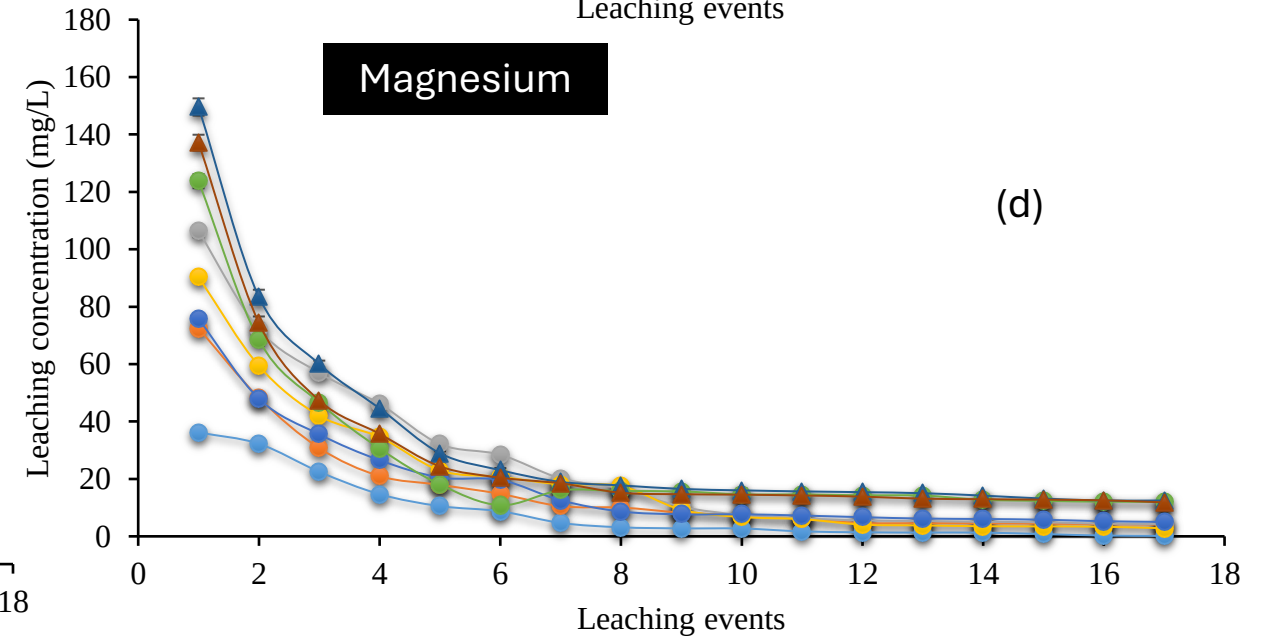
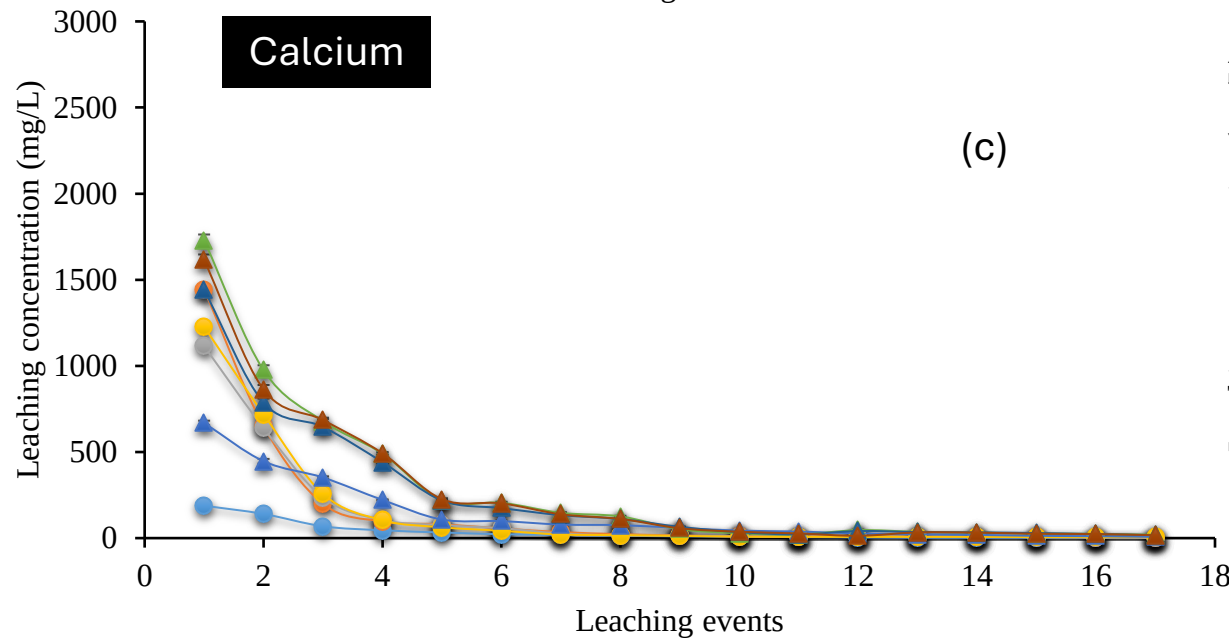
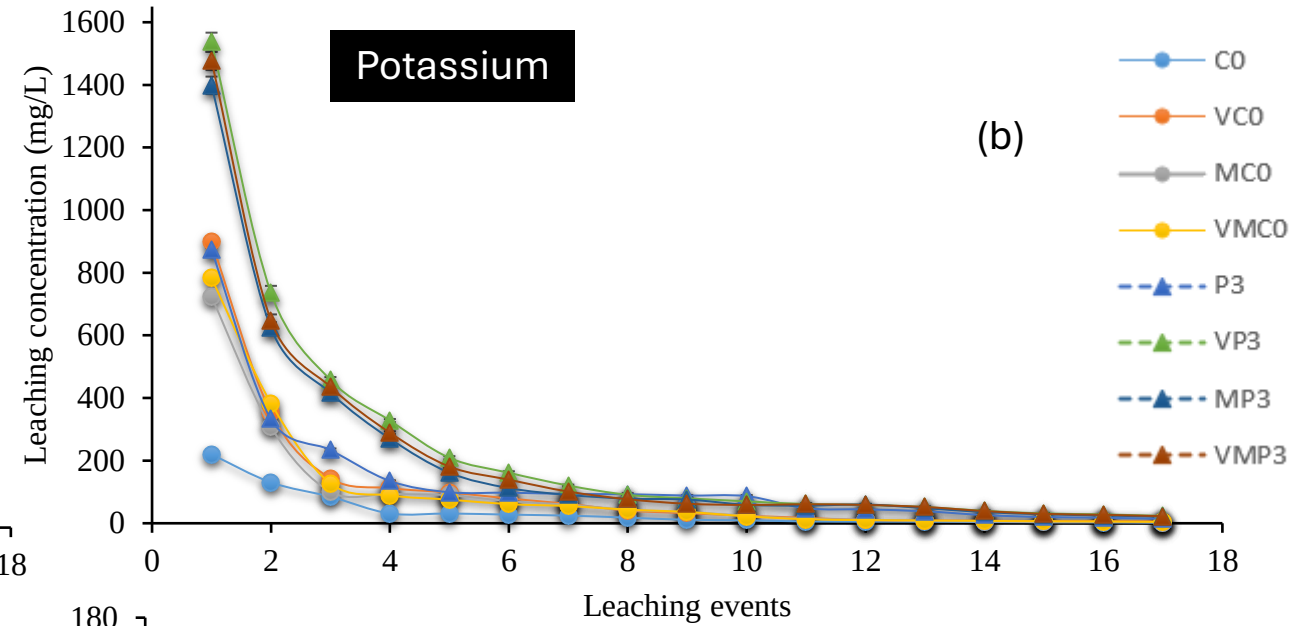
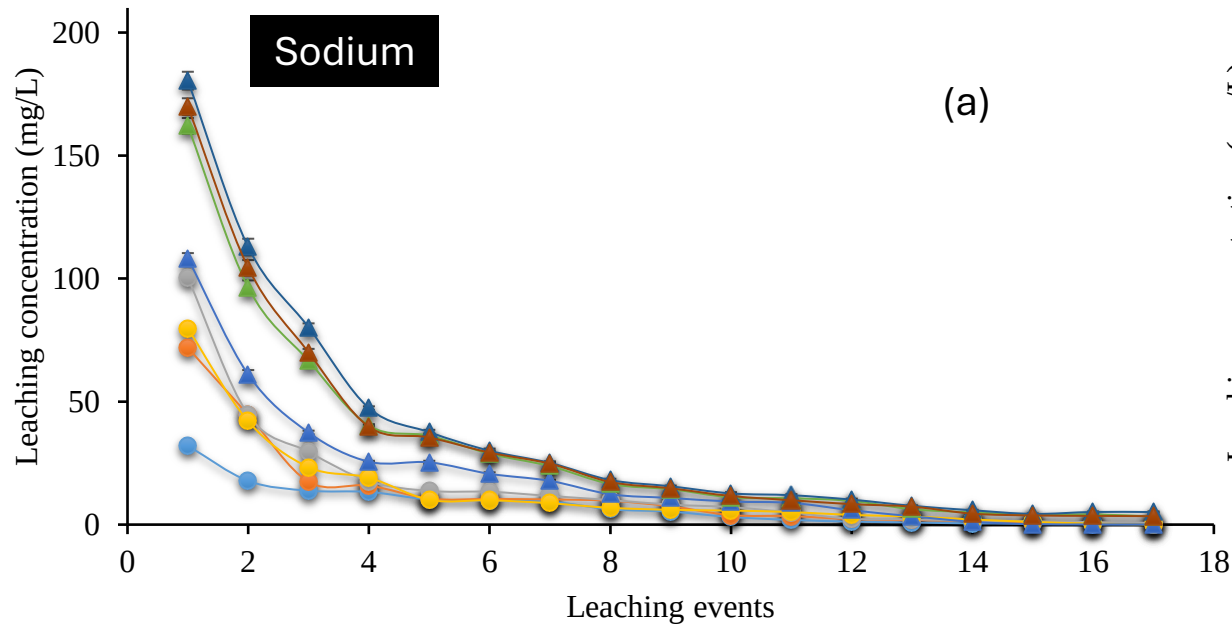
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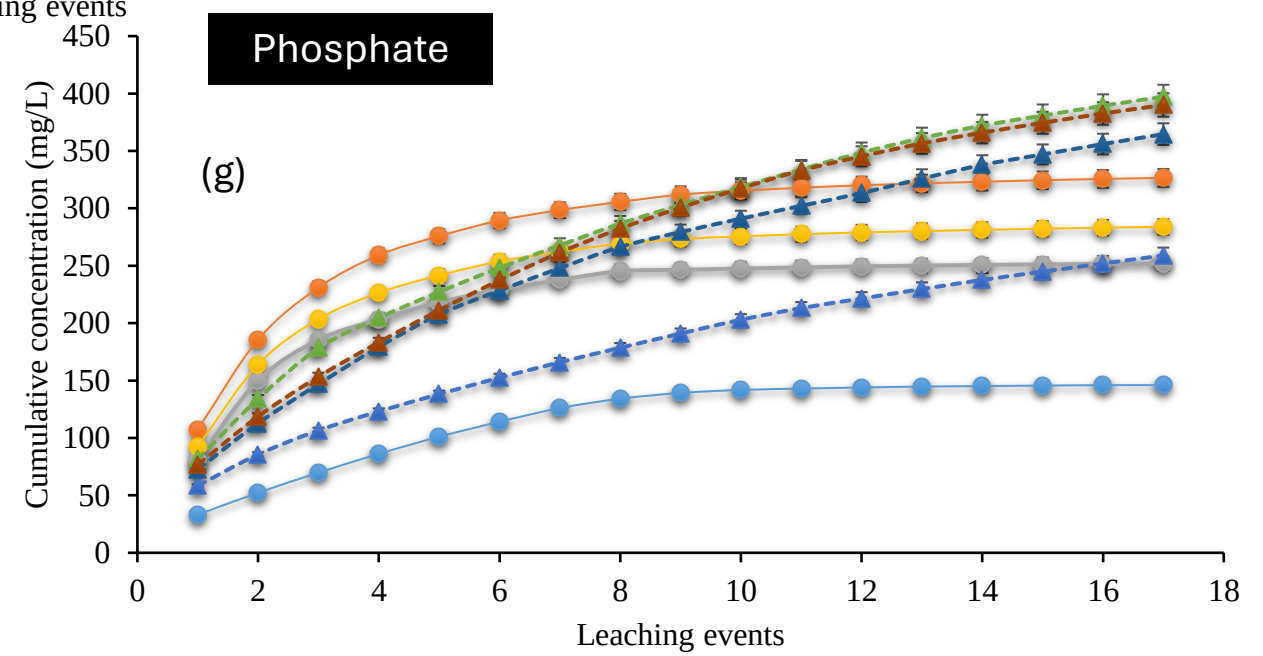
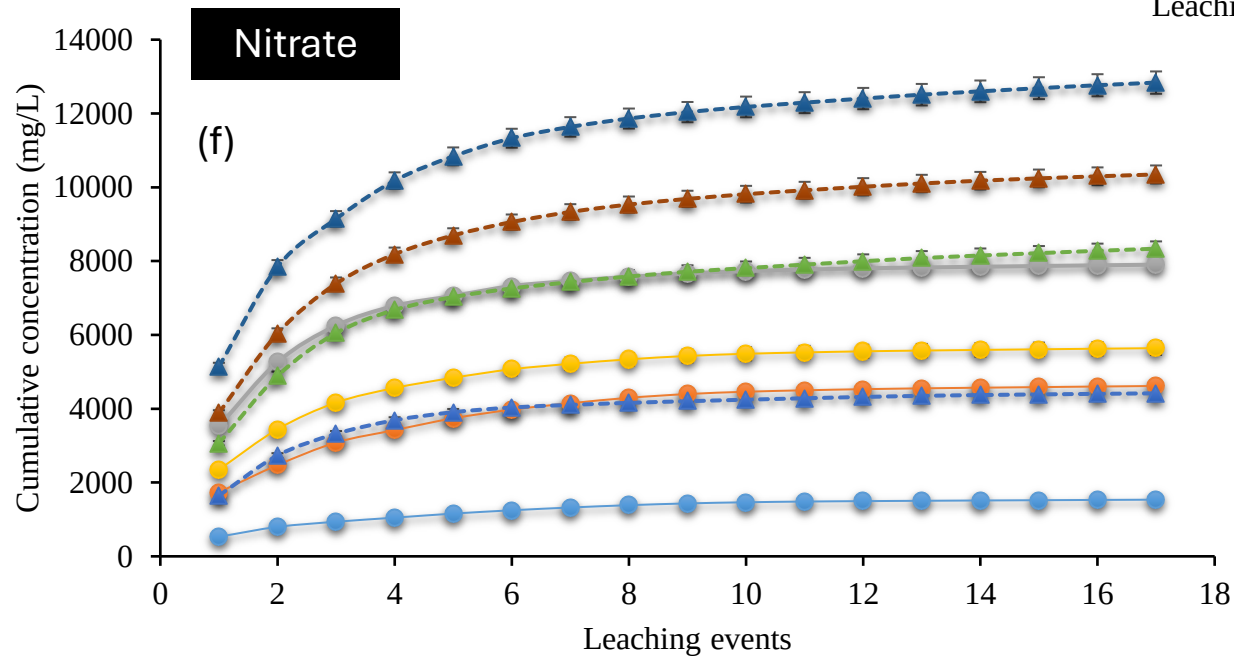
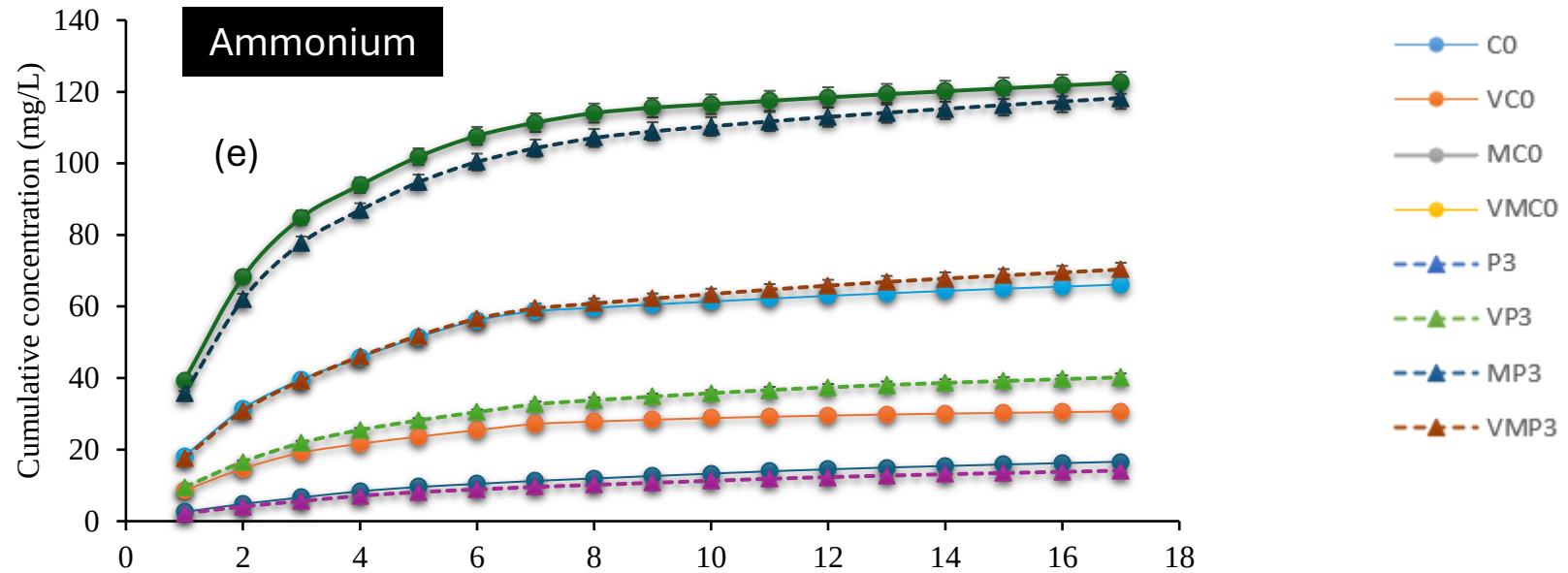
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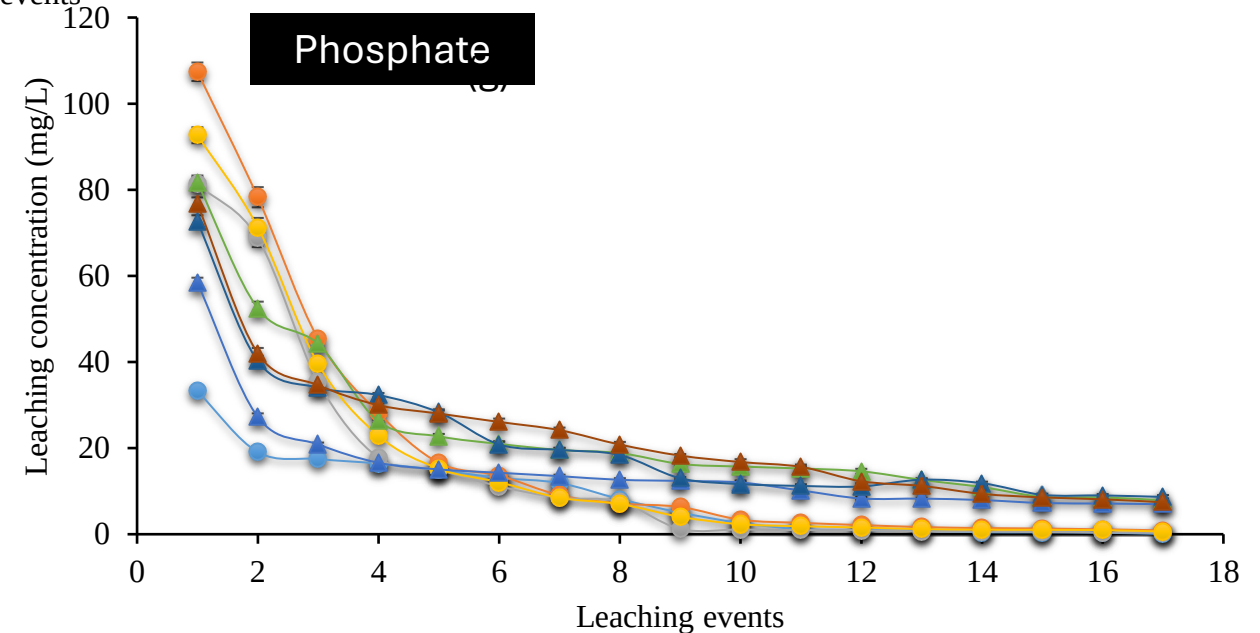
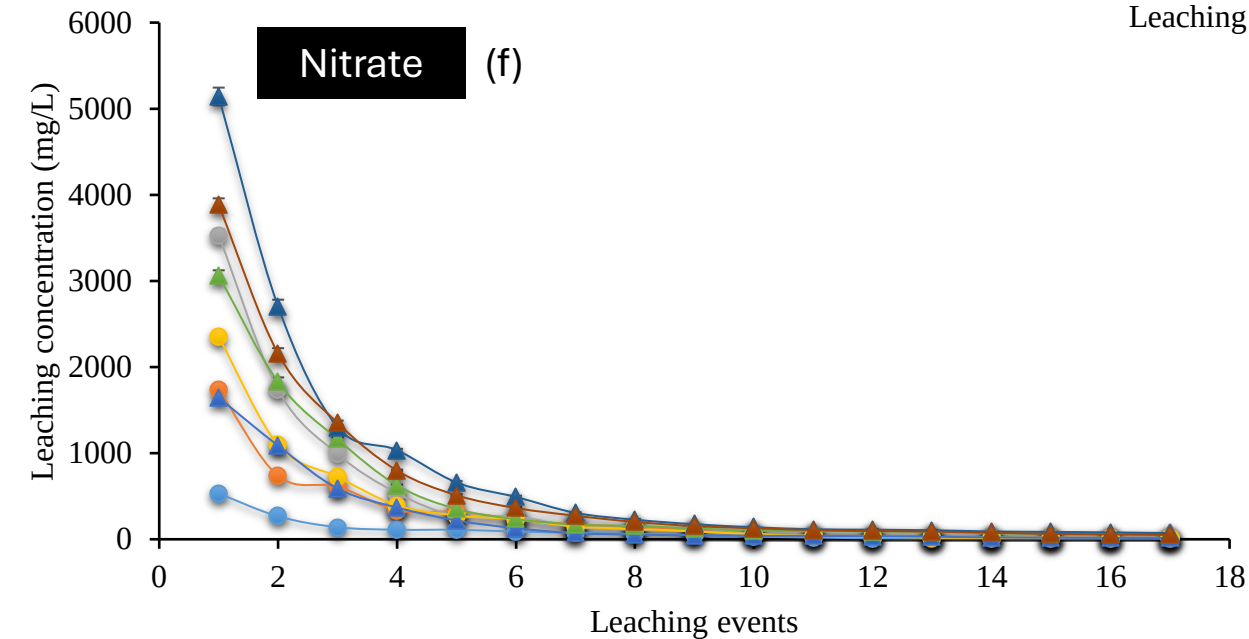
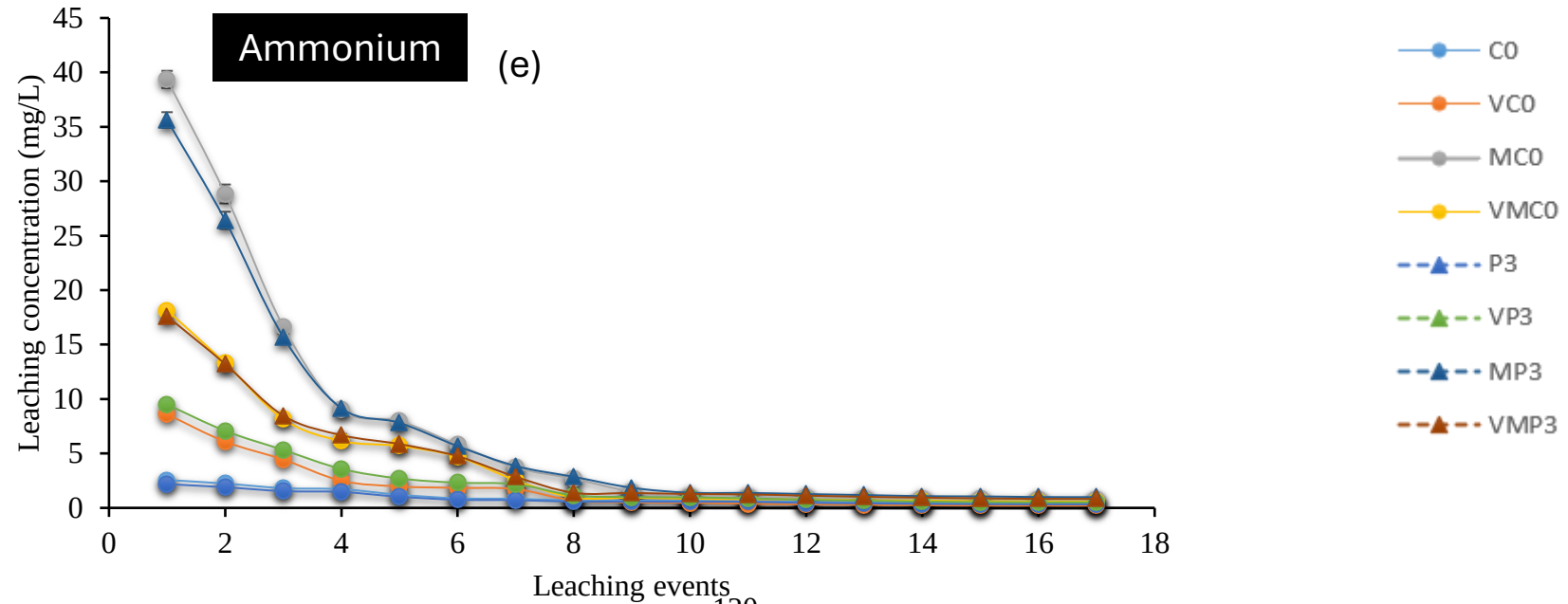
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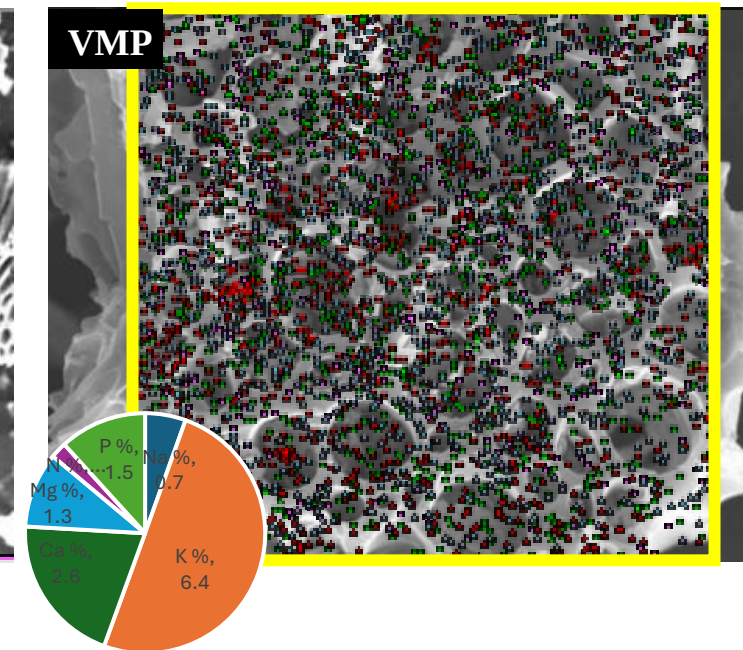
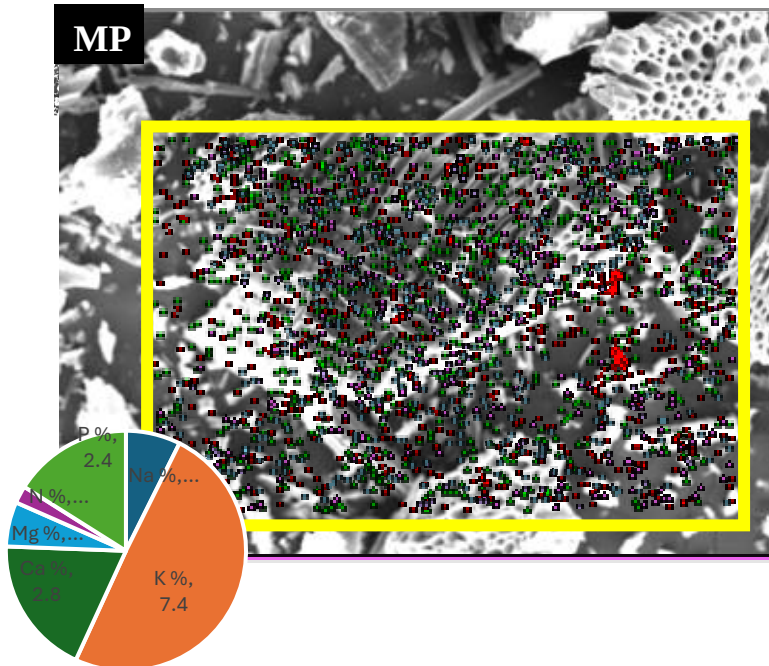
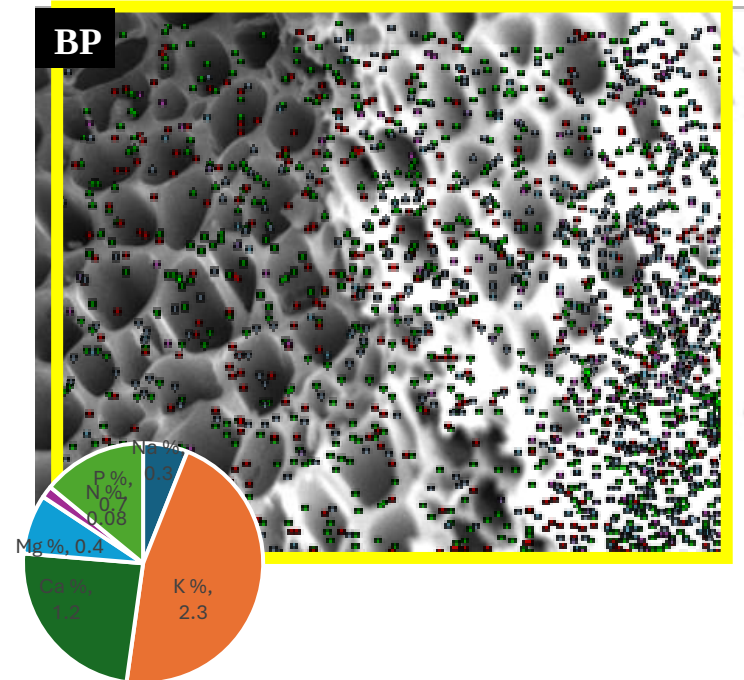
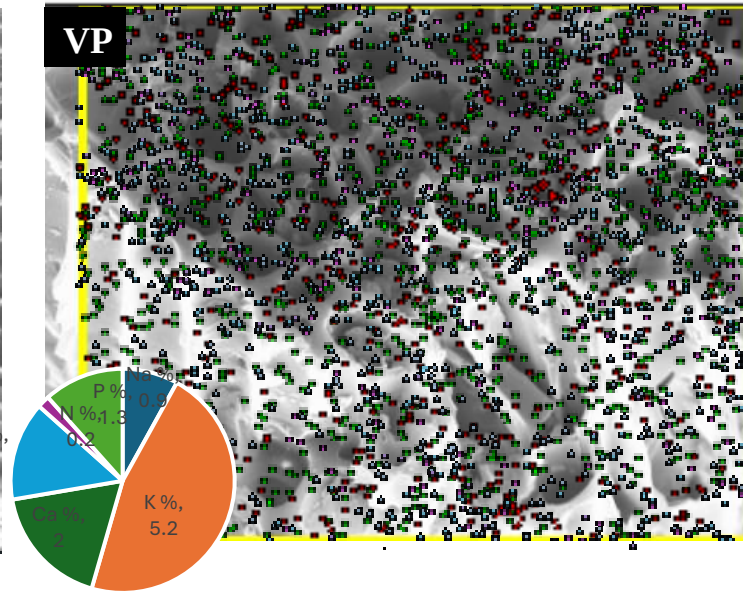
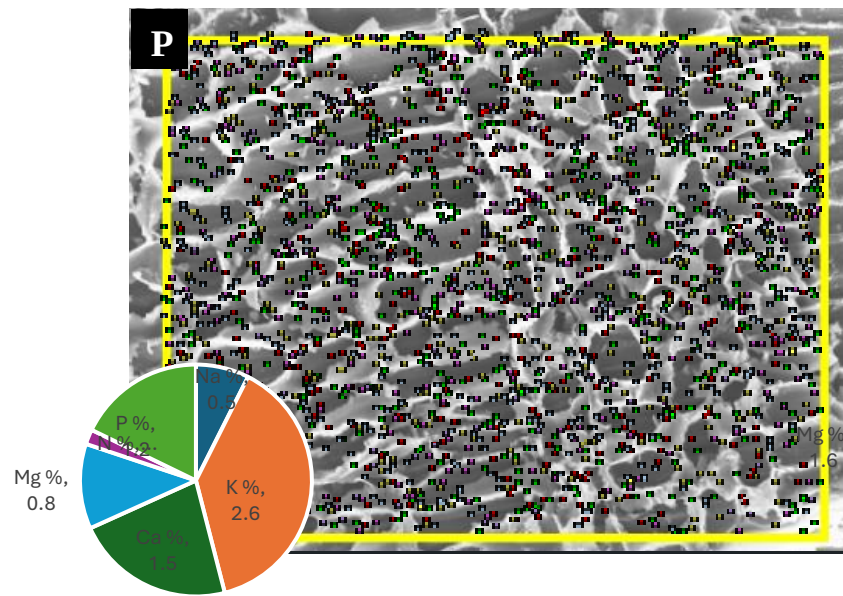
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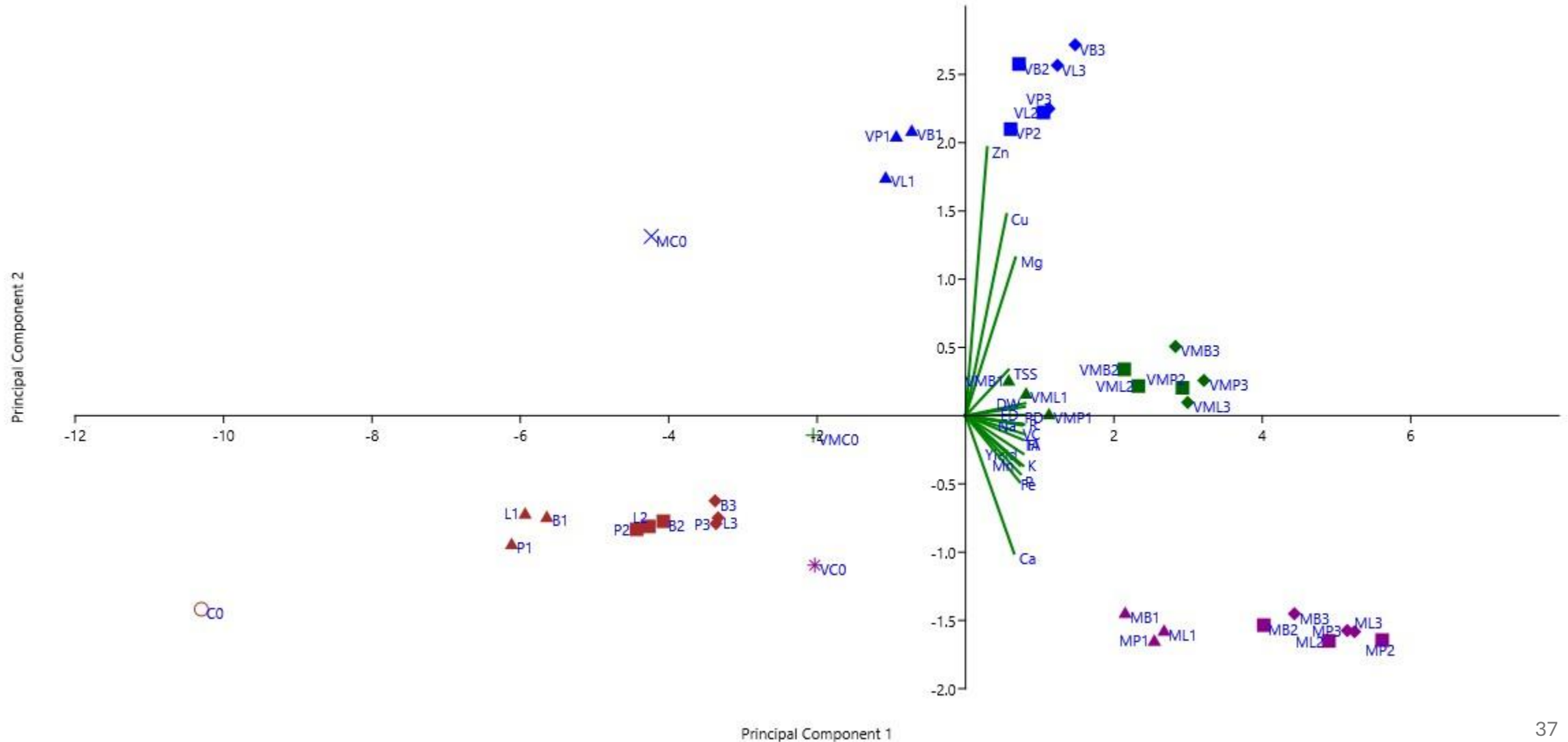
Leachate column test



SEM analysis for chars post leaching experiment



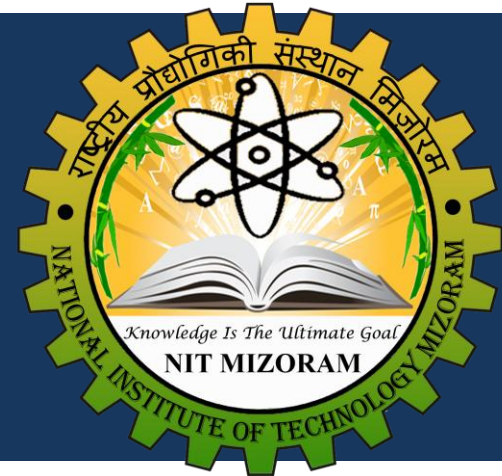
Principal component analysis (tomato)



Conclusions

- *The positive impacts* of biochars/single-use plastic- char composites and organic fertilizers *co-application* on plants growth, productivity allows more consideration on the *feasibility of char and organic supplementation* as a *helpful cultural practice* in the production of bell peppers and tomatoes in tropical laterite soils.
- The *sole application of char* to soil yielded relatively *better plant responses with respect to control*, its relative significance when *compared to application of organic fertilizers cannot be justified*. The *co-application* of organic fertilizers and chars can however substantially *enhance the nutrient use efficiency* from organic fertilizers.
- The added benefits of *larger fruit sizes, higher dry weights, improved fruit quality parameters* also advance the case for co-amendment.
- Integrated application of *manure and polystyrene-char composite* (10 t/ha) has *improved the productivity of bell pepper and tomato by 112 %, and 84 % as compared to the application of manure alone*. Moreover, these increments in the fruit yields *when compared to non-supplemented soil* can rise by *238 % (bell pepper), 198 % (tomato)*.
- The *co-application of single-use plastics-char composites at 10 t/ha along with manure* could be the *most productive treatment* for *bell pepper and tomato production in the study area*.

Thank You



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