Comparative Assessment of Vegetable Crop Performances and Ecological Indicators during Transition from Conventional to Ecological Agriculture

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Authors’ contributions
This work was carried out in collaboration among all authors. Authors LHPG, KSH, HGASS, SBAW, THMUMT, WSPYU and JMS designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors WAPW and KWLKW managed the analyses of the study. Authors NKGKRM and YMKK managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT
Selected field vegetable crop combinations and increasing dosage of bio-char application, together with other alternative agronomic components of ecological agriculture (EA) were compared with conventional agriculture (CA) during the first three seasons of transition from CA to EA under hot-humid tropical conditions and sandy regasolic soils in Kalpitiya, Sri Lanka. The recommendations of the Department of Agriculture (Sri Lanka) was followed for managing conventional agriculture plots while alternative ecological options were followed for plant nutrient and pest managements.

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1. INTRODUCTION

Dense population in Sri Lanka and rest of the South Asia requires more food from limited lands. Gradual declining of arable lands due to natural as well as manmade disasters aggravates this situation. As a result, Kalpitiya formerly a coastal fisheries center belongs to agro-ecological region, IL1b of Sri Lanka, has been widely used for field vegetable and fruit cultivation during last 40 years, despite its highly sandy soils and very low annual rainfall [1]; Illeperuma [2]; Dharmagunawardena et al. [3]. As a measure to overcome the inherent low water holding capacity and Cation Exchange Capacity (CEC) (regarding plant nutrient retention) of Kalpitiya soils, farmers tend to apply over dosages of chemical fertilizers and excessive frequency of irrigation regimes, leading to nitrate pollution in groundwater, residual effects on food chains and ultimately causing adverse effects on food and health. Hence sustainability of such agricultural system has become always questionable.

Sri Lanka consists of 6.55 million ha of land area where only about 50% is arable due to unsuitable terrain, inland water bodies and forest reservations. In 1870 when the population was 2.7 million, the per capita land area was 2.7 ha. Based on the 2012 estimated population of 20 million, the per capita availability of arable land reduced to about 0.15 ha, indicating heavy pressure on agricultural lands [4]. So farm lands have shrunk in parallel to that and commercial areas have become vital.

Kalpitiya peninsula belongs to northwestern coast of Sri Lanka and it is one of the highly productive unconfined aquifers, and it is characterized by its shallow nature and sandy aquifer media derived from marine origin during the Quaternary age. Most of the lands of the Kalpitiya area are agricultural lands mainly in western and middle part of the peninsula.

Cultivations are carried out on fine- to coarse-textured sandy soil. Due to excess use of agro chemicals and fertilizers, nitrate concentrations of groundwater of the area were measured during the last decade [5,6], and it was revealed that the groundwater was highly vulnerable to nitrate contaminations. However, the farm lands of the area are being expanded and heavily cultivated during last two decades. Hence, the groundwater of the coastal sandy aquifers may have also been contaminated simultaneously. So government has taken several actions but even after taking several attempts it failed. So it is better to introduce eco friendly concept as a new solution.

Sustainable cropping systems are capable of maintaining their productivity and usefulness to society indefinitely by resource conservation and practicing a socially supportive, commercially competitive and environmentally sound agriculture. It maintains the ecosystem services in the environment, protecting biodiversity and other values of the nature in the surrounding area. Hence this research was conducted for three consecutive seasons to develop a sustainable (ecological) cropping system for vegetable cropping system at Kalpitiya, as an alternative for conventional cropping system. Other than that, it was aimed to identify appropriate intercropping combinations and the suitable dosage of biochar and several other alternative options in ecological crop management.

2. METHODOLOGY

2.1 Time and Venue

The research was conducted at Agricultural Research Station at Kalpitiya belongs to agro-ecological region, IL1b (8.2295° N, 79.7596° E) having the mean day temperature range of 32-35°C, an elevation of 3-10 m msl, <900 mm annual rainfall, winds up to 18-35 km hr⁻¹ and
Sandy regasol soil group) in three consecutive seasons during 2016-2017. Three field experiments were conducted to compare crop growth and yield of selected vegetable inter-crop combinations under ecological agriculture (EA) in comparison with conventional agriculture (CA). An abandoned experimental field (for three years) was selected for the field research, assuming no residual effects due to agro-chemical use.

2.2 Season-1 (Maha -2016/17)

The first experiment was conducted during Maha (rainy) season in 2016/17 as a two factor Factorial Incomplete Split-plot design having six (06) main plots (three vegetable crop combinations under conventional [CA] and ecological [EA] cropping systems). The crop combinations tested were A1: capsicum (Capsicum annum)-beet (Beta vulgaris), A2: okra (Abelmoschus esculentus)-beet and A3: mea (vigna unguiculata)-Ceylon spinach (Basella alba). Only the ecological main plots were subdivided to form three (03) sub-plots to accommodate biochar dosages; 0, 1, and 2 kg per m$^2$. The experiment was replicated 3 times. The main plot size was 9 m$^2$ while a common inter-row space of 90 cm was kept for the main crop and a common inter-row space of 30 cm was kept for the companion crop. The intra-row spacing of main crops were 75, 60 and 30 cm, respectively while the same for companion crops were 15, 15 and 25 cm, respectively in crop combinations A1 through A3. Crop management of conventional crop combinations was conducted as sprinkler irrigated raised beds following the recommendations of the Department of Agriculture [7] while the inorganic fertilizer and pesticide recommendations were replaced with compost (at the rate of 2 kg m$^{-2}$, in two splits) and integrated pest management (IPM), respectively in the ecological crop combinations. IPM was basically composed of maintaining a live fence of Gliricidia sepium, planting marigold (Tagetes erecta) as a pest repellent, hanging sticky traps, keeping water traps and periodical spraying of neem extract and garlic-chili extract, alternatively. Commercially available crop varieties were selected based on the farmers’ preference.

2.3 Season -2 (Yala-2017) and Season-3 (Maha-2017/18)

Two cropping systems (EA and CA) were compared using three new crop combinations, spinach-beet, radish (Raphanus sativus)-onion (Allium cepha), and okra-onion under the same new crop combinations layout as a two factor Factorial experiment with three replicates. All vegetable combinations in EA were treated with the best bio-char dosage (2 kg m$^2$) (according to the results of previous Maha season) and also with newly introduced bio-fertilizer source, Jeeva muthum (at the rate of 2 L m$^2$; in 4 splits) [8] in the two subsequent seasons. The experiment was conducted as a Two Factor Factorial experiment where main plots were the two cropping systems while the sub plots were three crop combinations. Crop management was conducted similar to Season-1.

2.4 Evaluation

Data collected through the project on soil properties, water quality plant growth, yield, and other environmental and economic parameters were used to analyze the agronomic (technological) soundness, ecological profile and the economic sustainability of the introduced cropping system models in comparison with the existing conventional model in a three season field research, as described above. The data on ecological indicators covered soil, water, crop and biotic factors of the environment. For examples, EC, pH, residual N,P,K Ca, soil organic matter and heavy metal contents in soil samples and pest incidence and natural enemy populations were monitored periodically. In addition, crop growth measurements, yield and quality of harvest, cost components and essential weather parameters were recorded simultaneously to evaluate the potential food safety and economic viability of the introduced cropping systems.

3. RESULTS AND DISCUSSION

3.1 Effect of Cropping System - Season 01

Effect of ecological agriculture: In the first season growth of crops under conventional agriculture (CA) was significantly higher than ecological agriculture (EA) (at p<0.05). For example, plant dry weight and leaf area of conventionally grown okra, beet and mae were significantly higher than their ecological counterparts (Fig. 1). The highest plant dry weight was obtained by conventionally grown beet (25.9±5.0 g per plant) in beet-capsicum combination (A1) while the highest leaf area index was resulted by conventionally grown Mæ (0.06) in mæ-spinach combination (A3). Plant growth data agrees with the well-established fact, plant growth and crop yields are
relatively lower than the conventional farming system during the “organic transition” period (first 3 years).

The overall results showed that crop growth in EA was significantly lower than CA (at p<0.05) for the main crop components (i.e. beet, mae and okra) of the tested crop combinations during the first season. This could be a result of deficiencies in the anticipated ecosystem services provided by beneficial soil microbes in the environment during the first season of transition from CA to EA as described by Kremen and Miles [9].

3.2 LER of Intercropping Combinations- Season 01

According to Land Equivalent Ratio (LER) of three different crop combinations, all ecologically cultivated (EA) crop combinations were higher than 1.0. Therefore, intercropping under EA has not made any overall loss of yields in all the crop combinations. Meanwhile as a result of higher per plant yields of okra and mae, Crop combinations A2 and A3 showed a comparatively higher LER under CA (Table 1). Meanwhile similar intercropping yields of beet under CA and EA (Table 1) can be considered as an improvement under intercropping when compared with reported 75% yield reductions of beet under mono cropping [10].

3.3 Effect of Bio-Char– Season 01

In the first season of application, bio-char level-1 (1 kg m⁻²) showed a slight set-back in leaf area of all crops. However, bio-char level-2 (2 kg m⁻²) indicated a relatively high or similar leaf area to without bio-char treatment. Based on the results of beet, bio-char level-2 (2 kg m⁻²) can be identified as the best application dosage (Fig. 2). Based on the reports on long-term effects of bio-char application Stainer et al. [11], much better effect of bio-char can be expected in the subsequent seasons of farming.

![Fig. 1. Plant dry weight and leaf area index of the main component crops in season 01](image)

![Table 1. Land equivalent ratio (LER) of the crop combinations in season 01](table)

| Crop combinations | Monocropping yield (t/ha) | Intercropping yield-EA (t/ha) | Intercropping yield-CA (t/ha) | LER-EA | LER-CA |
|-------------------|---------------------------|-------------------------------|-------------------------------|--------|--------|
| A1 Capsicum       | 12.5                      | 3.6                           | 4.3                           | 1.08   | 1.08   |
| Beet              | 13                        | 10.5                          | 10.9                          |        |        |
| A2 Okra           | 12.5                      | 11.7                          | 17.3                          | 1.69   | 2.12   |
| Beet              | 13                        | 9.8                           | 9.6                           |        |        |
| A3 Mae            | 22.5                      | 11.7                          | 16.7                          | 1.02   | 1.32   |
| Spinach           | 50                        | 15.0                          | 17.3                          |        |        |

EA: Ecological agriculture; CA: Conventional agriculture
3.4 Effect of Cropping System - Season 02

In the second season, radish-onion combination, (grown under 2 kg m\(^{-2}\) of bio-char and bio-fertilizer) gave different results for conventional and ecological cropping systems. The highest LAI was obtained by radish and onion grown in CA (0.049 and 0.025, respectively). Greater results in CA were demonstrated by the yam dry weight of Radish. However, leaf dry weight and number of leaves of radish were significantly higher in EA, compared to CA (Fig. 3). Improvements in some growth parameters while others are yet to at the second season of transition, agrees with the eventual yield increases expected from a transitional cropping system [12,13].

According to above results, EA appeared to be catching up in terms of aspects of some plant growth in the second season.

Average Fresh weight or the yield (yam and foliage) of radish grown in EA was 276.6±17.5 g plant\(^{-1}\) while it was 282.5± 49.6 g plant\(^{-1}\) for radish grown in CA, indicating no significant difference between the two cropping systems. Further to this, some yam quality parameters such as yam girth of radish was not significantly different between the two cropping systems but yet the yam length was significantly higher in CA compared to EA in Radish (Fig. 4).

3.5 Effect of Cropping System - Season 03

In the third season radish and onion were cultivated similar to second season. As illustrated in Fig. 5, yam/bulb number of both radish and onion were significantly higher in EA. The same difference could be found in leaf number of onion but the opposite in radish. Meanwhile, there was no significant difference in yam/bulb dry weight of both radish and onion between two cropping systems (EA and CA) (Fig. 5). Lack of difference in dry weight between EA and CA agrees with lack of yield differences reported for organic maize crop in second year of transition from conventional agriculture.

3.6 Residual Plant Nutrients and Heavy Metal Accumulation in soil – Seasons 01 and 03

As shown in Table 1, the soil analysis conducted at the end of the first season indicated no significant difference between ecological and conventional agricultural fields for P, K and organic matter (OM). However, conventional fields contained significantly higher N content than ecological fields. This difference has been disappeared by the end of the third season. Meanwhile, ecological fields have shown a significantly higher soil P and K contents than conventional fields by the end of the third season (Table 1). Meanwhile lack of agro-chemical use in the ecological agricultural fields has
contributed to almost zero levels of Cd and Hg while detectable levels have been reported in the conventional plots. However, lack of significant difference in soil. As content between ecological and conventional fields needs to be further investigated Table 1.

3.7 Other Ecological Indicators

Insect counts conducted using sticky traps reported many small arthropod pest species as well as several natural enemies. Most insect pests were either bean flies or flea beetles while natural enemies were ladybird beetles and few different types of unidentified insects. The collection of insect sticky traps showed a great increase after the first month of the cropping season (Fig. 6). However, their difference between EA and CA plots were not significant. The mean collection per pit-fall traps were very low (1 – 3 insects per month) in which plant hoppers were the dominant category.

Fig. 3. Leaf dry weight, bulb dry weight and leaf number in radish – season 02

Fig. 4. Girth and length of radish yams in season-02
Fig. 5. Bulb dry weight, leaf length and yam number of radish and onion – season-03

Fig. 6. Collection of insects on to sticky traps over the time

EA: Ecological agriculture; CA: Conventional agriculture
Table 2. Soil N, P, K, organic matter contents and heavy metal contents in ecological and conventional fields

| Season | Cropping system | Soil N (ppm) | Soil P (ppm) | Soil K (ppm) | Organic Matter (%) |
|--------|-----------------|--------------|--------------|--------------|-------------------|
| 1      | Ecological      | 1.7±0.10     | 29.6±4.70    | 80.7±8.50    | 1.60±0.22         |
|        | Conventional    | 2.1±0.20     | 32.6±4.90    | 81.3±13.90   | 2.10±0.33         |
| 3      | Ecological      | 1.1±0.01     | 21.4±2.20    | 46.3±1.10    | 1.59±0.12         |
|        | Conventional    | 1.0±0.11     | 14.5±1.50    | 44.4±0.50    | 1.47±0.08         |

Cd (ppm) | Hg (ppm) | As (ppm) |
--- | --- | --- |
Ecological | 0.00±0.00 | 0.00±0.00 | n.a. |
Conventional | 0.19±0.07 | 0.09±0.00 | 0.70±0.02 |

Severe pest infestations and disease incidences could not be detected, except minor infestations of mites and aphids in the first two seasons and powdery mildew and okra mosaic virus in the third season. They were successfully controlled through IPM procedures in EA and chemical pest management in CA.

4. CONCLUSIONS

All the intercropping combinations tested in the first season have been successful in yield performances (LER > 01) under ecological as well as conventional cropping systems. Hence, Capsicum-beet, Okra-beet and mae-spinach crop combinations could be identified to be appropriate for ecological agriculture. Further investigations on the plant growth and yam/bulb development in subsequent seasons added radish-onion (small) into the above list. Ecological agriculture was lower in plant growth rates and yield performances at the first season but a gradual progress could be evident in the next two seasons, outranking conventional agriculture with respect to yam/bulb number of radish and onion and the leaf size (length) of onion at the third consecutive season. A bio-char amendment of 2 kg m⁻² could be identified as the best dosage, based on the leaf area of beet. Meanwhile, season-long analysis of soils showed improvements in soil N, P and K contents and reduction in Cd and Hg accumulation after three seasons of ecological agriculture practices. Insect pest/natural enemy incidence were not different between two cropping systems but there was a gradual increase in incidence at the mature stages of crops in both cropping systems.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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