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Jatropha-based alley cropping system's contribution to carbon sequestration

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Key words: Alley cropping, Agroforestry, Carbon sequestration, *Jatropha curcas,* hedgerow.

Abstract

The study was conducted to evaluate the total carbon stocks sequestered in a Jatropha – based alley cropping system treated with varying fertilizer applications. The study was laid out in Randomized Complete Block Design with three replications. The alley was planted with corn in two seasons Treatments include control (no fertilizer), organic fertilizer and inorganic fertilizer applied to the alley crops. Findings showed that the treatments with fertilizer applications had higher carbon stock in the jatropha hedges. The carbon content of the corn stover was also higher in organic and inorganic fertilizer-applied treatments. However, highest soil carbon content was shown in treatments applied with organic fertilizer (4.28 Ton ha^{-1}). The inorganic fertilizer treatment had the lowest soil carbon content with a mean of 4.28 Ton ha^{-1}. In terms of total carbon stock of the entire jatropha-based alley cropping system, there was a significant difference among treatments with organic fertilizer application having the highest mean of 7.79 Ton ha^{-1} while the inorganic treated plots had 6.53 Ton ha^{-1}. The no fertilizer treatment had the least carbon stocks with 6.53 Ton ha^{-1}. This recent study revealed that the jatropha-based alley cropping system is a potential land-use for carbon sequestration. This farming system needs to be promoted in upland areas to function not only as soil and water conservation measures but also as a possible remedy for global warming.

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Introduction

One of the approaches recognized as a suitable farming technology for upland areas is agroforestry (Lasco and Visco, 2003). This technology was believed to play a major role in halting and even reversing the decline in agricultural production (Chivenge, 2006). Agroforestry has also an important role in providing livelihood and restoring the watershed and environmental functions of the uplands (PCARRD, 2006).

The alley cropping system of agroforestry is commonly adopted in sloping lands (Palada *et al.* as cited by Matta-Machado *et al.*, 1995). This involves planting of hedgerows along the contours and growing agricultural crops in the alleys formed between the hedgerows (Lasco and Visco, 2003). Hedgerow plants can be trees or other plants that have multiple uses, which can provide a range of benefits to farmers, and have the capacity to retard soil loss.

Jatropha curcas (Physic Nut or Jatropha) plant, having been recognized as a possible alternative source of biodiesel, has been grown all throughout the world. The Philippine government is becoming interested on the massive production of this plant as a potential solution to the current petroleum crises. The areas identified for jatropha plantation in the Philippines are marginal sites or other sites not used for prime agricultural crop production. These areas are usually located in sloping lands or in moderately rugged terrains. The said areas are in most cases also very suitable for agroforestry practices like alley cropping. In fact, there are already existing alley cropping systems in the Philippines using *J. curcas* as hedgerows.

Land uses such as an agroforestry system have a significant role in moderating climate change since they can be sources and sinks of carbon (Lasco *et al.*, 2001). The potential to sequester C in agroforestry systems in tropical and temperate regions is promising, but little information is available to date (Oelbermann *et al.*, 2004).

This study that investigated the extent of carbon sequestration of jatropha-based alley cropping system, therefore, is of interest. This attempted to quantify the contribution of jatropha-based alley farming system in mitigating climate change by determining its extent in carbon sequestration.

Materials and methods

Location and Description of the Study Site

The study was conducted at the 2-year old Jatropha based alley cropping system of Central Mindanao University, Musuan, Bukidnon (Fig. 1). The average elevation of the site is 430 m asl and the slope gradient ranges from 25 to 30 %.

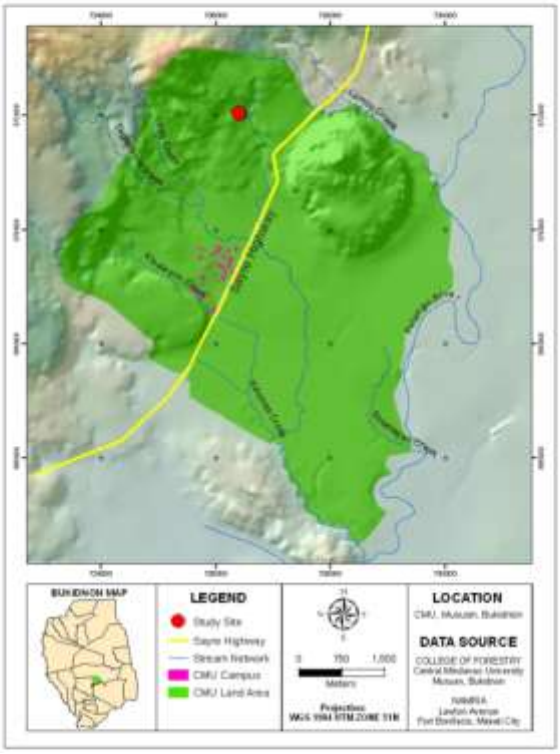

Fig. 1. The study site.

Experimental Design and Lay-out

The study was conducted for two croppings. It was laid-out in Randomized Complete Block Design (RCBD) replicated three times (Appendix 1). The following treatments were as follows:

Treatment 1 Control (No Fertilizer)
Treatment 2 Organic Fertilizer
Treatment 3 Inorganic Fertilizer

Plot length per treatment was sixteen meters (16 m) with half a meter buffer at the edge of the alley and one (1) meter buffer per treatment. Distance between rows of the alley was 0.67m. X-Tekh Bio-fertilizer was used in this study as the biofertilizer treatment. Application was done using a knapsack sprayer and the prescription was based on the standard recommendation or protocol of the company. The application protocols were as follows (XTekh Flier, nd):

10 – 15 DAP : 35 ml or 50 ml X-Tekh Micro/ 16L water
25 – 30 DAP : 70 ml or 50 ml X-Tekh Micro/ 16L water
35 – 45 DAP : 100 ml X-Tekh Micro/ 16L water. Add 100 ml X-Tekh Potassium/16 liter

Two 2 bags of fertilizer (complete)/hectare were applied per hectare apart from the liquid X-tekh bio-fertilizer.

Inorganic fertilizers applied were based on the recommendations from the analysis of the soil samples by the Soils and Plant Analysis Laboratory of the CMU - College of Agriculture.

Cultural Treatments

Weeding was done in the experimental area as the need arises. Prior to the cropping period, hedgerows were pruned at a distance of 50 cms from the ground and the pruning were scattered uniformly on the alley to serve as mulch.

Data collection

Hedgerow (*Jatropha curcas*):

Destructive sampling was done to assess the carbon stocks of the hedgerow plants. Samples of *J. curcas* hedgerow were harvested in each treatment. Harvested samples were weighed using a scale and biomass values were determined using the formula (Pulhin, 2009):

$$ODWt = TWF - \{TWF * (SWF - SODW)\}/SWF$$

Where: *ODW* = Total oven dry weight
TFW = total Fresh weight
SFW = Sample Fresh weight
SODW = Sample oven-dry weight

The below ground biomass (roots) was determined using the formula (Pulhin, 2009):

Root Biomass = Exp [-1.0587 + 0.8836 ×LN(AGB)]

Where: Exp = e to the of
LN = natural log
AGB = Above Ground Biomass

Carbon estimates were determined using the formula (Pulhin, 2009):

Carbon in tree biomass = Biomass × % Carbon in Tree

Alley crop (Maize)

Within the 16 meter length per treatment, four 1 x 1 meter square quadrat were established. All stover of mature (harvestable) age within the quadrats were taken for biomass determination. The formula in determining the biomass and carbon stocks for the alley crop were the same with the method used in the hedgerow.

Soil Organic Carbon

Within the established quadrats, soil samples were collected for soil carbon determination. Soil samples were obtained within the 0-30 cm depth. The soil samples were brought to the CMU College of Agriculture Soil and Plant Analysis and Laboratory (SPAL) for soil organic matter and bulk density determination. Soil samples were collected thrice for determination of carbon sequestration in each treatment. One was done before the start of the first cropping, another before the start of the second cropping and the third collection was before the harvest of the second cropping.

After the soil organic matter was obtained, the soil organic carbon (SOC) was computed using the formula below (De La Cruz, undated):

$$\%\,\boldsymbol{SOC} = \%\,\boldsymbol{Organic\ Matter}/\boldsymbol{1.724}$$

In order to express the amount of SOC from percent to *tons C/ha*, the following formula were used (De La Cruz, undated):

- Weight of soil/ha = 10,000m² × 0.30 m × bulk density ,
- Ton C in soil/ha = % SOC × wt of soil in kg/ha × 1 ton/1000kg .

Total Carbon Sequestration:

The total carbon sequestration per treatment of the Jatropha based alleycropping system was determined using the formula:

Total carbon = hedgerow + alley crop + soil

Data Analysis

The test of significant difference among treatments was determined using the Analysis of Variance (ANOVA). Least significant difference and Tukey's, on the other hand, were used in comparing treatment means. The Statistical Package for the Social Sciences (SPSS) version 16 was used in the data analyses.

Results and discussion

Table 1 presents the biomass of the *Jatropha curcas* hedgerow during the first and second cropping of the said agroforestry system. Statistical analyses show no significant difference among fertilizer treatments in all the parameters measured both for the upper and lower hedges.

Table 1. Hedge Biomass of the Jatropha based Alley cropping system.

Fertilizer Treatments	First Cropping (Ton Ha $^{-1}$)			Second Cropping (Ton Ha $^{-1}$)			Biomass gain (Ton Ha^{-1})		
	AGB	BGB	TGB	AGB	BGB	TGB	AGB	BGB	TGB
	Upper Hedge								
Control (F1)	2.37	0.74	3.11	2.49	0.78	3.27	0.13	0.03	0.16
Organic Fertilizer (F2)	2.72	0.84	3.56	2.88	0.88	3.76	0.16	0.05	0.20
Inorganic Fertilizer (F3)	2.58	0.80	3.38	2.74	0.84	3.58	0.15	0.05	0.20
Level of Significance	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)	24.01	21.46	23.39	24.24	23.62	23.62	30.03	0.0	29.16
	Lower Hedge								
Control (F1)	2.76	0.85	3.61	2.90	0.89	3.79	0.13	0.037	0.173
Organic Fertilizer (F2)	2.81	0.86	3.67	2.95	0.90	3.85	0.14	0.040	0.177
Inorganic Fertilizer (F3)	3.04	0.93	3.97	3.19	0.97	4.16	0.15	0.043	0.197
Level of Significance	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)	9.67	8.03	9.31	9.68	8.44	9.41	0.0	10.19%	0.0

Legend:

AGB: Above Ground Biomass

BGB: Below Ground Biomass

TGB: Total Ground Biomass

In the upper hedge, the biomass of the organic fertilizer treatments had the highest values both for the first and the second cropping. Total above ground biomass of organic fertilizer treatment were 3.56 Ton Ha^{-1} and 3.76 Ton Ha^{-1} for the first and second cropping, respectively. The no fertilizer treatment had the lowest with 3.11 Ton Ha^{-1} for the first cropping and 3.27 Ton Ha^{-1} in the second cropping. In terms of total biomass gain, both organic and inorganic fertilizer treatments had 0.20 Ton Ha^{-1} while the no fertilizer treatment had only 0.16 Ton Ha^{-1}. The data show that hedges where alley plots were applied with fertilizers (organic and inorganic) are bigger in sizes compared with hedges where alley plots have no application with fertilizers. Hedgerows in this study were not applied with fertilizer. The nutrients received basically by the hedge plants came from what were available in the soil and from those that were leached out from the alley plots. It was further believed that the nutrients leached out from the alley plots were partly trapped by the hedges and were used up by *J. curcas* for its growth and development. Hedgerow system can improve the capture and cycling of nutrients (Wojtkowski, 2002). Nutrient loss can be associated with soil erosion occurring in the area. This is supported by Nelson *et al.* (1998a) who pointed out that erosion differentially moves the finer, most fertile soil fractions of the top soil.

The lower hedge shows that the biomass was found highest in the inorganic fertilizer treatment. Data show that the total biomass of the inorganic fertilizer treatment was 3.97 Ton Ha^{-1} in the first cropping and 4.16 Ton Ha^{-1} in the second cropping. The treatment with the least biomass was the no fertilizer with only 3.61 Ton Ha^{-1} and 3.79 Ton Ha^{-1} for the first and second cropping, respectively. For the biomass gain at the lower hedge, the inorganic fertilizer treatment had the highest with 0.197 Ton Ha^{-1} and is closely followed by organic fertilizer treatment with 0.177 Ton Ha^{-1}. The least among the treatments was the no fertilizer treatment with only 0.173 Ton Ha^{-1}. *J. curcas* in F3 and F2 plots were bigger than F1 which had the shortest hedgerow plants among the treatments. The relatively bigger sizes of F2 and F3 hedges can be attributed to the fertilizer applied in the alley crops. It is again presumed that some of the fertilizer applied to the alley crops also benefited the hedgerow plants.

The hedge carbon of the jatropha-based alley cropping system showed no significant difference in all parameters among the fertilizer treatments (Table 2). Same as with biomass, the organic fertilizer treatments had the greatest total carbon in the upper hedge with 1.60 Ton Ha^{-1} and 1.69 Ton Ha^{-1} for the first and second cropping, respectively. The no fertilizer treatment had the lowest with only 1.4 Ton Ha^{-1} in the first cropping and 1.47 Ton Ha^{-1} during the second cropping. On the other hand, the carbon gain between the first and second cropping shows that both organic and inorganic fertilizer treatments had 0.09 Ton Ha^{-1} as against no fertilizer treatment with only 0.07 Ton Ha^{-1}. The higher sizes of the F2 and F3 hedges which resulted to higher biomass is basically the reason why carbon stocks were high in these treatments. Tandug *et al.* (2010) stressed that diameter and total height of trees are important variables to biomass gain. Biomass is directly proportional to the amount of carbon stored in plants.

Table 2. Hedge Carbon of the Jatropha-Based Alley cropping system.

Fertilizer Treatments	First Cropping (Ton Ha^{-1})			Second Cropping (Ton Ha^{-1})			Carbon Gain (Ton Ha^{-1})		
	AGC	BGC	TGC	AGC	BGC	TGC	AGC	BGC	TGC
	Upper Hedge								
Control	1.06	0.33	1.40	1.12	0.35	1.47	0.06	0.017	0.07
Organic Fertilizer	1.22	0.38	1.60	1.30	0.40	1.69	0.07	0.017	0.09
Inorganic Fertilizer	1.16	0.36	1.52	1.23	0.38	1.61	0.07	0.020	0.09
Level of Significance	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)	24.0	21.58	23.54	24.22	22.21	23.60	0.0	29.62	37.46
	Lower Hedge								
Control (F1)	1.24	0.38	1.62	1.31	0.40	1.71	0.063	0.02	0.077
Organic Fertilizer (F2)	1.27	0.39	1.65	1.33	0.41	1.73	0.063	0.02	0.080
Inorganic Fertilizer (F3)	1.37	0.42	1.79	1.43	0.43	1.87	0.070	0.02	0.087
Level of Significance	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)	9.48	7.98	9.55	9.90	7.65	9.28	13.46	0.0	11.98

Legend:
AGC: Above Ground Carbon
BGC: Below Ground Carbon
TGC: Total Ground Carbon

In the lower hedge, inorganic fertilizer treatment had the highest total carbon for both first and second cropping with 1.79 Ton Ha^{-1} and 1.87 Ton Ha^{-1}, respectively. The least among the treatment in total carbon was the no fertilizer treatments with 1.61 Ton Ha^{-1} in the first cropping and 1.71 Ton Ha^{-1} during the second cropping. In terms of carbon gain at the lower hedge, inorganic fertilizer treatment was highest with 0.087 Ton Ha^{-1} and was followed by organic fertilizer with 0.080 Ton Ha^{-1} while the no fertilizer treatment was lowest with 0.077 Ton Ha^{-1}.

Significant difference was shown in the carbon content of the stover in the first cropping and there is high significant in the second cropping (Table 3). Data showed that organic fertilizer had the highest amount of carbon stored with 0.11 Ton Ha^{-1} and 0.08 Ton Ha^{-1} in the first and second cropping, respectively. However, its difference from inorganic fertilizer is not significant. The no fertilizer treatment had the lowest carbon stock for both first and second cropping with 0.07 Ton Ha^{-1} and 0.03 Ton Ha^{-1}, respectively. No fertilizer treatment is significantly different to both organic and inorganic fertilizer treatment in the first cropping and highly significant in the second cropping. This recent findings is parallel to the investigation made by Allmaras *et al.* (2004) that nitrogen fertilization increased stover C by 20%.

Table 3. Carbon stock in the corn stover of the jatropha-based alley cropping system.

Treatments	First Cropping	Second Cropping
No Fertilizer	0.07[b]	0.03[b]
Organic Fertilizer	0.11[a]	0.08[a]
Inorganic Fertilizer	0.09[a]	0.09[a]
Level of Significance	*	**
CV (%)	10.14	11.52

Means followed by the same letter in a column are not significantly different at 5%.

Carbon content in plants can be associated with its biomass production. The greater the biomass, the higher will be its carbon content. In this study, those treatments applied with fertilizers have greater biomass content and carbon storage. Nutrients provided by F2 and F3 treatments attributed to the result of this study. F2 received commercial inorganic fertilizer supplemented with X-Tekh biofertilizer while F3 was applied with ammonium phosphate and urea. Degree of application of X-Tekh for F2 was based on the recommendation of the company, while, that for F3 was according to the suggestion made after soil analysis of the study site. This is consistent with the findings of Tisdale *et al.* (1990) where an adequate supply of nitrogen was found to be associated with vigorous vegetative growth and a dark green color of the plant. On the other hand, a good supply of phosphorus has been associated historically with increased root growth. The study of Ohlrogee and associates (no date) as cited by Tisdale *et al.* (1990) revealed that when soluble phosphate and ammonium nitrogen are supplied together in a band, plant roots will proliferate extensively in the area of the treated soil. Good root system leads to better uptake of nutrients desired by the crop for growth and development.

In the soil carbon of the jatropha based alley cropping system, no significant difference was shown among treatments before the study was conducted. However, after the first cropping, significant difference was shown. Furthermore, high significant was shown among treatments after the second cropping (Table 4). Among the treatments, organic fertilizer had the highest carbon content both after the first and second cropping with 4.91 Ton Ha^{-1} and 4.28 Ton Ha^{-1}, respectively. The no fertilizer treatment was the second highest with 3.12 after the first cropping and 2.98 after the second cropping. However, its difference from inorganic fertilizer, which had the lowest, is not significant. The information reported by Triberti *et al* (2008) has shown parallel findings with this recent study where from 1972 to 2000 in the Southeast Po valley (Italy), Soil Organic Carbon (SOC) stock increased at mean rates of 0.16, 0.18, and 0.26 t ha^{-1} $year^{-1}$ with the incorporation of residues, slurry and manure, corresponding to sequestration efficiencies of 3.7, 3.8 and 8.1% of added C with these various materials. The authors added that manure, thus, confirmed its efficacy in increasing both SOC content and soil fertility on the long-term.

Table 4. Soil Carbon of the jatropha-based alley cropping system.

Treatments	Before first cropping	Before Second Cropping	After second cropping
No Fertilizer	3.75	3.12b	2.98b
Organic Fertilizer	3.52	4.91a	4.28a
Inorganic Fertilizer	2.38	3.05b	2.96b
Level of Significance	ns	*	**
CV (%)	24.22	36.36	7.31

Means followed by the same letter in a column are not significantly different at 5%.

Findings can be attributed to the organic fertilizer used in the study. Xtekh biofertilzer is a bio-fertilizer microorganism and potassium bio-fertilizer. It is a revolutionary high technology liquid fertilizer (organic based) consisting of organic and microbial elements. The composition of this fertilizer may have enhanced the increase of carbon content in the soil. Accordingly, some of the benefits that can be derived from X-tekh bio-fertilizer include: (a) improved root development and growth leading to increased nutrient uptake; (b) increase in crop yields; (c) increase in quality – color, taste and size of fruit; (d) increased resistance from pest and diseases; (e) aids uniform crop establishment; (f) restores the normal soil microflora; (g) improves soil structure for optimum water retention; (h) reduces fertilizer requirement; (i) reduces leaching problems, (j) is environment friendly; and, (k) easy to apply and handle (X-Tekh Flier, nd).

Table 5. presents the carbon stocks of the alley farming system in the first and second cropping. Findings show that the above ground carbon stocks did not show significant difference both for the two cropping period. Result, however, revealed that the below ground carbon stock show significant difference in the first cropping while highly significant difference was shown in the second cropping. Organic fertilizer treatments had the highest carbon stocks both in the first and second cropping. The inorganic and no fertilizer treatments, on the other hand, are not significantly different.

Table 5. Total carbon sequestered in the alley cropping system.

Treatments	First Cropping			Second Cropping		
	AGC	BGC	TC	AGC	BGC	TC
No Fertilizer	2.38	3.84[b]	6.22[b]	2.58	3.73[b]	6.31[b]
Organic Fertilizer	2.60	5.68[a]	8.27[a]	2.70	5.08[a]	7.79[a]
Inorganic Fertilizer	2.62	3.83[b]	6.45[b]	2.76	3.77[b]	6.53[b]
Level of Significance	ns	*	*	ns	**	*
CV (%)	10.14	12.08	10.86	10.48	6.17	6.87

Means followed by the same letter in a column are not significantly different at 5%.

Legend:

AGB: Above Ground Carbon

BGB: Below Ground Carbon

TC: Total Carbon

On total carbon stocks, significant difference were shown in the two cropping system. Organic fertilizer treatment had the highest carbon stock at 8.27 Ton Ha^{-1} and 7.79 Ton Ha^{-1} for the first and second cropping, respectively. No fertilizer treatment had the lowest with 6.22 in the first cropping while 6.31 in the second cropping. Its difference with the inorganic fertilizer, however, is not significant.

The high below ground carbon in the organic fertilizer treatment was attributed to its high carbon stock in the soil. The use of organic rich fertilizer such as X-

Tekh may have increased the carbon content of the soil. In fact, the use of organic fertilizer has been promoted in the recent times because it is believed to be environmentally friendly and is providing healthy products to the consumer. It has also several advantages such as: (1) promotion of soil aggregation, improvement of soil color, friability, and prevention of soil erosion; (2) increase water holding capacity in sandy soils; (3) supplies essential nutrients and materials or increases organic matter level; (4) increases soil cation exchange capacity; and, (5) improves biological activities and enhances the rapid multiplication of fungi, bacteria, actinomycetes and other soil organisms.

Yan and Gong (2010) reported that the use of organic fertilizer increased SOC and soil fertility and consequently resulted in a larger yield trend when compared to a balanced chemical fertilizer. Their model simulation and pot experimental results also indicated that soils with higher SOC had a higher root/shoot ratio such that the long-term use of organic fertilizer not only directly increases SOC, but indirectly contributes to carbon sequestration by favoring root development.

Conclusion

In summary, it can be concluded that jatropha based alley cropping system has the potential in sequestering carbon which is one of the causes of global warming. Findings show that a total of 6.45 to 6.53 ton ha-1 has been stock in the said farming system during the assessment. The alley crop (corn) had sequestered a range of 0.03 to 0.11 Ton ha-1 for the two croppings. Those crops which were fertilized had more carbon stocks than those those without fertilizer applications. The hedges aligned with those alley crops applied with fertilizers had higher carbon stocks than those hedges planted along with alley crops with no fertilizer application. It was also shown that the soil carbon content is enhanced by the application of organic fertilizers in the alley crop. Significant increase of carbon had been observed in soils where application of organic substances is employed.

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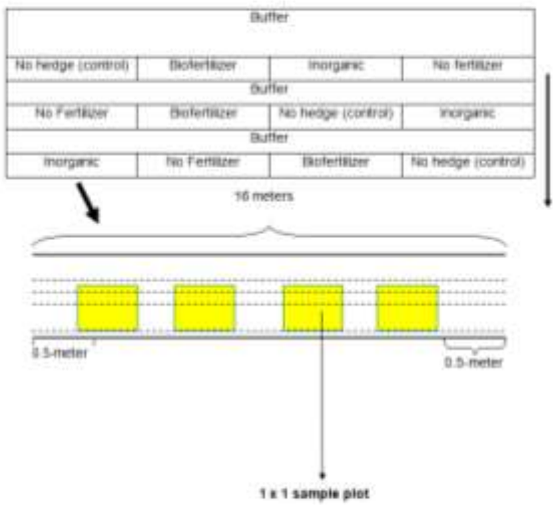
Appendix 1. Experimental lay-out of the main plot.



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