Enhancing Productivity and Livelihoods among Smallholders Irrigators through Biochar and Fertilizer Amendments at Ekxang Village, Vientiane Province, Lao PDR

Presented at the 9th Annual
Graduate Research Symposium in Environmental Science & Policy at
Clark University, Worcester, Massachusetts, USA on March 11, 2015

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Abstract

Climate change and climate variability pose significant risks to smallholders in the rainfed lowlands of Lao PDR. Increased surface temperatures, declining rainfall, persistent drought and depleting soil nutrients all serve to impact agricultural productivity and livelihoods. This study investigates the impact of five treatments on soil nutrients, moisture, growth and yield of water spinach *(Ipomoea aquatica).*The treatments tested were rice husk biochar only, biochar inoculated with cattle manure, manure tea, inorganic fertilizer (NPK), and the control. The costs and benefits of the treatments were also assessed. The randomized complete block design was used to assign five treatments and eight replications to the experimental units. Biochar was produced through slow pyrolysis. Soil physical properties were assessed with the visual soil assessment method and 15-randomized soil samples were collected for chemical analyses. Sprinklers were used for irrigation and a weather station installed to monitor the climate. Descriptive statistics, analysis of variance and least significant difference tests were employed to analyze the data. Costs-benefits evaluation of the treatments was conducted to determine the net benefits relative to the initial costs ratio. The result of ANOVA of mean yield indicates that the difference in yield among the treatments was statistically significant. The computed F value (8.28) was higher than the tabular F value (2.64) at the 0.05 significance level. The net benefits to initial costs ratio of treatments suggest that the control (4.11), RHB+CM+NPK (1.64), RHB+MT (1.01), and RHB+CM (0.93) are preferred. The net benefits and initial costs evaluation of treatments is important to assess whether utilizing these treatments would impact smallholders' livelihoods. The results of this study contribute to the evidence that biochar could play an essential role to mitigate climate change risks by enhancing soil quality, increasing crop yield and improving the livelihoods of smallholders.

Scientific Background

- Scientific consensus of anthropogenic-induced greenhouse gases emissions *(IPCC, 2013)*.

- Climate change and climate variability pose significant risk to smallholders in the rainfed lowlands of Lao PDR (Pavelic et al., 2010).
- These changes influence shifts in ecosystem regimes inducing regional and global food insecurity issues.
- Water scarcity for agricultural productivity during the hot-dry season continues to be a major challenge *(Pavelic et al, 2010)*.
- The integration of sustainable groundwater use and soil management practices has the potential to improve smallholders' water use, increase agricultural productivity and livelihoods *(Pavelic et al., 2010)*.

Research Objectives

- To evaluate whether rice husk biochar inoculated with cattle manure, manure tea, NPK and amended in soil would increase soil nutrient status, improve crop growth, and yield relative to the control.
- To assessed the potential of biochar to improve soil water availability.
- To assess groundwater irrigation quality and crop water use efficiency for agricultural productivity.
- To evaluate the costs and benefits of treatments relative to agricultural productivity and the livelihoods of smallholders.

**This study contributes to the overarching aim of the ACIAR supported research project that examines the technical and non-technical feasibility of groundwater irrigation in Lao PDR (http://gw-laos.iwmi.org/).

Schematics of Slow Pyrolysis

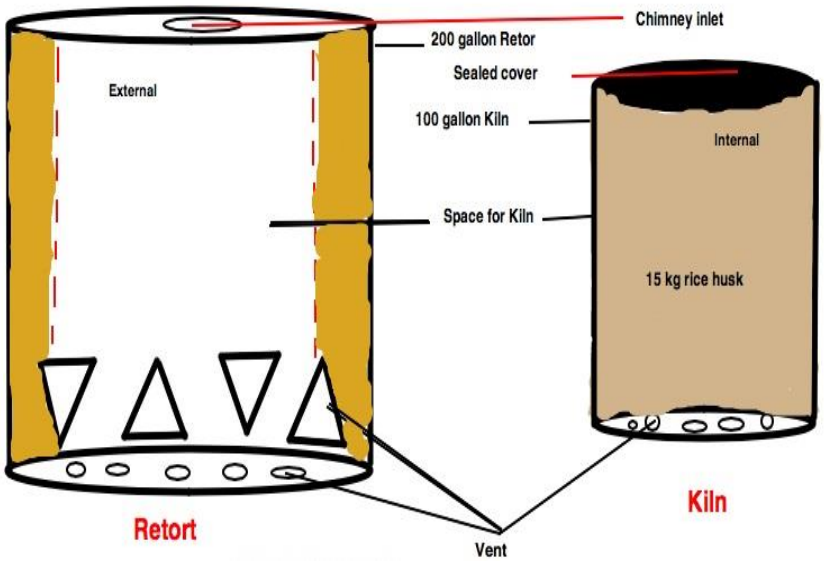


Figure 1: The Metal Drum Kiln & Retort

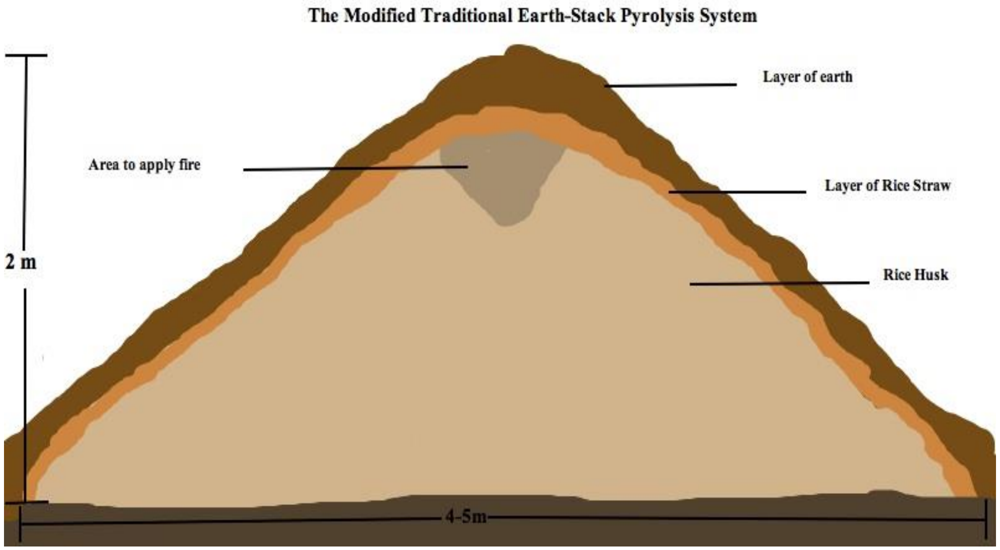


Figure 3: The Modified Earth-Stack Pyrolysis System

Figure 2: Flow Diagram of the Metal Drum Pyrolysis System

Figure 4: Flow Diagram of the Modified Earth-Stack Pyrolysis System

Materials & Methods

A. Experimental Design

I. **Randomized Complete Block Design** *(Gomez & Gomez, 1984)*

  i. 5-Treatments, 8-Replications, 1-trial crop Water spinach *(Ipomoea aquatic), <u>Pak Bong</u> (Table 1)*

  ii. Experimental Units: W40m x L16m

  iii. 5-blocks, 8-plots (1m x 9m) Layout (Figure 14).

B. Assess Soil Nutrients, Crop Growth & Yield

  i. **Visual Soil Assessment** (Semi-quantitative): soil physical state (*Shepherd et al, 2008)*. (Table 2)

  ii. **Randomized Soil Sampling** (quantitative): soil chemical properties.

  - *Pre-Treatment, Treatment & Post-Treatment stages* (Table 3)

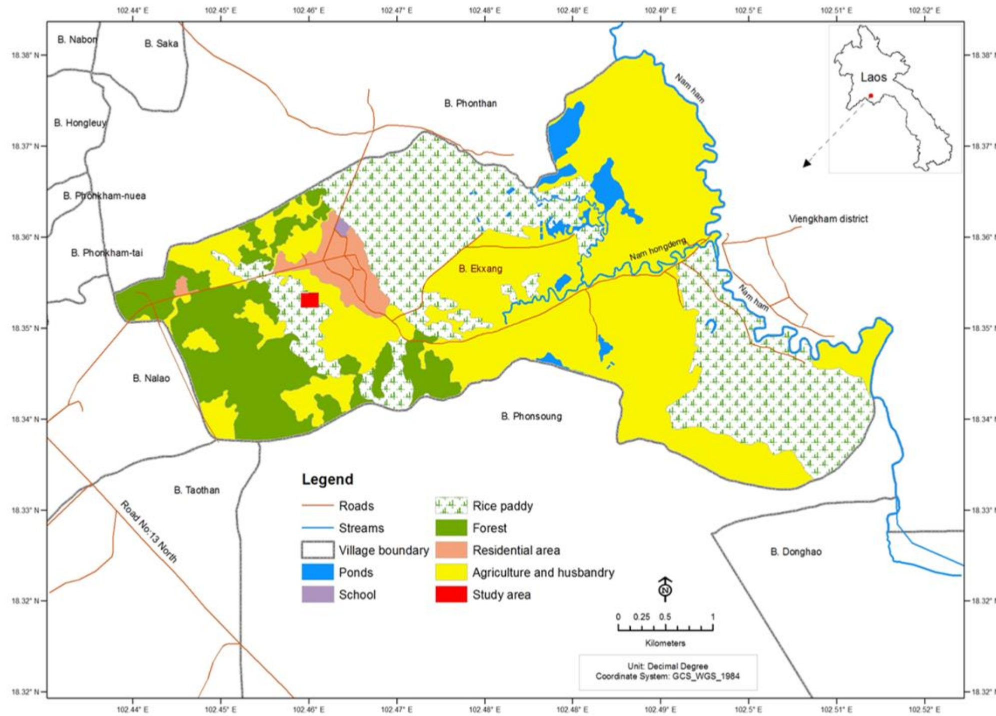
  iii. **Monitored Crop Growth Parameters**

  Fresh weight (g), height (cm), root mass (%), root depth (cm), # of shoot/plant, # of leaves/plant, & leaf surface area (cm^2).

  - *Destructive sampling* (*Bell & Fischer, 1994, Fermont & Benson, 2011*). (Table 4)

  iv. **Whole Plot Harvest** (*Fermont & Benson 2011*).

  Measured harvested yields in kg per treatment and replication



Source: IWMI Groundwater Project, 2014.
Produced by: T. Soutoukee, IWMI-GIS Specialist-Lao PDR

Figure 5: Ekxang Village Land Use Map

C. Evaluate Soil Water Availability

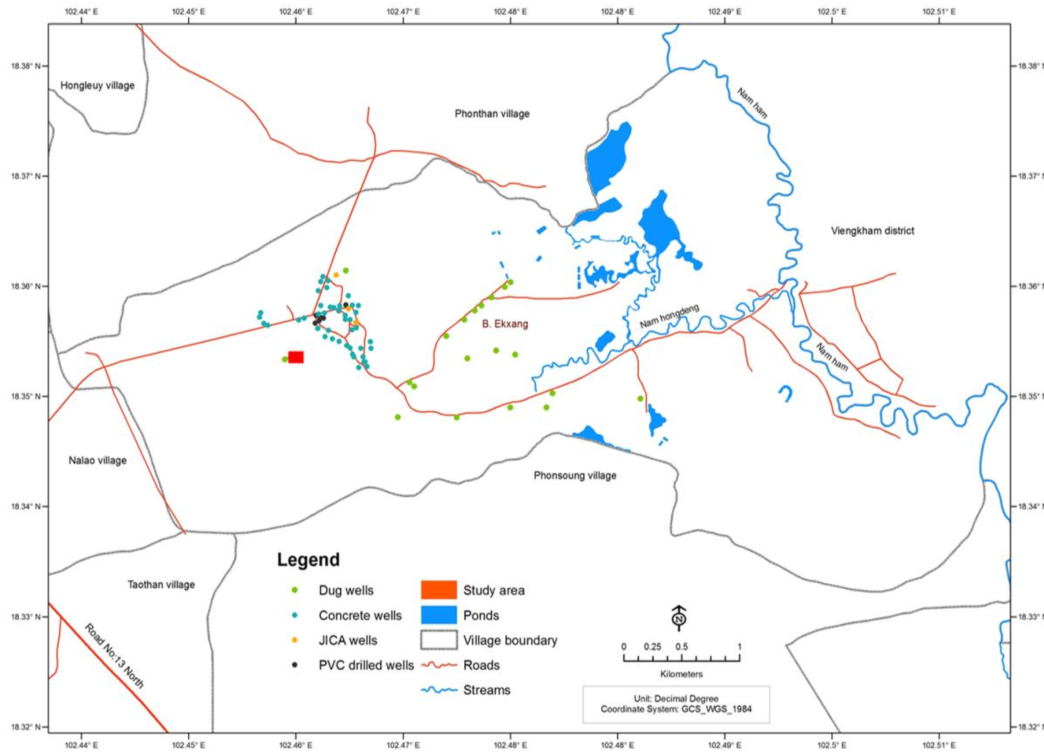
i. Soil Moisture Monitoring *(Allen et al., 1998).*

ii. Climate Station Instillation (Figure 11) *(Mancuso, 2005, Allen et al., 1998).*

D. Irrigation Groundwater Quality & Sprinklers' Spray Uniformity

i. Water & Soil Salinity and Sodicity Assessments (Table 6) *(Ayers & Westcot, 1976; Fipps, 2003; Hanson et al., 2006).*

ii. Installed 144 Sprinklers' Spray Collectors (Figures 7 & 9) *(ASAE, 2001).*



Source: IWMI Groundwater Project, 2014.
Produced by: T. Soutoukee, IWMI-GIS Specialist-Lao PDR

Figure 6: Ekxang Village Water Resources

E. Inputs and Outputs Evaluation of Agricultural Productivity

i. Net Benefits to Total Cost Assessment (Table 5) *(Shackley et al. 2011, Kulyk 2012).*

ii. Net Revenue Evaluation

Table 1: Treatment Description, rates of application and irrigation rate

#	Treatment Description	Code	[a]Application Rate (tons/ha)	[b]Field Rate (kg/m^2)	Irrigation Rate (mm/event)
1	Control Rice Straw and Rice Husk	RS + RH	15t/ha RS + 15t/ha RH	1.5kg/m^2 RS + 1.5kg/m^2	4
2	Rice Husk Biochar applied only	RHB	30tons/ha	3kg/m^2	4
3	Rice Husk Biochar inoculated with Cattle Manure	RHB + CM	15t/ha RHB + 15t/ha CM	1.5kg/m^2 RHB + 1.5kg/m^2 CM	4
4	Rice Husk Biochar inoculated with Manure Tea	RHB + MT	15t/ha RHB + 40L/ha MT	1.5kg/m^2 RHB + 4t/ha	4
5	Rice Husk Biochar inoculated with Cattle Manure plus NPK	RHB + CM + NPK	15t/ha RHB + 15t/ha CM + 23t/ha NPK	1.5kg/m^2 RHB + 1.5kg/m^2 CM + 0.23kg/m^2 NPK	4

[a]The referenced rate of application [b]Scalable rate used at the field

Table 2: Visual Soil Assessment Soil Quality Parameters

No	VSA Soil Quality Parameters	Total Soil Cubes [$200mm^3$]	Pre-Treatment	Post-Treatment
1	Soil texture	4	2	2
2	Soil Structure	4	2	2
3	Soil Porosity	4	2	2
4	Soil Color	4	2	2
5	Number & Color of Soil Mottles	4	2	2
6	Earthworm [number & Average size]	4	2	2
7	Potential rooting depth	4	2	2
8	Surface Ponding	4	2	2
9	Surface Crusting & Cover	4	2	2
10	Soil Erosion [rain/wind]	4	2	2

Source: Shepherd et al. 2008.

Table 3: Soil samples and Parameters

#	Test Parameters	Pre-Treatment Soil Samples (400g/S)	Treatment Soil Samples (400g/S)	Post-Treatment Soil Samples (400g/S)	Total Soil Samples Collected
1	Organic Matter (%OM)	5	5	5	15
2	Total Nitrogen (N)	5	5	5	15
3	Total Phosphorous (P)	5	5	5	15
4	Total Potassium (K)	5	5	5	15
5	pH (H20, KCl)	5	5	5	15
6	%CaCO3	5	5	5	15
7	Cation Exchange Capacity	5	5	5	15

Table 4: Randomized Samples of Water Spinach at Destructive Sampling

Date of Sampling	Block ID	Plot ID	Treatment Color	Treatment Name	Samples Collected
05/29/2014	5	34	Yellow[1]	Control	75
05/30/2014	3	17	Yellow[2]	Control	53
05/23/2014	5	39	Red[1]	RHB Only	108
05/30/2014	2	11	Red[2]	RHB Only	75
05/23/2014	1	1	Green[1]	RHB + CM	105
05/29/2014	4	27	Green[2]	RHB + CM	105
05/22/2014	1	5	Blue[1]	RHB + MT	129
06/01/2014	2	16	Blue[2]	RHB + MT	75
05/23/2014	5	38	Black[1]	RHB + CM + NPK	100
06/01/2014	3	24	Black[2]	RHB + CM + NPK	90

(1 = Subplot 1; 2 = Subplot 2)

Table 5: Costs and Benefits Evaluation of Agricultural Productivity

Cost Variables	Units	Benefit Variables	Units
Land Plowing	LAK	Rice Straw	LAK/bag
Raised-Beds Preparation	LAK	Rice Husk	LAK/bag
Cattle Manure	LAK/kg	Pyrolysis System Savings	LAK/year for 3-years
Seeds	LAK/kg	Net Revenue from sales	LAK
Inorganic Fertilizer	LAK/kg	Water Cost Savings	LAK
Irrigation System	LAK	Biochar Application Cost Savings	LAK
On-Farm Transportation	LAK/trip	Carbon Sequester	C/tRHB
On-Farm Communication	LAK	CO_2 Pricing	LAK/tCO_2
Electricity	LAK/hWk/day	Soil Fertility Savings (Manure)	LAK for 3-years
Pyrolysis System	LAK	Land Acquisition Saving	LAK
Labor	LAK/day	Harvesting Savings	LAK
Lunch	LAK/person/day	Seeds Planting Savings	LAK
Farm Security	LAK	Social Benefits	LAK
Time	Days		
Farm Tools	LAK		
Social Cost	LAK		

**Foreign Currency Exchange Rate (8,500.00LAK = $1.00USD)*

Table 6: Irrigation Groundwater Parameters for Laboratory Analyses

Test No.	Test Parameter	Number of Test	Unit Cost	Total Cost
1	Calcium (Ca)	1	$6.00	$6.00
2	Magnesium (Mg)	1	$6.00	$6.00
3	Sodium (Na)	1	$7.00	$7.00
4	Potassium (K)	1	$7.00	$7.00
5	Chloride (Cl)	1	$7.00	$7.00
6	Sulphate (SO4)	1	$8.00	$8.00
7	Total Nitrogen (T-N)	1	$12.00	$12.00
8	Ammonium Nitrogen (NH4-N)	1	$7.00	$7.00
9	Nitrate Nitrogen (NO3-N)	1	$8.00	$8.00
10	Ortho-Phosphate (PO4-P)	1	$7.00	$7.00
11	Bicarbonate (CHO3-)	1	$7.00	$7.00

Note: (Currency Exchange Rate: $1.00 USD = 8,500.00 LAK at the time of payment)

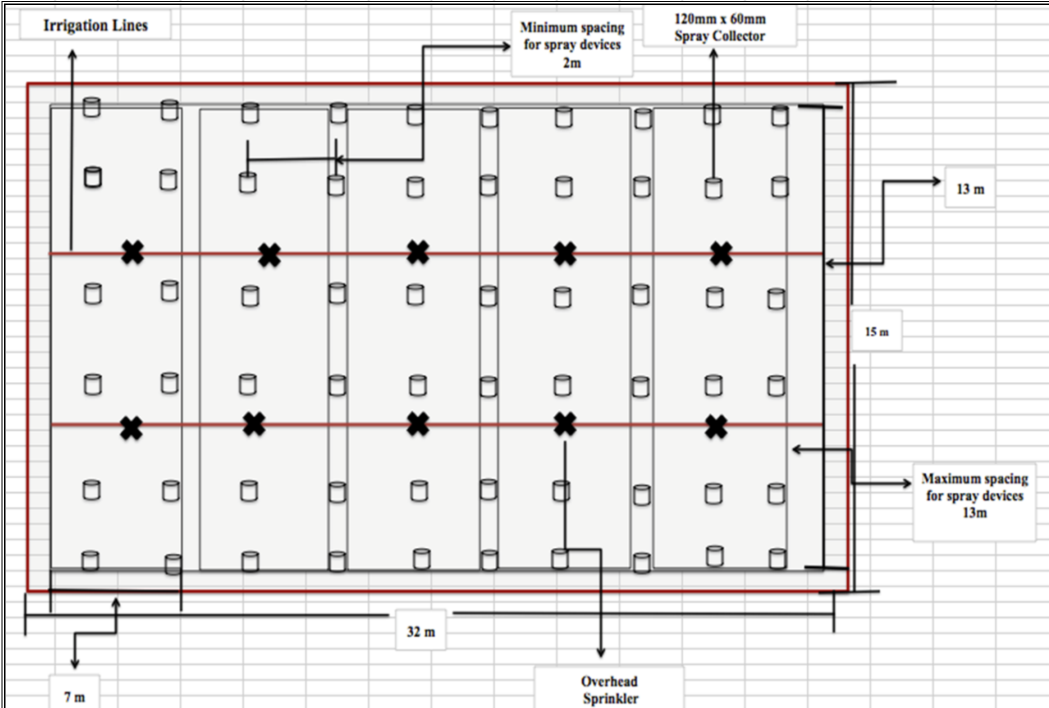


Figure 7: Schematics of Spray Collectors' Layout

Figure 9: Experimental Units Installed with Spray Collectors

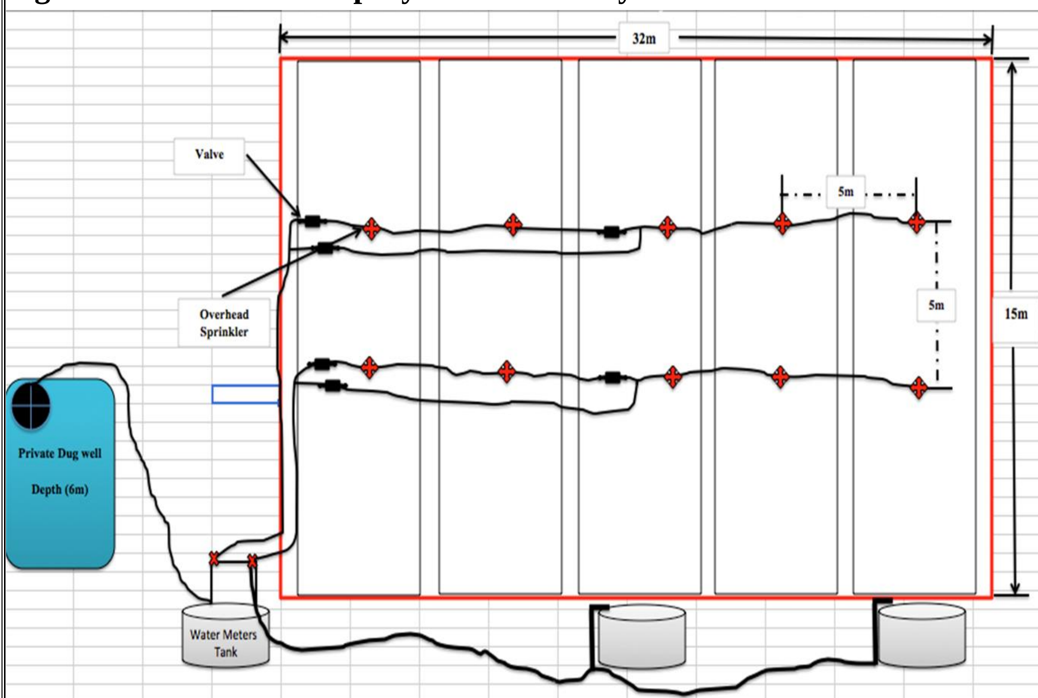


Figure 8: Schematic of the Irrigation Layout

Figure 10: Testing the Irrigation System Prior to Planting Seeds

Figure 11: Weather Station

Figure 12: Rain Gauge

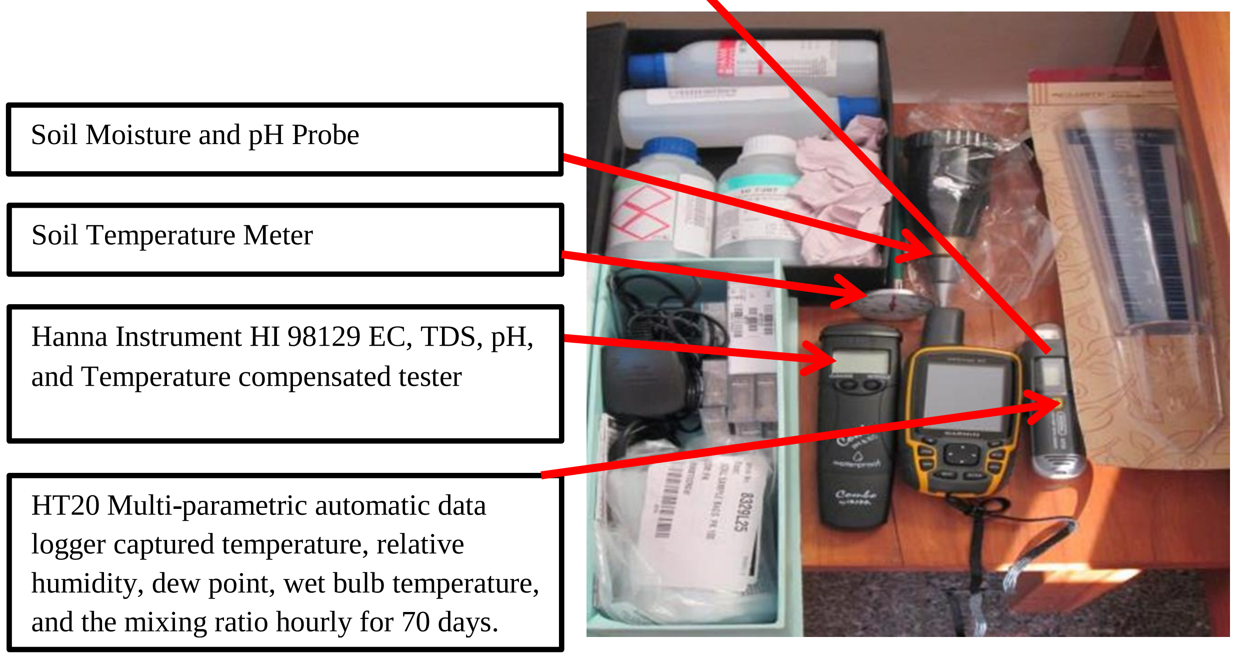


Figure 13: Field Instruments

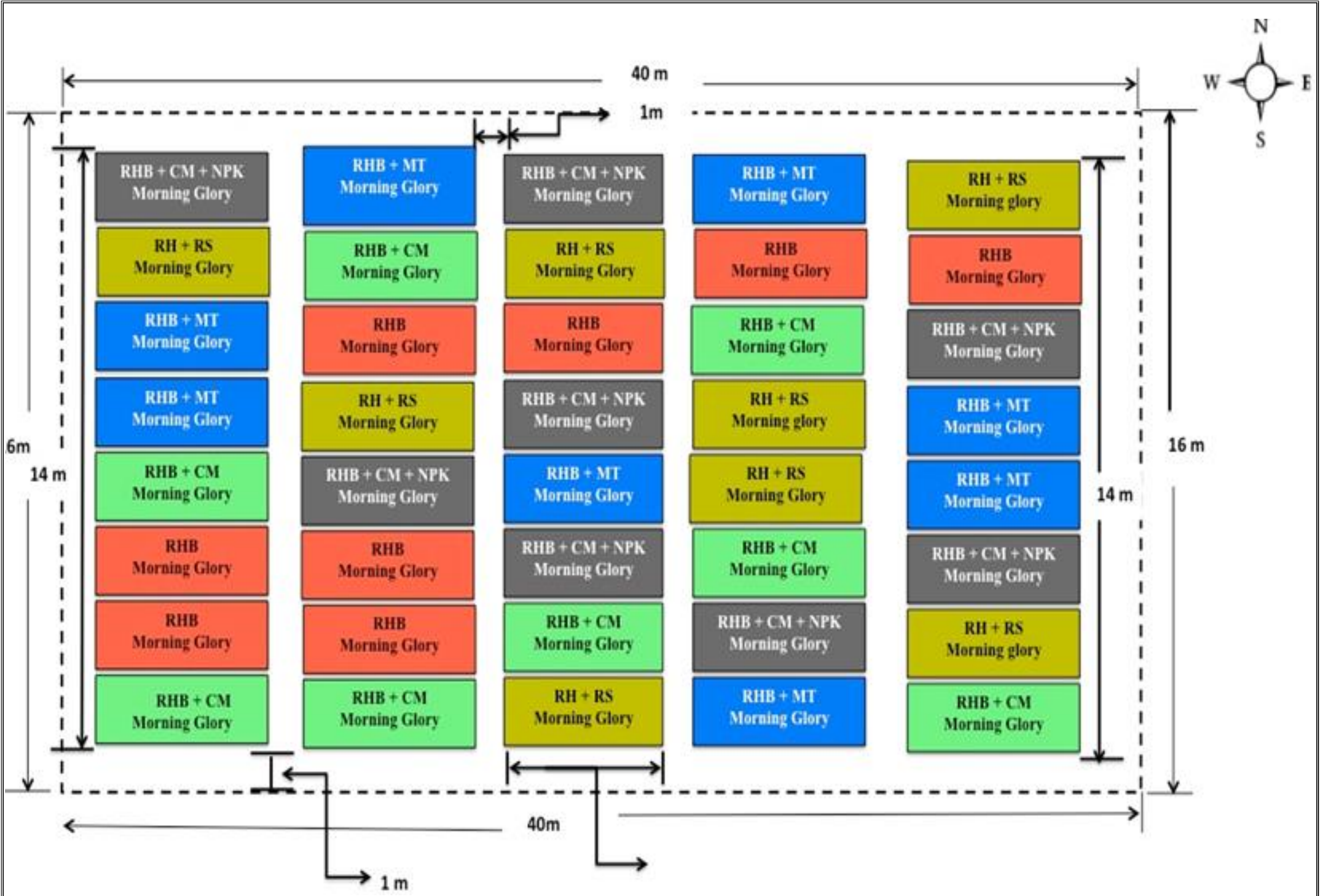


Figure 14: Randomized Layout of Treatments & Replications

Data Analyses

A. **Bio-geophysical & Socioeconomic Characteristics**

i. Ekxang Village (*Ban Ekxang*), Vientiane Province

ii. Coordinates 18° 21.172' (N) to 102° 27.471' (E), Elevation: 180m

iii. Surface and Groundwater Resources

iv. 150 yrs. old, 3-tribes: Hmong, Khamu & Lao Lum (*Pavelic et al. 2010, Maokhamphiou 2014*).

Data Analyses	**Enhance soil nutrient, crop growth and yield?**	MS Excel 2011	**Statplus version 5** • VSA • Descriptive Statistics • One-Way ANOVA • Fisher's LSD Test
	Increase soil moisture availability?	MS Excel 2011	Soil Moisture Analysis Field Water Balance Climatic Factors
	Irrigation groundwater quality, spray distribution and soil salinity & SAR	MS Excel 2011	Water Quality Analysis Soil Salinity and SAR Sprinkler Spray Analysis
	Cost-benefits evaluation of agricultural productivity	MS Excel 2011	Cost-Benefits Analysis Net Benefit-Total Cost Ratio Estimated Net Revenue per Yield

v. Population: 1,280, contains 237 households, 260 females *(Pavelic et al. 2010, Suhardiman et al. 2013, Maokhamphiou 2014)*.

vi. Main Sources of Household Income: *Paddy rice production, free-range livestock, small-scale animal husbandry, and cash crop (lettuce, watermelon, water spinach, beans, dragon fruit, cucumber, herbs), contract farming, and non-farming activities (fishing, art and craft, labor-based contracts, seamstress, food vendors, and shops.*

Results

✧ Soil Physical Properties

Table 6. Pre-Treatment Visual Soil Assessment (VSA) Analysis

Landowner: Ms. Tadam	Location: Ekxang Village	Sample Depth: 20 cm	Soil Type: Silty Clay	Drainage Class: N/A	Land Use: Paddy Rice Production	Coordinates: N. 18° 21. 177" E. 102° 27.467
Date of Assessment: 01/29/2014	Soil Texture Class: Silty clay					
Textural Group (0-1m): Clay	Sandy	Loamy	**Silty**	**Clay**	Other	
Soil Moisture Condition:	**Dry**	Slightly Moist	Moist	Very Moist	Wet	10%
Weather Conditions:	**Dry**	Wet	Cold	Warm		

Visual Indicators of Soil Quality		Visual Score (VS) 0 = Poor condition 1 = Moderate condition 2 = Good condition	Weighting	VS ranking
Soil texture	pg. 2	1 = Moderate condition	x3	3
Soil structure	pg. 4	1 = Moderate condition	x3	3
Soil porosity	pg. 6	1 = Moderate condition	x3	3
Soil color	pg. 8	0 = Poor condition	x2	0
Number and color of soil mottles	pg. 10	1 = Moderate condition	x2	2
Earthworms (Number = 0), (Av. Size = 0)	pg. 12	1 = Moderate condition	x3	0
Potential rooting depth (40 cm)	pg. 14	1 = Moderate condition	x3	0
Surface ponding	pg. 18	2 = Good condition	x1	2
Surface crusting and surface cover	pg. 20	2 = Good condition	x2	4
Soil erosion (wind/water)	pg. 22	2 = Good condition	x2	4
	SOIL QUALITY INDEX (sum of VS rankings)			**21**

Soil Quality Assessment	Soil Quality Index
Poor	<15
Moderate	**15-30**
Good	>30

Table 7. Post-Treatment Visual Soil Assessment (VSA) Analysis

Landowner: Ms. Tadam	Location: Ekxang Village	Sample Depth: 20 cm	Soil Type: Silty Clay	Drainage Class: N/A	Land use: Paddy Rice Production	Coordinates: N. 18° 21. 177" E. 102° 27.467"
Date of Assessment: 06/02/2014	Soil Texture Class: Silty clay					
Textural Group (0-1m):	Sandy	Loamy	**Silty**	**Clay**	Other	
Soil Moisture Condition:	Dry	Slightly Moist	Moist	Very Moist	**Wet**	80%
Weather Conditions:	Dry	**Wet**	Cold	Warm	Av.,	

Visual Indicators of Soil Quality		Visual Score (VS) 0 = Poor condition 1 = Moderate condition 2 = Good condition	Weighting	VS ranking
Soil texture	pg. 2	2 = Good condition	x3	6
Soil structure	pg. 4	2 = Good condition	x3	6
Soil porosity	pg. 6	1 = Moderate condition	x3	3
Soil color	pg. 8	1 = Moderate condition	x2	2
Number and color of soil mottles	pg. 10	2 = Good condition	x2	4
Earthworms (Number = 10), (Av. Size = 0)	pg. 12	1 = Moderate condition	x3	3
Potential rooting depth (30 cm)	pg. 14	0 = Poor condition	x3	0
Surface ponding	pg. 18	2 = Good condition	x1	2
Surface crusting and surface cover	pg. 20	2 = Good condition	x2	4
Soil erosion (wind/water)	pg. 22	2 = Good condition	x2	4
	SOIL QUALITY INDEX (sum of VS rankings)			**34**

Soil Quality Assessment	Soil Quality Index
Poor	<15
Moderate	15-30
Good	**>30**

Table 8. Earthworms Observations in the Soil

Treatment Types	Pre-treatment	Treatment	Post-Treatment	Standard Deviation	Mean
Control (RS + RH)	0	4	13	6.66	5.67
RHB	0	5	10	5.00	5.00
RHB + CM	0	10	10	5.77	6.67
RHB + MT	0	8	8	4.62	5.33
RHB + CM + NPK	0	13	7	6.51	6.67

Table 9. F-Test Two-Sample for Variances of Earthworms Observations

	Descriptive Statistics						Summary of Results			
Treatment Variables	Sample Size (n)	Degree of Freedom (df)	Mean (M)	Variance	Standard Deviation	Mean Standard Error (SE)	F-Value (5%)	p-level 1-tailed	F Critical Value (5%)	p-level 2-tailed
Control vs. RHB	6	4	5.67; 5.00	44.33; 25.00	6.66; 5.00	3.84; 2.89	1.77*	0.36	19.	0.72
Control vs. RHB + CM	6	4	5.67; 6.67	44.33; 33.33	6.66; 5.77	3.84; 3.33	1.33*	0.43	19.	0.86
Control vs. RHB + MT	6	4	5.67; 5.33	44.33; 21.33	6.66; 4.62	3.84; 2.67	2.08*	0.32	19.	0.65
Control vs. RHB + CM + NPK	6	4	5.67; 6.67	44.33; 42.33	6.66; 6.51	3.84; 3.76	1.69*	0.49	19.	0.98
RHB vs. RHB + CM	6	4	5.00; 6.67	25.00; 33.33	5.00; 5.77	2.89; 3.33	1.33*	0.43	19.	0.86
RHB vs. RHB + MT	6	4	5.00; 5.33	25.00; 21.33	5.00; 4.62	2.89; 2.67	1.17*	0.46	19.	0.92
RHB vs. RHB + CM + NPK	6	4	5.00; 6.67	25.00; 42.33	5.00; 6.51	2.89; 3.76	1.69*	0.37	19.	0.74
RHB + CM vs. RHB + MT	6	4	6:67; 5.33	44.33; 21.33	5.77; 4.62	3.33; 2.67	1.56*	0.39	19.	0.78
RHB + CM vs. RHB + CM + NPK	6	4	6.67; 6.67	33.33; 42.33	5.77; 6.51	3.33; 3.76	1.27*	0.44	19.	0.88
RHB + MT vs. RHB + CM + NPK	6	4	5.33; 6.67	21.33; 42.33	4.62; 6.51	2.67; 3.76	1.98*	0.34	19.	0.67

*Earthworms' variations are statistically the same across each compared treatment during the treatment and post-treatment stages.

✧ Chemical Properties

Table 10. Descriptive Statistics of Potassium (K+ meq/100g) in the Soil

TREATMENT STAGE	Control	RHB	RHB + CM	RHB + MT	RHB + CM + NPK
Pre-Treatment	0.09	0.11	0.23	0.35	0.23
Treatment	0.49	0.26	0.37	0.26	0.81
Post-Treatment	0.16	0.13	0.20	0.10	0.23
Standard Deviation (SD)	0.21	0.08	0.09	0.13	0.33
Sample Variance (SV)	0.05	0.01	0.01	0.02	0.11
Mean (M)	0.25	0.17	0.27	0.24	0.42
Coefficient of Variance (CV%)	0.87	0.49	0.34	0.54	0.79
Total Sum Squares (TSS)	0.27	0.10	0.23	0.20	0.76
Skewness	0.62	0.66	0.62	0.33	0.71
Mean Deviation (MD)	0.16	0.06	0.07	0.09	0.26
Median Error (ME)	0.08	0.03	0.04	0.05	0.14
Median	0.16	0.13	0.23	0.26	0.23
Sum Standard Error (SSE)	0.37	0.14	0.16	0.22	0.58
Coefficient of Dispersion (COD)	0.83	0.38	0.25	0.32	0.84
Alpha (α) Value	0.05				

Table 11. ANOVA (One-way) of Potassium (K+ meq/100g) in the Soil

Summary

Groups	Sample size	Sum	Mean	Variance
Control	3	0.7400	0.2467	0.0456
RHB	3	0.5000	0.1667	0.0066
RHB + CM	3	0.8000	0.2667	0.0082
RHB + MT	3	0.7100	0.2367	0.0160
RHB + CM + NPK	3	1.2700	0.4233	0.1121

ANOVA

Source of Variation	SS	d.f.	MS	Computed F	p-level	F critical
Between Groups	0.1075	4	0.0269	0.7123	0.6021	3.4780
Within Groups	0.3773	10	0.0377			
Total	0.4848	14				

Table 14: Descriptive Statistics of Phosphorous (%P_2O_5) per Treatment

TREATMENT STAGE	Control	RHB	RHB + CM	RHB + MT	RHB + CM + NPK
Pre-Treatment	0.01	0.01	0.01	0.02	0.03
Treatment	0.03	0.02	0.02	0.02	0.04
Post-Treatment	0.02	0.02	0.03	0.01	0.04
Standard Deviation (SD)	0.01	0.01	0.01	0.01	0.01
Sample Variance (SV)	0.00	0.00	0.00	0.00	0.00
Mean (M)	0.02	0.02	0.02	0.02	0.04
Coefficient of Variance (CV%)	0.50	0.35	0.50	0.35	0.18
Total Sum Squares (TSS)	0.00	0.00	0.00	0.00	0.00
Skewness	0.00	0.71	0.00	0.71	0.56
Mean Deviation (MD)	0.01	0.00	0.01	0.00	0.01
Median Error (ME)	0.00	0.00	0.02	0.00	0.00
Median	0.02	0.02	0.02	0.02	0.04
Sum Standard Error (SSE)	0.02	0.01	0.02	0.01	0.01
Coefficient of Dispersion (COD)	0.33	0.17	0.33	0.17	0.11
Alpha (α) Value	0.05				

Table 15. Analysis of Variance (One-Way) - Phosphorous

Descriptive Statistics

Groups	Sample size	Sum	Mean	Variance
Control	3	0.06	0.020	0.0014
RHB	3	0.05	0.017	0.0009
RHB + CM	3	0.06	0.020	0.0014
RHB + CM + NPK	3	0.11	0.038	0.0043
RHB + MT	3	0.05	0.017	0.0009
Total	15		0.022	0.0001

ANOVA

Source of Variation	d.f.	SS	MS	Computed F	p-level	F Critical	Omega Sqr.
Between Groups	4	0.0009	0.0002	3.7157	0.0420	3.4780	0.4200
Within Groups	10	0.0006	0.0001				
Total	14	0.0016					

Table 12: Descriptive Statistics of Soil Nitrogen (%N) per Treatment

TREATMENT STAGE	Control	RHB	RHB + CM	RHB + MT	RHB + CM + NPK
Pre-Treatment	0.01	0.18	0.02	0.10	0.08
Treatment	0.07	0.04	0.06	0.04	0.06
Post-Treatment	0.11	0.08	0.08	0.07	0.09
Standard Deviation (SD)	0.05	0.07	0.03	0.03	0.02
Sample Variance (SV)	0.00	0.01	0.00	0.00	0.00
Mean (M)	0.06	0.10	0.05	0.07	0.08
Coefficient of Variance (CV%)	0.79	0.72	0.57	0.43	0.20
Total Sum Squares (TSS)	0.00	0.00	0.00	0.00	0.00
Skewness	0.24	0.47	0.38	0.00	0.38
Mean Deviation (MD)	0.00	0.00	0.00	0.00	0.00
Median Error (ME)	0.00	0.00	0.00	0.00	0.00
Median	0.07	0.08	0.06	0.07	0.08
Sum Standard Error (SSE)	0.00	0.00	0.00	0.00	0.00
Coefficient of Dispersion (COD)	0.48	0.58	0.33	0.29	0.13
Alpha (α) Value	0.05				

Table 13: ANOVA (One-way) of Treatments on the Levels of Soil Nitrogen (%N)

Descriptive Statistics

Groups	Sample size	Sum	Mean	Variance
Control	3	0.1900	0.0633	0.0171
RHB	3	0.3000	0.1000	0.0404
RHB + CM	3	0.1600	0.0533	0.0104
RHB + CM + NPK	3	0.2300	0.0767	0.0181
RHB + MT	3	0.2100	0.0700	0.0165
Total	15		0.0727	0.0017

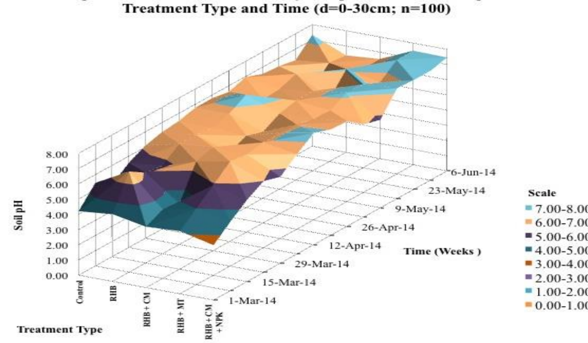
ANOVA

Source of Variation	d.f.	SS	MS	Computed F	p-level	F Critical	Omega Sqr.
Between Groups	4	0.0037	0.0009	0.4711	0.7562	3.4780	-0.1642
Within Groups	10	0.0196	0.0020				
Total	14	0.0233					

Table 16. Fisher Least Significant Difference Test

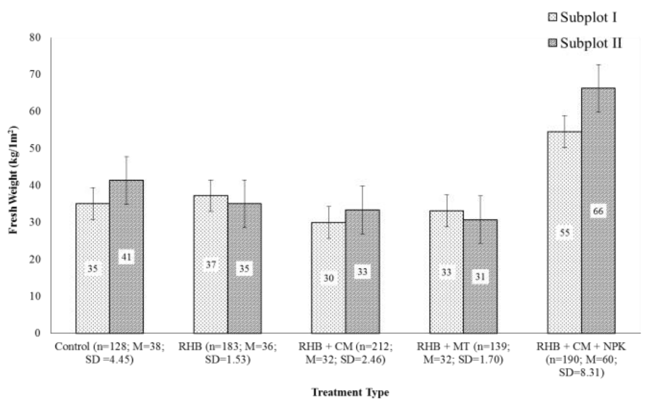
Group vs. Group (Contrast)	*Difference*	*Test Statistics*	*p-level*	*Accepted?*
Control vs. RHB	0.	0.52	0.62	*Rejected*
Control vs. RHB + CM	0.E+0	0.E+0	1.	*Rejected*
Control vs. RHB + CM + NPK	-0.02	2.73	0.02	*Accepted*
Control vs. RHB + MT	0.	0.52	0.62	*Rejected*
RHB vs. RHB + CM	0.	0.52	0.62	*Rejected*
RHB vs. RHB + CM + NPK	-0.02	3.25	0.01	*Accepted*
RHB vs. RHB + MT	0.E+0	0.E+0	1.	*Rejected*
RHB + CM vs. RHB + CM + NPK	-0.02	2.73	0.02	*Accepted*
RHB + CM vs. RHB + MT	0.	0.52	0.62	*Rejected*
RHB + CM + NPK vs. RHB + MT	0.02	3.25	0.01	*Accepted*

Spatial Distribution of the Daily Soil pH Measurements per Treatment Type and Time (d=0-30cm; n=100)

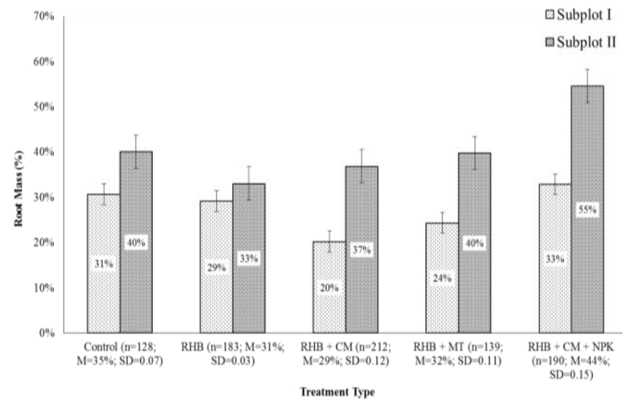


✧ Water Spinach Growth & Yield

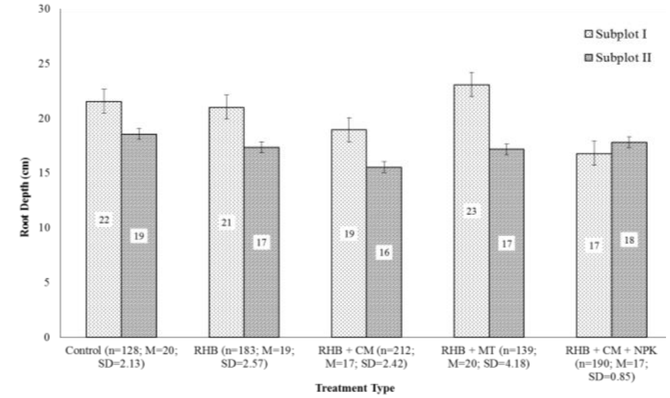
Fresh Weight (g) of Water Spinach by Treatment during the Destructive Sampling (1m²/Subplot)



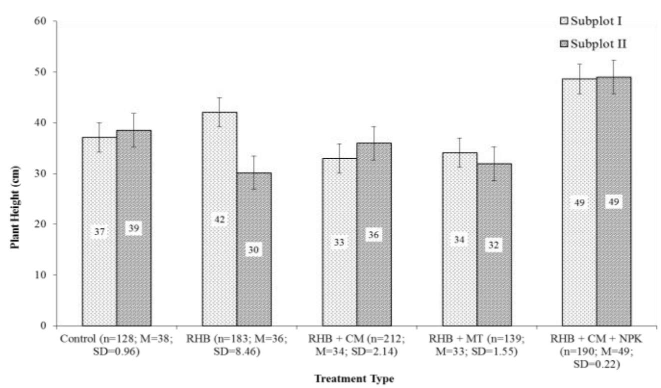
Root Mass (%) of Water Spinach by Treatment Type during the Destructive Sampling (1m²/Subplot)



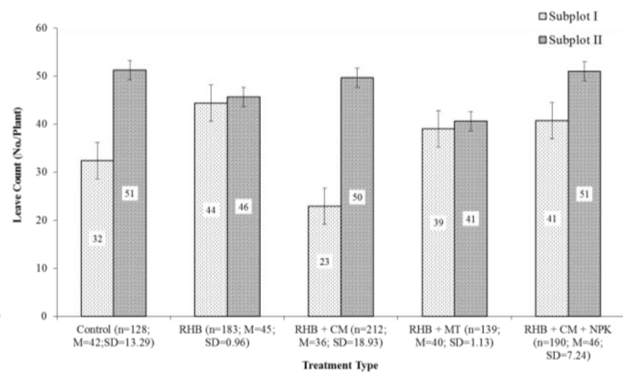
Root Depth (cm) of Water Spinach by Treatment Type during the Destructive Sampling (1m²/Subplot)



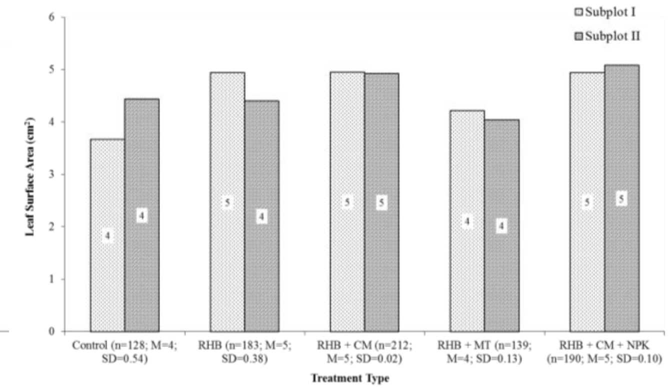
Plant Height (cm) of Water Spinach by Treatment Type during the Destructive Sampling (1m²/Subplot)



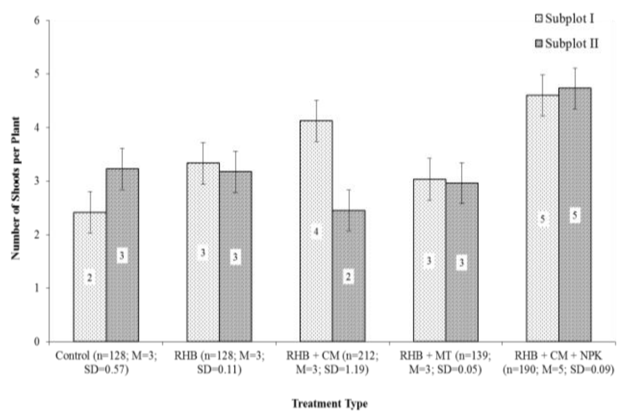
Leaf Count (No./Plant) of Water Spinach by Treatment Type during the Destructive Sampling (1m²/Subplot)



Leaf Surface Area (cm²) of Water Spinach by Treatment Type during the Destructive Sampling (1m²/Subplot)



Number of Shoots per Plant of Water Spinach by Treatment Type during Destructive Sampling (1m²/Subplot)



Leaf Coloration of Water Spinach by Treatment Type during the Destructive Sampling (1m²/Subplot)

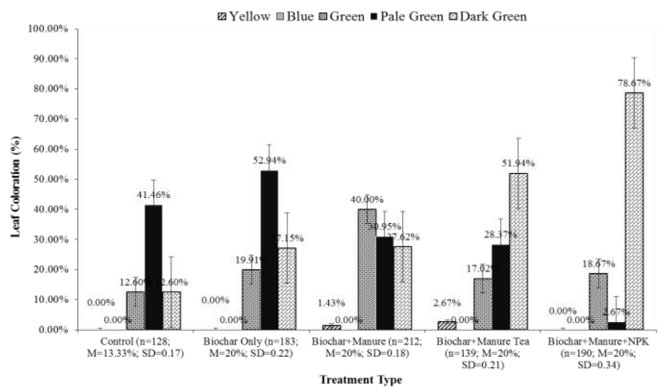


Table 18: Summaries of Yield of Water Spinach per Treatment Type

Descriptive Statistics

Groups	Sample size	Sum	Mean	Variance
Control	8	281.1	35.14	10,036.21
RHB + CM	8	274.	34.25	9,676.
RHB + CM + NPK	8	350.	43.75	15,396.
RHB + MT	8	288.	36.	10,662.
RHB Only	8	210.	26.25	5,992.
Total	40		35.08	65.26

Table 19: One-Way Analysis of Variance of Treatments' Means Yields of Water Spinach of the RCBD from Table 18

Source of Variation	df	SS	MS	Computed F	p-level	F Critical	Omega Sqr.
Between Groups	4	1,237.41	309.35	8.28**	0.0000826	2.64	0.42
Within Groups	35	1,307.56	37.36				
Total	39	2,544.97					
Hartley F max	5.74	Degrees Of Freedom	5	7			
Cochran C	0.37	Degrees Of Freedom	5	7			
Bartlett Chi-square	5.34	Degrees Of Freedom	4	p-level	0.25		

** *Statistically significant at the 0.05 confidence interval.*

Table 20 Fisher's Least Significant Difference between means and significance of pairwise comparison computed from the Analysis of Variance (RCBD) of Treatments and Replications on the Mean Yield of Water Spinach from Table 19.

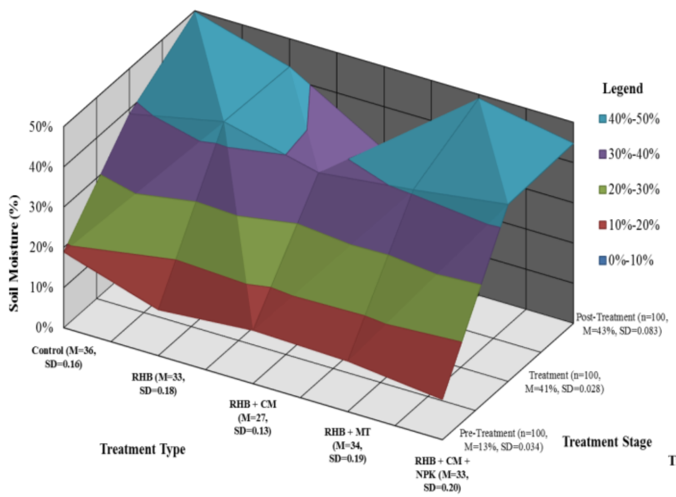
Group vs Group (Contrast)	Difference	Test Statistics	p-level	Accepted H_o?
Control vs RHB + CM	0.89	0.29	0.77	rejected
Control vs RHB + CM + NPK	-8.61	2.82	0.01	accepted
Control vs RHB + MT	-0.86	0.28	0.78	rejected
Control vs RHB Only	8.89	2.91	0.01	accepted
RHB + CM vs RHB + CM + NPK	-9.5	3.11	0.	accepted
RHB + CM vs RHB + MT	-1.75	0.57	0.57	rejected
RHB + CM vs RHB Only	8.	2.62	0.01	accepted
RHB + CM + NPK vs RHB + MT	7.75	2.54	0.02	accepted
RHB + CM + NPK vs RHB Only	17.5	5.73	0.	accepted
RHB + MT vs RHB Only	9.75	3.19	0.	accepted

Table 21: Estimating Total Yield of Water Spinach Based on the Destructive Samples and the Whole Plot Harvest

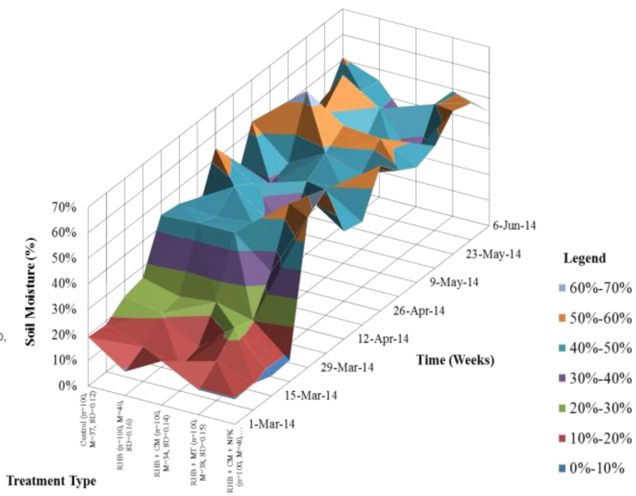
	Estimated Yield Based on Descriptive Sampling					**Yield Per Treatment and Replication**		**Predicted Yield (tons/ha)**	
Treatment Groups	Subplot I Mean Yield (kg/m^2)	Subplot II Mean Yield (kg/m^2)	Mean Yield (kg/m^2)	Cultivated Area (m^2)	Estimated Yield (kg/72m^2)	Whole Plot Harvest (kg/72m^2)	Differences (kg/72m^2)	Destructive Samples	Whole Plot Harvest
Control	2.63	2.19	2.41	72	173.59	281.10	107.51	26.58	43.04
RHB	4.02	2.63	3.32	72	239.18	210.00	29.18	36.62	32.15
RHB + CM	3.14	3.51	3.32	72	239.36	274.00	34.64	36.65	41.95
RHB + MT	4.28	2.31	3.29	72	236.88	288.00	51.12	36.27	44.09
RHB + CM + NPK	5.45	5.96	5.71	72	410.94	347.20	63.74	62.91	53.16
Grand Total	19.52	16.60	18.06	360.00	1299.96	1400.30	100.34	199.02	214.38

✧ Soil Water Availability

Daily Average Soil Moisture (%) Variations by Treatment Type and Treatment Stage (d=0-30cm; n=100)



Soil Moisture (%) Variations by Treatment Type and Monitoring Week March 31, 2014 to June 8, 2014 (d=0-30cm; n=100)



The Effects of Biochar-based Treatments on Dry Bulk Density per Treatment Stage and Sample Depth

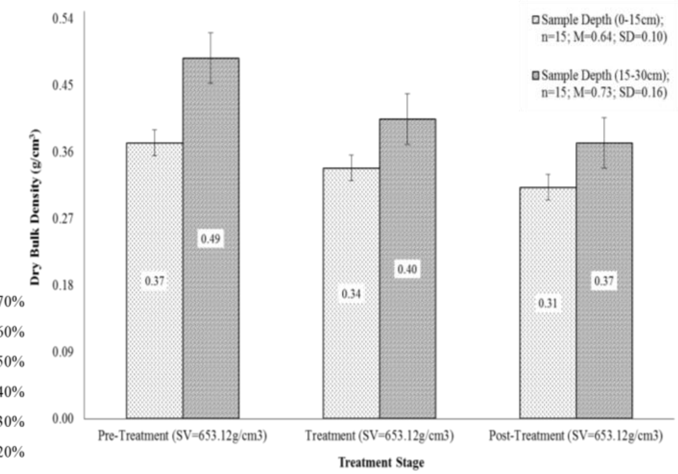


Table 24: Estimating Changes in Soil Water

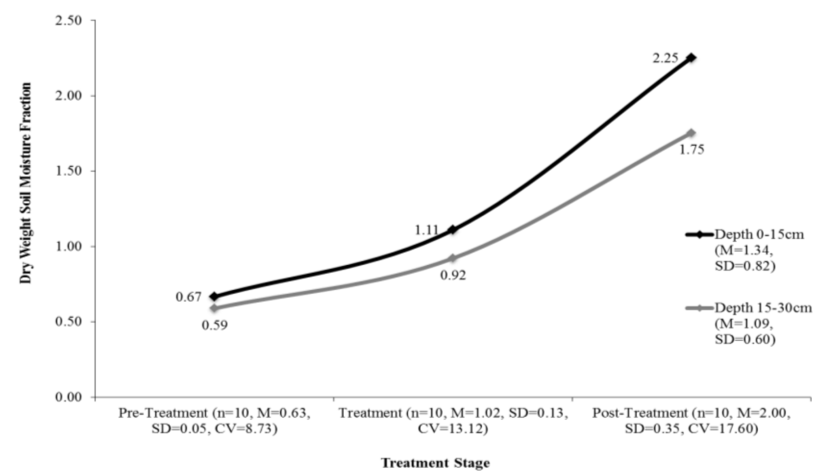
SW_C	=	$(P + I + G_E + M_1)$	-	$(ET_c + D_D + R_O + M_2)$	$G_E = 0$ $R_O = 0$
SW_C	=	$(P + I + M_1)$	-	$(ET + M_2)$	$D_D = 0$ $M_1 = 110$
SW_C	=	(418.16 mm + 340.03mm+110mm)	-	(633.41mm+62mm)	$M_2 = 63$ P = 418.16mm
SW_C	=	868.19mm	-	696.41mm	*I = 340.03mm
SW_C	=	171.78mm			ET_c = 633.41mm

*I denotes net irrigation, which includes the calculated difference between precipitation *(P)* and evapotranspiration *(ET_c)* and the adjusted daily irrigation applied, if the *ETc* exceeds precipitation and the daily available soil moisture storage was less than 50%, that is, below 55mm, which the maximum allowable deficit *(MAD)*. The soil water storage capacity *(SWSC)* denoted as (M_1) after a precipitation was 110mm and M_2 indicates the current soil water storage *(CSWS)*, which was estimated to be 63mm using the water

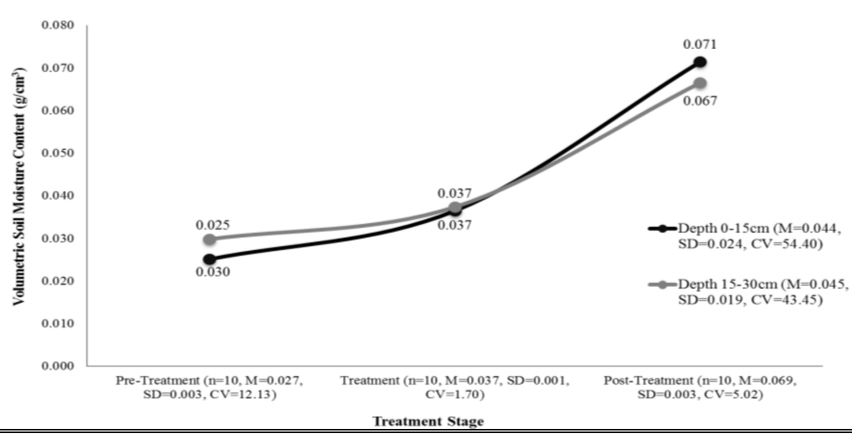
Table 25: Estimating Soil Water Surplus

SWs	=	P + I - ETc (ΔW1 - W2/Δt)	
SWs	=	418.16mm + 340.03mm - 633.41mm	X (110mm-62mm) / 70 (days)
SWs	=	124.78mm	0.686mm/day
SWs	=	$85.56mm^2$	

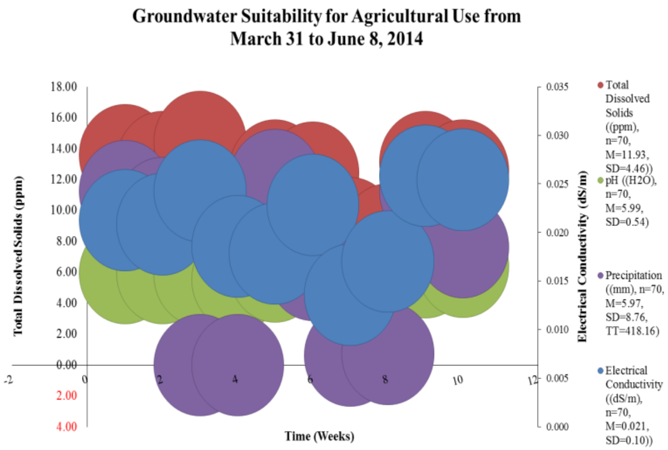
Dry Weight Soil Moisture Fraction at Bulk Density Sampling per Treatment Stage

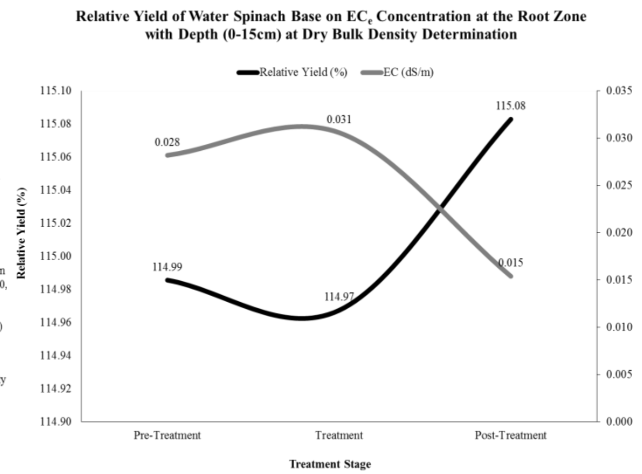


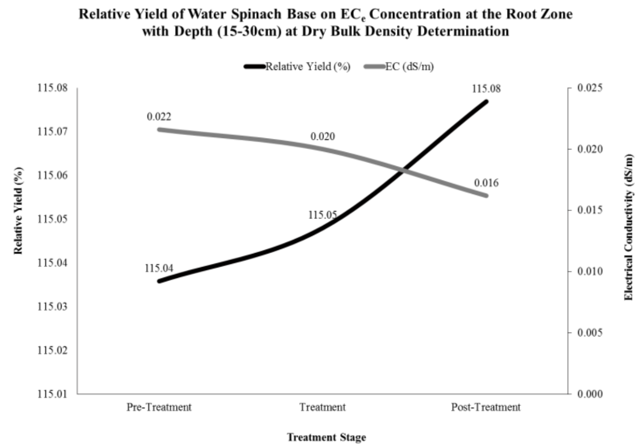
Volumetric Soil Moisture Content at Bulk Density Sampling per Treatment Stage

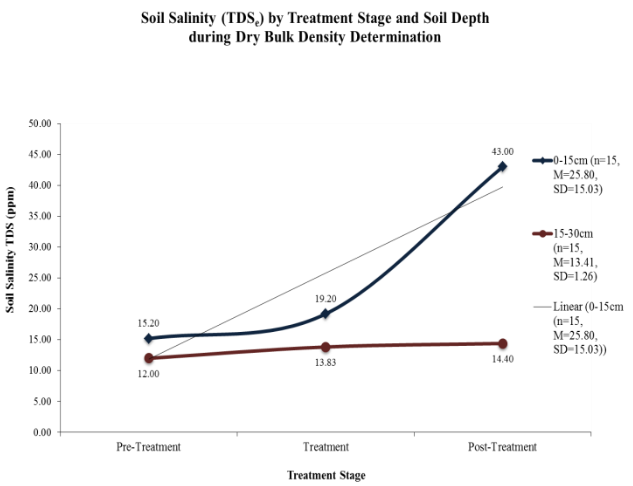


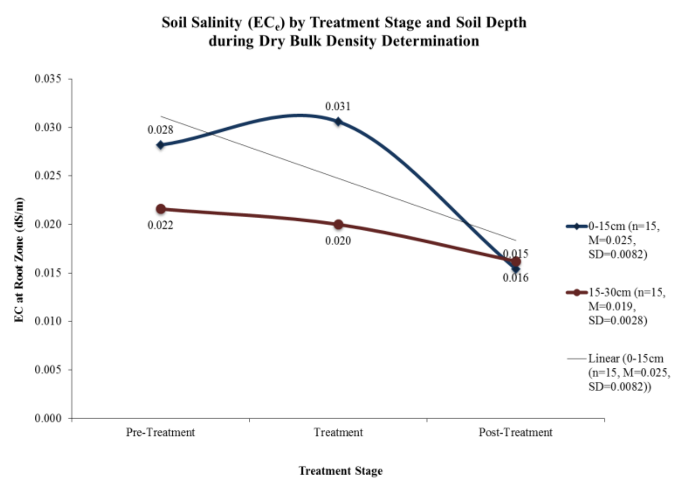
✧ Irrigation Groundwater Quality, Sprinklers' Spray Coverage & Climatic Factors

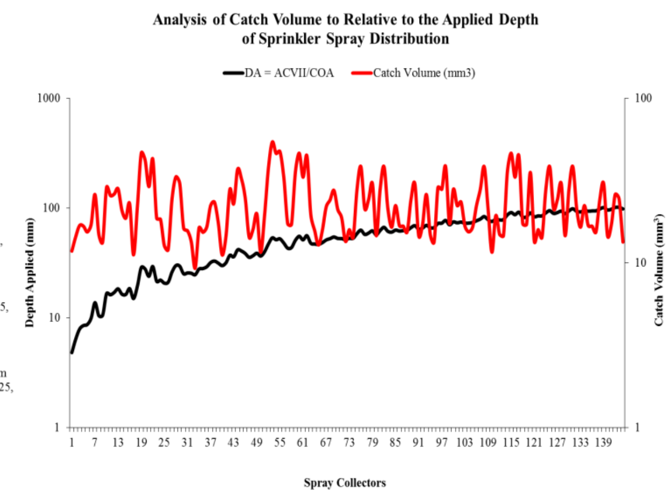








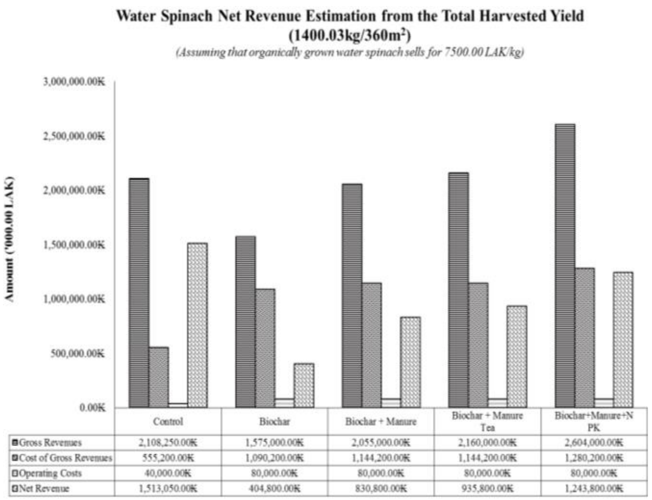


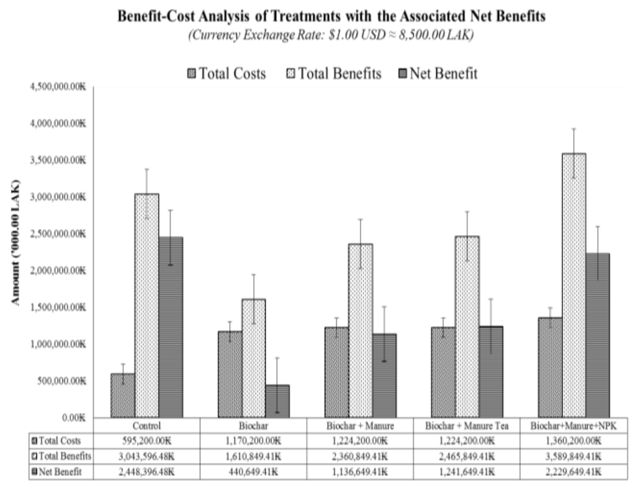


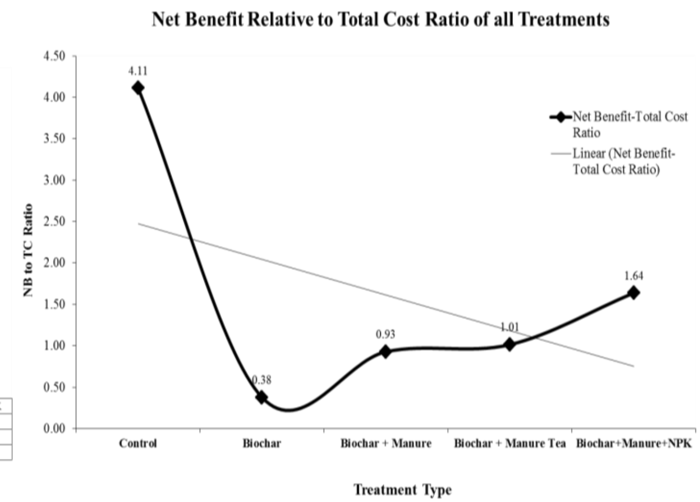
Parameters	Chemical Symbol	Lab Results (mg/L)	Atomic Weight (AW)	Valences (V)	(meq/L)	(ppm)	Sum of Cation (meq/L)	Mean H_2O_{pH}	SAR_{IW}	EC_{IW} (dS/m)	TDS (ppm)
Calcium	Ca	12.40	40.01	2	0.620	12.40	**0.515**	**5.99**	**0.174**^{ns}	**0.021**^{ns}	**12**
Magnesium	Mg	2.95	24.31	2	0.243	2.95	***TH-$_{Values}$***		**<10**	**<1.3**	**175**
Sodium	Na	7.41	22.99	1	0.322	7.41					
Potassium	K	4.10	39.10	1	0.105	4.10					
Bicarbonate	HCO_3^{2-}	7.40	61.02	1	0.121	7.40					
Sulphate	SO_4	45.70	96.06	2	0.951	45.70					
Chloride	Cl	1.77	35.45	1	0.050	1.77					
Nitrate Nitrogen	NO_3.N	0.18	76.01	24	0.058	0.18					
Ammonium Nitrogen	NH_4.N	0.21	32.00	8	0.054	0.21					
Ortho-Phosphate	PO_4.P	0.24	126.00	3	0.006	0.24					

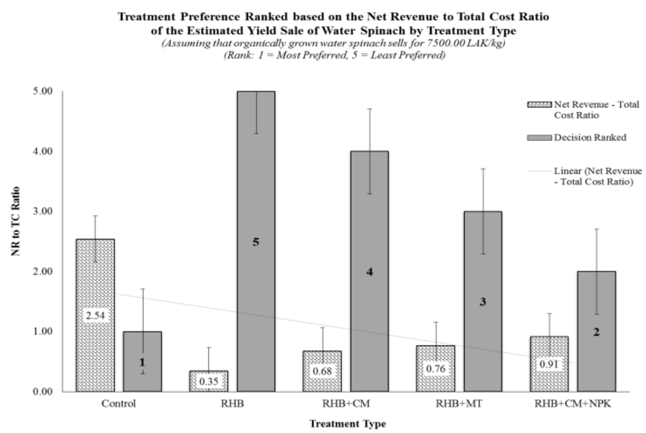
ns *= no significant impact on the relative potential yield.* ***TH-$_{Values}$*** *= recommended threshold values.* ***EC_{IW}*** *= EC concentration in groundwater used for irrigation.* ***SAR_{IW}*** *= derived from the concentration of sodium, calcium, and magnesium.*

✧ Inputs and Outputs Evaluations of Treatments









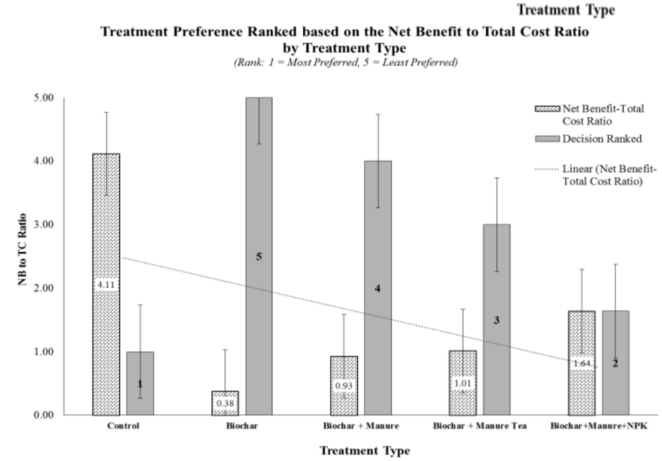


Table 23: Costs-Benefits Evaluation Matrix

Treatment	Time (dy)	R. Bio. (kg)	Biochar (kg)	NPK (kg)	Manure (LAK/bg)	Land Plow (LAK)	RB Prep (LAK)	Irrig. Sys. (LAK)	Seeds (LAK/kg)	F. Sec. (LAK)	NPK (LAK/kg)	F. Tools (LAK)	F. Trans (LAK/T)	F. Com (LAK)	Elect (LAK/kWh/dy)	Soc. Cost (LAK)	Pyro Sys (LAK)	Lunch (LAK)	Labor (LAK/dy)
	General Attributes										**Cost Attributes**								
Control	3	500	325	0	0	25,000	30,000	250,000	32,000	125,000	0	30,000	25,000	15,000	23,200	0	0	30,000	10,000
RHB	7	3000	488	0	0	25,000	30,000	250,000	32,000	125,000	0	70,000	25,000	15,000	23,200	247,500	247,500	70,000	10,000
RHB + CM	7	108	488	0	54,000	25,000	30,000	250,000	32,000	125,000	0	70,000	25,000	15,000	23,200	247,500	247,500	70,000	10,000
RHB + MT	7	108	488	0	54,000	25,000	30,000	250,000	32,000	125,000	0	70,000	25,000	15,000	23,200	247,500	247,500	70,000	10,000
RHB + CM + NPK	7	108	488	17	54,000	25,000	30,000	250,000	32,000	125,000	136,000	70,000	25,000	15,000	23,200	247,500	247,500	70,000	10,000
Total	31	3824	2275	17	162,000	125,000	150,000	1,250,000	160,000	625,000	136,000	310,000	125,000	75,000	116,000	990,000	990,000	310,000	50,000

RS (LAK/bg)	L. Acq. Sav. (LAK)	H. Sav. (LAK)	Seeds P. Sav. (LAK)	RH (LAK/t)	B. App Sav. (LAK)	Stored C. (C/tRHB)	CO_2 Price (LAK/tCO_2)	Pyro Sav. (LAK/3y)	Soil Fert. Savings (LAK/3y)	N. Revenue (LAK)	Soc. Benefits (LAK)	H_2O Savings (LAK)	T. Costs (LAK)	T. Benefits (LAK)	N. Benefit (LAK)	NB/IC Ratio	Cum Initial Costs (LAK)	Ranked NB-TC Ratio	Ratio NR /TC	Ranked NR-TC
					Benefits Attributes								**Totals**			**Decision Variables & Ranks**				
175,000	125,000	75,000	15,000	8,750	25,000	0.079	12,021	0	525,000	1,513,050	562,021	7,755	595,200	3,043,597	2,448,397	4.11	595,200	1	2.54	1
0	125,000	75,000	15,000	26,250	25,000	0.040	3,005	742,500	78,750	404,800	106,755	8,789	1,170,200	1,610,849	440,649	0.38	1,765,400	5	0.35	5
0	125,000	75,000	15,000	26,250	25,000	0.040	3,005	742,500	240,750	830,800	268,755	8,789	1,224,200	2,360,849	1,136,649	0.93	2,989,600	4	0.68	4
0	125,000	75,000	15,000	26,250	25,000	0.040	3,005	742,500	240,750	935,800	268,755	8,789	1,224,200	2,465,849	1,241,649	1.01	4,213,800	3	0.76	3
0	125,000	75,000	15,000	26,250	25,000	0.040	3,005	742,500	648,750	1,243,800	676,755	8,789	1,360,200	3,589,849	2,229,649	1.64	5,574,000	2	0.91	2
175,000	625,000	375,000	75,000	113,750	125,000	0.238	24,041	2,970,000	1,734,000	4,928,250	1,758,042	42,911	5,574,000	13,070,994	7,496,994	8.07			5.25	

✧ Main Findings

Soil Physical, Chemical Properties & Soil Water Availability

- Increased the SQI from moderate soil (21) to good soil (>34).
- Significant increase in earthworms presence in the treatment (40) and post-treatment (>48) stages.
- Decreased dry bulk density relative to soil depth.
- Significantly increased and stabilized soil pH.
- Statistically significant difference F (3.72) > F critical (3.48) of soil Phosphorous (P_2O_5).
- Increases in soil Nitrogen (N), Potassium (K_2O), soil organic matter (SOM), and cations exchange capacity (CEC) were not statistically significant among the treatment groups.
- Significantly increase the soil biochemical processes.
- Pre-treatment mean soil moisture (<10%), Treatment (>30%), and Post-Treatment (>50%).
- The pre-treatment SM show significant lower dry soil moisture fraction (M=0.63, SD=0.05) compared with the treatment (M=1.02, SD=13), and post-treatment (M=2.00, SD=0.35).
- Significant increase in the volumetric soil moisture content of the immediate topsoil (0-15cm) = 0.071g/cm^3 relative to the subsoil (15-30cm) = 0.061g/cm^3, which suggest significant moisture retention at the root zone.

Growth & Yield of Water Spinach

- Biochar inoculated with cattle manure plus NPK (RHB+CM+NPK) show significant increases in all growth parameters.
- Variances in plots sampled to determine crop growth were observed.
- RHB+CM+NPK significantly increased the root mass (55%) of water spinach.
- Root depth decreased with increasing root mass.
- RHB+CM+NPK show increased mean plant height (49cm).
- Biochar only, biochar inoculated with cattle manure and RHB+CM+NPK had increased mean leaf surface area of 5cm^2.
- There was statistically significant difference among treatments groups relative to mean yields of water spinach with the computed F (8.28) > F critical (2.64) at the 0.05 level of significance.

Groundwater Quality, Water Balance Estimation & Irrigation

- The evidence demonstrates that the level of EC (0.21dS/m) was significantly lower than the recommended salinity threshold value 1.3dS/m would have triggered a saline soil condition.
- The calculated sodium absorption ratio (SAR) was 0.174) was less than the recommended level (10).
- Electrical conductivity at the root zone decrease with soil depth of 0-15cm (n=15, M=0.025, SD=0.0082) and 15-30cm (n=15, M=0.019, SD=0.028).
- Total Dissolved Solid increase at the topsoil layer with depth of 0-15cm (n=15, M=25.80, SD=15.03) and remain steadily constant in the subsoil layer with depth of 15-30cm (n=15, M=13.41, SD=1.26).
- The computed soil water change of the experimental units was 171.78mm, soil water surplus was calculated at 85.56mm^2, while the total available water 42mm of water per mm of soil.
- Irrigation sprinkler spray was relatively uniform with mean wind speed (4mph).

Cost-Benefits Evaluations of Treatments

- Overall, RHB+CM+NPK produced the highest total yield 347.20kg of water spinach at the total cost of 1,360,200.00 LAK and total benefits of 3,589,849.00 LAK.
- However, the evidence of the net benefit (NB) to total cost (TC) ratio demonstrates that the control (4.11), RHB+CM+NPK (1.64), RHB+MT (1.01), and RHB+CM (0.93) are the optimal treatment choices that would significantly impact productivity and the livelihoods.
- Biochar applied only have no significant impact on productivity and farmers' livelihoods and produced the lowest NB-TC ratio (0.38).

✧ Recommendations

- Groundwater quality assessment for agricultural use should be integrative and locally accessible to smallholders.
- Irrigation infrastructures should resonate with the needs and resources of smallholders' irrigators to foster maintenance and sustainability.
- Local, regional or provincial, state, and non-state actors should invest in smallholder irrigation infrastructures to enhance sustainable groundwater usability and efficiency.
- Sustainable groundwater irrigation for agricultural use should be equipped with monitoring stations to determine water quality for early detection of potential pollutants and their sources.
- Smallholders should be engaged in policy formulations for sustainable groundwater irrigation to promote ownership and systems sustainability.
- Agricultural extension services should be sensitive to local irrigation regimes, education, training, and the provision of resources to smallholders.
- Smallholders are willing to adapt to new irrigation infrastructures, but fear of failure due to financial insecurity should they attempt to change their current agricultural irrigation systems to more efficient alternatives.

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Acknowledgements/Special Thanks: Thanks to Purdue University, IWMI, WRED, Clark University, and those who contributed directly or indirectly to the success of this project. Special thanks to my family.