For session 5: Multi-criteria assessment....
For oral presentation

Soil indicators respond to changes in banana plantation management

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The north Queensland region of Australia produces over 90% of Australia's bananas. However, to maintain its importance as a banana-growing region, producers are seeking innovative methods to manage their plantations in order to protect environmentally sensitive areas, reduce impacts from climatic events and suppress soil borne diseases. The development of a healthy soil is an aspiration sought to address these constraints, using indicators based on soil physical, chemical and biological parameters. From 2012 to 2015, 104 soil samples were received for analysis from three different crops; bananas (86), vegetables (7) and citrus (11). The banana samples were received from different management scenarios; conventional (49), newly planted fields (15), non-Cavendish producers (4) and Ecoganic production (18). Ecoganics is a farmer certification program that combines environmental management systems with sustainable production practices. A stepwise-discriminate analysis was used to determine if bananas could be separated from other crops, and if the different types of banana management systems could be separated based on soil parameters. The stepwise discriminate analysis also identified the minimum set of soil parameters required to discriminate between crops and management systems. Crop type could be separated based on eight soil parameters; Cu, silt, Al, bacterivores, clay, nematode diversity, CEC and labile C, with a 1% error rate. This indicated different crops had different soil requirements. Banana management systems could be separated using eight soil parameters; fluorescein diacetate, enrichment index, Na, plant-parasitic nematodes (%), predatory nematode (%), structure index, organic C and fungivore abundance. However, the separation of banana management groups had a 21% error, as non-Cavendish was confused with newly planted bananas 25% of the time. The results confirmed that crop management has considerable soil effects, particularly on the biology. The use of soil indicators can guide farm management decisions to implement practices most likely to overcome banana productions constraints.

Key words: farm management, soil biology, soil health, soil parameters, sustainable farming.

Introduction

The Australian banana industry produced 285,535 tonnes, valued at AU$565 million, from 13,496 ha in 2012 (FAOSTAT). In 2012, Australia was the 37th largest producing nation of bananas in terms of production, but the 41st largest producer in terms of area and the 50th nation in terms of yield. Due to its favourable climate most of the Australian banana production occurs in north Queensland (93%), which produces about AU$ 400 million annually, with smaller production areas located in the sub-tropics of Western Australia (2%), northern New South Wales and south-east Queensland (6%) and in the tropics around Darwin in the Northern Territory (2%). Banana production in Australia is primarily for domestic consumption.

The banana farms of north Queensland are mainly family-based businesses with a typical farm size of 15 to 20 ha, although some plantations are as large as 500 ha (Stirling and Pattison 2008). Production in north Queensland is about 30-40 t ha yr-1, which is characterised by a high level of technology and mechanisation relative to other banana producing countries due to high labour costs (Stirling and Pattison 2008). Agrochemicals are commonly used against weeds, bunch pests, foliar diseases and soil-borne pests and diseases. The use of a spraying calendar is still widespread, but there is increasing attention, by governmental regulations and policies, to promote integrated pest management (IPM)(Kernot et al. 1998). In recent years there has been increasing concern about erosion and runoff of agrochemicals, nutrients and sediments, which may pollute rivers and other ecosystems (Anonymous 2001; Kernot et al. 1998; Pattison et al. 2008; Rasiah et al. 2009). The tropical banana industry in Queensland was identified as a contributor of nutrients and sediments to waterways and the Great Barrier Reef lagoon (Anonymous 2001; Kleiese et al. 1997; Moody and Aitken 1997). Sustainability and soil health are now key focal points of the Australian banana industry to improve soil-based resources (Pattison et al. 2008; Rasiah et al. 2009).

There is growing concern that monoculture of bananas, using the same clone renders commercial banana production systems more susceptible to pests and diseases due to lack of diversity (Pattison and Lindsay 2006; Smith et al. 1998). Moreover, there is a need to address problems in the banana industry such as soil erosion, ecosystem contamination and incidence of pests and diseases, which may be accomplished by using integrated approaches. Organic agriculture is seen as one way of farming that aims to integrate and manage these aspects in an ecological sound way. Organic agriculture aims to achieve disease control through promoting healthy soils featuring enhanced biological activity and thus improved soil suppression of soil-borne pests and diseases. This may be realised by application of organic amendments instead of synthetic fertilizers, thereby stimulating soil microbial biomass and activity. Moreover, organic agriculture aims to maintain or increase above- and below-ground biodiversity by more effectively employing crop rotation and intercropping techniques compared to conventional systems. Ecoganics is a farmer certification program that combines environmental management systems with sustainable production practices. However, very little literature is available on organic banana production in North Queensland or in Australia in general.

For the banana industry to improve soil management there is a need to develop indicators that are able to quantify changes in soil properties and which may be used to design and promote improved land management practices. Such indicators should encompass a holistic view of soil management techniques and account for changes in physical, chemical and biological soil properties (Karlen et al. 2003). A better understanding of the soil ecosystem may result in development of a stable, resilient soil system that is able to recover from stress, and demonstrates enhanced biological diversity and more efficient internal nutrient cycling (van Bruggen and Semenov 2000). A selection of soil health indicators for use in the banana industry was developed by Pattison et al. (2008), using physical and chemical indicators, plus soil nematode community structure. However, there needs to be more extensive verification that changes in crop management such as organic production can result in improved soil health characteristics including the suppression of soil borne diseases such as plant-parasitic nematodes.

This study aimed to investigate the potential benefits of different farm management on banana production systems through a farm surveys. The hypothesis for the research was that management altered soil health indicators under bananas by improving microbial activity and diversity relative to "conventional" banana production resulting in more resilient soil properties that could suppress biotic stresses such as plant-parasitic nematodes. To test the hypothesis organic and conventional banana production systems were surveyed to compare physical, chemical and biological soil health indicators.

Materials and methods

Site selection and soil sampling

The area under survey covered tropical north Queensland, banana production area south of Cairns and north of Cardwell, and the Atherton Tablelands. From 2012 to 2015, 86 soil samples were received for analysis from three different management scenarios; conventional (53), newly planted fields (15), and Ecoganic production (18). Ecoganics is a farmer certification program that combines environmental management systems with sustainable production practices.

Soil samples were collected using a shovel to remove a square block of soil approximately 15 cm x 15 cm to a depth of 15 cm within 30 cm from the base of the banana plant, in front of the following sucker to form a composite soil sample (n=15) from each field. Stones and large pieces of organic matter were avoided during sampling. Soil was placed in a bucket and thoroughly mixed with a trowel.

Soil analysis

Collected bulked soil samples were analysed for physical, chemical and biological soil health indicators and samples were sent to a commercial laboratory, Incitec Pivot Ltd. Weribbee, Victoria, Australia, for further chemical analysis. The following soil health indicators were measured at the Department of Agriculture, Fisheries and Forestry laboratory at South Johnstone: labile C, fluorescin diacetate, β-glucosidase, and nematode community structure. Labile carbon contents were determined by the amount of C oxidised by 33mM $KMnO_4$ in duplicate 5 g sub-samples using the method described by Moody and Cong (2008). Similarly, fluorescein diacetate (FDA) hydrolysis rate was determined from duplicate 5 g sub-samples using a modified version of the method initially proposed by Schnürer and Rosswall (1982). β-glucosidase was determined with the procedure published by Eivazi and Tabatabai (1988) except the toluene was substituted with 0.1% Tween solution and the modified universal buffer was replaced with a McIlvaine buffer (pH 6.0).

Soil nematodes were extracted using a modified Baermann funnel technique (Whitehead and Hemming 1965). A 200 g sample of field soil maintained at the soil moisture capacity at the time of sampling was weighed onto a mesh sieve with a single ply of tissue and then placed into a tray with 250 mL of water and left for 48 hours. The nematodes were collected on a 25 μm sieve and backwashed into a vial. The total number of nematodes in the 200 g soil sample was determined on a counting slide and expressed as the number per 100 g of soil. A 50 μL aliquot was placed on a glass slide, with a minimum of 100 individual nematodes identified to genus level for plant-parasites and to the family level for free-living nematodes. Soil nematode community analysis was made on soil nematode trophic groups (parasites, fungivores, bacterivores, omnivores and predators).

Indices of the nematode community composition were calculated from the number of nematode taxa extracted from each plot. Nematode diversity was determined using the Shannon-Weiner index (Yeates and Bongers 1999). The bacterivore to fungivore ratio was calculated from the total abundance of bacterivores (B) and fungivores (F) (B/(B+F)) (Yeates and Bongers 1999). Additionally, the weighted functional guilds concept was applied, without plant-parasites (Ferris et al. 2001). Nematode families were assigned a colonizer-persister (c-p) score from 1–5, (colonizer c-p = 1; persister c-p = 5). The score depended on the changes in the environment, with the index values representing life-history characteristics associated with r- and K-selection, respectively (Bongers and Bongers 1998). For example, bacterivores with a c-p score of 2 were classified in functional guild Ba2 and predators with a c-p score of 4 were classified in functional guild Ca4. The nematode functional guilds were used to calculate the basal, enrichment index (EI), structure index (SI) and channel index (CI) of the soil food web (Ferris et al. 2001). Plant-parasitic nematodes were identified to species level and the abundance of each individual classification of plant-parasitic nematode was kept separate.

Statistics

As data was obtained from surveys only descriptive statistics could be used to determine differences in soil properties due to management of banana farms. To determine if farm management, either re-planted bananas, conventional banana or Ecoganic banana production systems could be discriminated from one another based on the measured soil parameters a forward-stepwise discriminate analysis was applied to all farm sites. Validation of the discrimination model was performed using the leave-one-out method to determine if the selected model could correctly predict groupings. The forward-discriminant stepwise analysis selected the minimum set of parameters that significantly contributed to the separation of groups, with a prediction error. Box and whisker plots of the selected parameters for each model were constructed using the median and the upper and lower quartiles for the different groupings. All statistical analysis were conducted using Genstat 16.

Results and discussion

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The forward stepwise discriminate analysis procedure determined that banana management could be separated with a minimum data set of ten soil parameters with a 19.5% validation error using the leave-one-out procedure (Figure 1). The high error rate indicted that there was overlap between the groups, based on using the soil characteristics. The leave-one-out validation model could correctly assign sites according to farm management as conventional 80% of the time, as Ecoganic 72% of the time and as replanted bananas 89% of the time (data not shown). The leave-one-out validation model confused Ecoganic bananas with conventional bananas 22% of the time (data not shown).

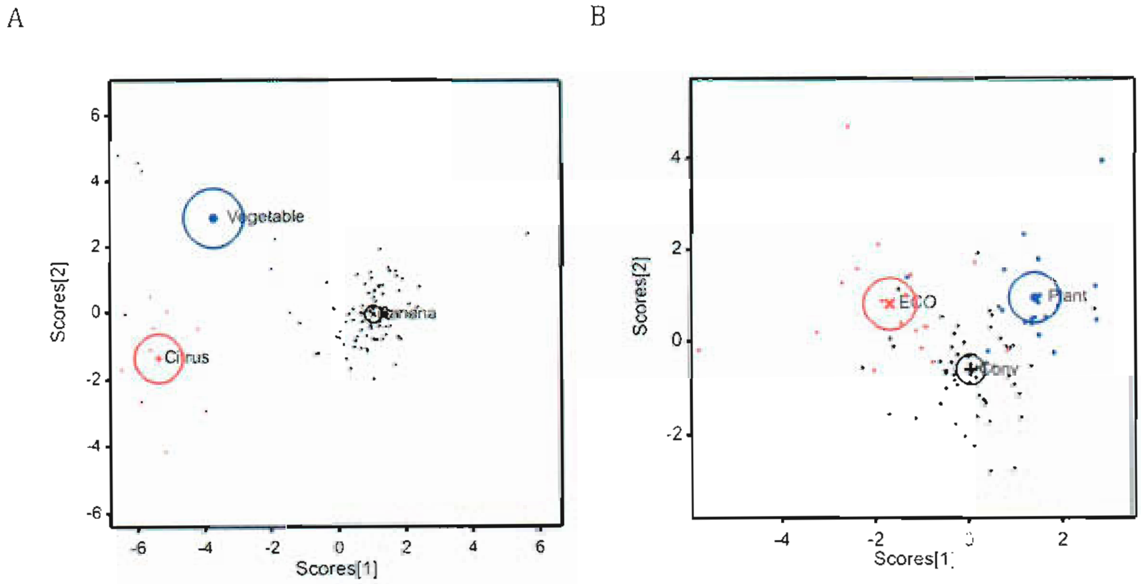

Figure 1: Stepwise discriminate analysis biplot for the separation of banana farm management using soil parameters

The ten optimal soil parameters required for the model were; FDA, nematode enrichment and channel indices, B/(B+F) ratio, nematode diversity, and abundance of Fu2 fungivores, Om4 omnivores, Ba1 and Ba3 bacterivores and Helicotylenchus multicientus, which were depicted using a box and whisker plot for each management system (Figure 2). The ten indicators did not include any soil chemical or physical parameters, even though they were included in the analysis. This would indicate that soils used for banana production in north Queensland have similar physical properties, which would correspond with soil type selection for drainage and structural characteristics. Furthermore, nutrients applied to bananas do not significantly influence the soil chemical properties of the soils. However, biological characteristics are sensitive to soil management changes, and therefore gave the greatest discrimination between farm management systems.

The Ecoganic farms tended to have a greater range of FDA measurements, a measure of microbial activity, compared to plant and conventional bananas with the plant bananas having a greater median value (Figure 2A). This would indicate increased microbial activity in replanted bananas, possibly from soil disturbance through tillage and mixed groundcover as the bananas become established. However, the conventional banana production tended to have the lowest FDA activity of the three different management systems (Figure 2A).

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The nematode enrichment index is an indicator of nutrient availability, with a higher value indicating greater nutrient enrichment and a low value indicating low nutrient availability. The Ecoganic banana production system tended to have a greater range and a lower median value compared to conventional and replanted bananas (Figure 2B). The reduced enrichment index observed with Ecoganic banana production would indicate a reduction in readily available nutrients, consistent with low inputs of nutrients and low soil disturbance. The re-planted bananas tended to have the greatest enrichment index, which was consistent with a disturbed soil with nutrient enrichment, which may be related to the increase in microbial activity measured by the increase in FDA (Figure 2A).

The channel index is a measure of how nutrients are decomposed, either through a bacterial or fungal channel. A lower value indicates a bacterial decomposition of nutrients and a high value a fungal decomposition of nutrients in the soil. The Ecoganic systems tended to have the greatest channel index, with fungal dominated decomposition of nutrients, relative to the conventional and re-plant banana systems (Figure 2 C). The greater channel index is consistent with a low enrichment index and the need for microbial decomposition of nutrients to release nutrients for plant growth.

The number of Fu2 fungivorous nematodes was greater in the re-planted bananas compared to conventional and Ecoganic systems (Figure 2D). Similarly, the abundance of Ba1 bacterivores was greater in the re-planted bananas (Figure 2E). The greater abundance of these two groups of nematodes is consistent with soil disturbance and increased nutrient availability. Ba1 bacterivores have a low c-p value, indicating that they are copitrophic or r selective organisms that can respond to nutrient enrichment, through high fecundity and reproduction rates. As re-planted bananas had recently undergone a tillage event, microorganisms and organic matter become exposed stimulating further microbial activity. This has a flow on effect in the soil food web with consumers of microorganisms such as nematodes then able to proliferate due to the increase in food resources. This observation is consistent with the increased enrichment index observed for plant bananas (Figure 2B).

The abundance of Ba3 nematodes was greatest in the Ecoganic productions system relative to conventional and re-planted bananas (Figure 2F). Unlike Ba1 nematodes, the Ba3 nematodes are indicative of more stable soil systems, being oligotrophic with reduced reproduction rates and sensitive to soil disturbance. The high number of Ba3 nematodes would indicate greater soil food web interactions that were required to decompose organic matter and soil nutrients, allowing the Ba3 nematodes to increase rather than Ba1 nematodes. The greater abundance of Ba3 nematodes is consistent with other soil indices that imply the Ecoganic production system has low soil disturbance, reduced easily accessible nutrients, with nutrient availability relying on recycling and interactions amongst soil organisms.

The B/(B+F) ratio is the ratio bacterivores relative to fungivores, with a greater value indicating more bacterial dominated soils, and a lower value indicating greater fungal activity. The conventional and Ecoganic systems tended to have a similar B/(B+F) ratio with a slight reduction where bananas had been re-planted (Figure 2G). This contrasts with the channel index, which indicated that the Ecoganic system had greater fungal activity (Figure

2C), but is consistent with greater abundance of fungivores in the re-planted bananas (Figure 2 G).

Helicotylenchus multicinctus is a plant-parasitic nematode that was found in greater abundance on conventional banana plantations (Figure 2H). However, there was high variability in the recovery of the H. multicinctus amongst the conventional farms, with most farms having low numbers of the nematode, but a few farms having very high nematode populations (Figure 2H). Very low abundance of *H. multicinctus* was observed on Ecoganic and re-planted bananas (Figure 2H).

The abundance of Om4 nematodes, tended to be reduced in conventional banana production systems relative to the Ecoganic and replanted banana systems (Figure 2I). Om4 nematodes are large, omnivorous nematodes that have long life cycles and are sensitive to soil disturbance. Therefore, it is rather surprising that that Om4 nematodes should be found in high abundance in re-planted bananas, when other nematodes indicators imply that the re-planted bananas is a disturbed system, with high nutrient availability. However, it does demonstrate that conventional banana production management can have a suppressive effect on predatory soil organisms.

Nematode diversity, calculated as the Shannon index of diversity tended to be variable in all banana production systems (Figure 2J). The re-planted bananas tended to have the least variation (Figure 2J). Nematode diversity may be a function of the cropping system and vegetative cover. As bananas were the dominant crop in all production systems surveyed, with some variation in weed and ground cover in all production systems, there was not a large variation in diversity values. However, as re-planted bananas converts from a disturbed systems to a more stable monoculture system, there may be an opportunity for organisms to be found around the roots of banana plants. As the system "matures" microbial recycling of nutrients may diminish and plant-parasitic organism may then begin to dominate the nematode community.

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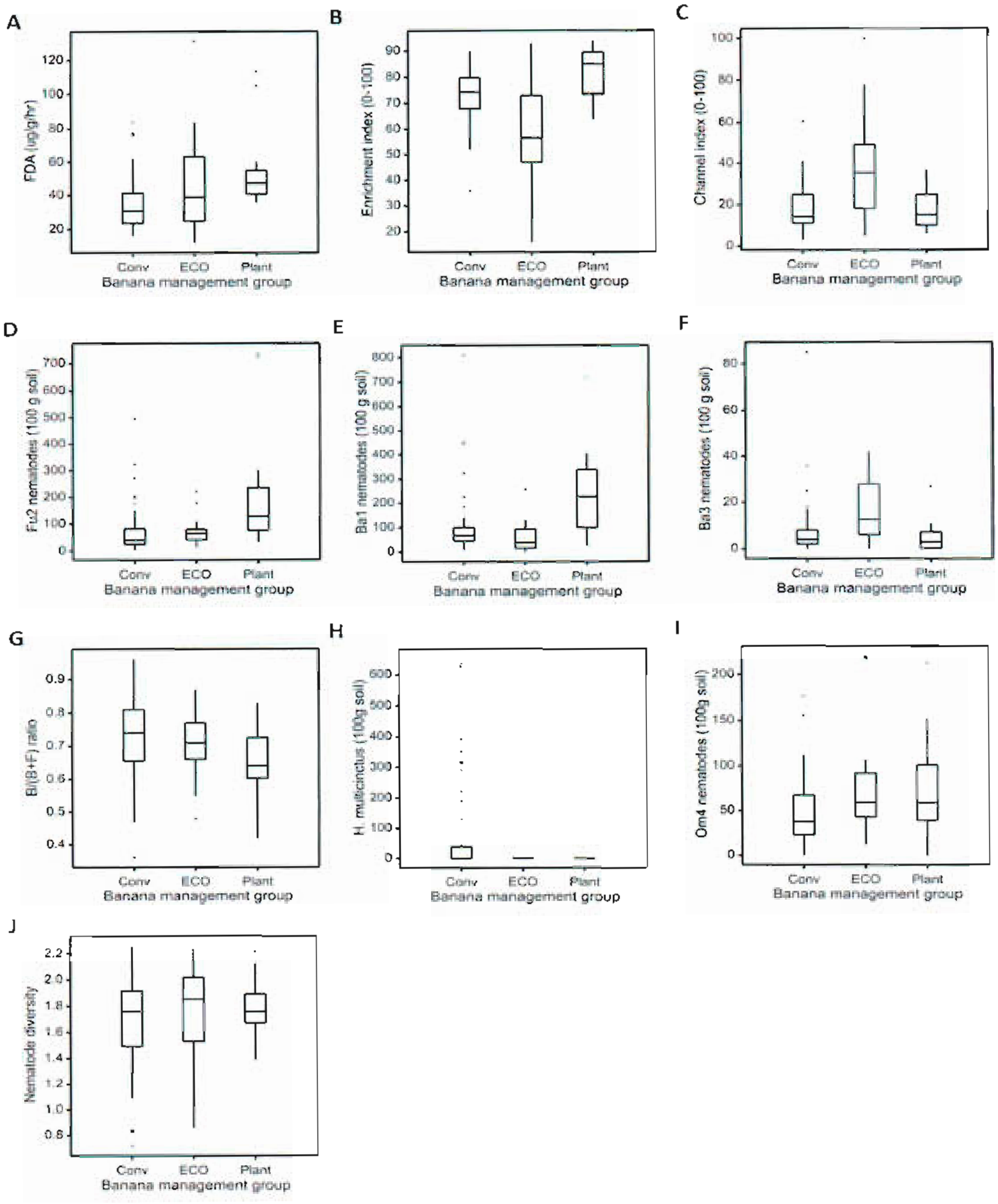

Figure 2: Box and whisker charts for the optimal set of soil parameters used to separate soil types; FDA (A), enrichment index (B) channel index (C), Fu2 fungivore (D), Ba1 bacterivores (E), Ba3 bacterivores (F) nematode B(B+F) ratio (G), Om4 omnivores (I) and nematode diversity (J).

Conclusion

The results confirmed that crop management systems have substantial effect soil on soil biology. Low input systems such as Ecoganics, tended to reduce the organisms that respond to freely available nutrients and promoted longer lived organisms that rely on interactions with other soil organisms to decompose organic matter and recycle nutrients. Re-planting bananas is a major soil disturbance that increases microbial activity, and releases nutrients. However, there was variation in the amount of disturbance following banana re-planting, with only increased numbers of rapidly reproducing bacterivores and fungivorous nematodes indicating a large shift from soil biology found in other types of management systems. Overall, there was no single soil biological indicator that could be used to separate the different types of banana production systems. However, there was overlap in soil biological properties when banana are characterised as specific systems, which requires multiple indicators to confer shifts in soil biological interactions. The survey confirmed that the use of soil indicators can guide farm management decisions to implement practices most likely to overcome banana productions constraints.

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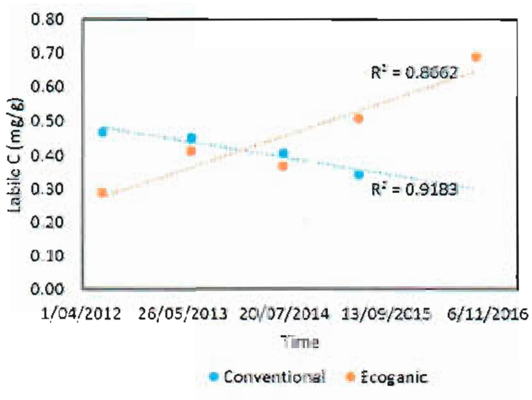
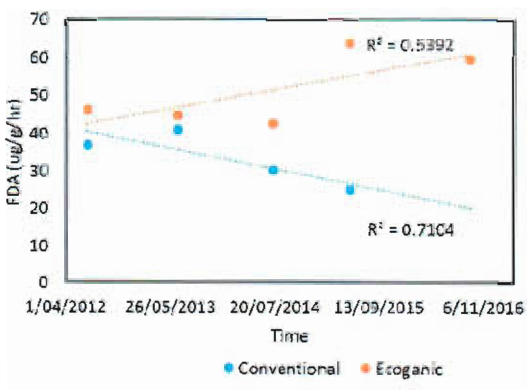
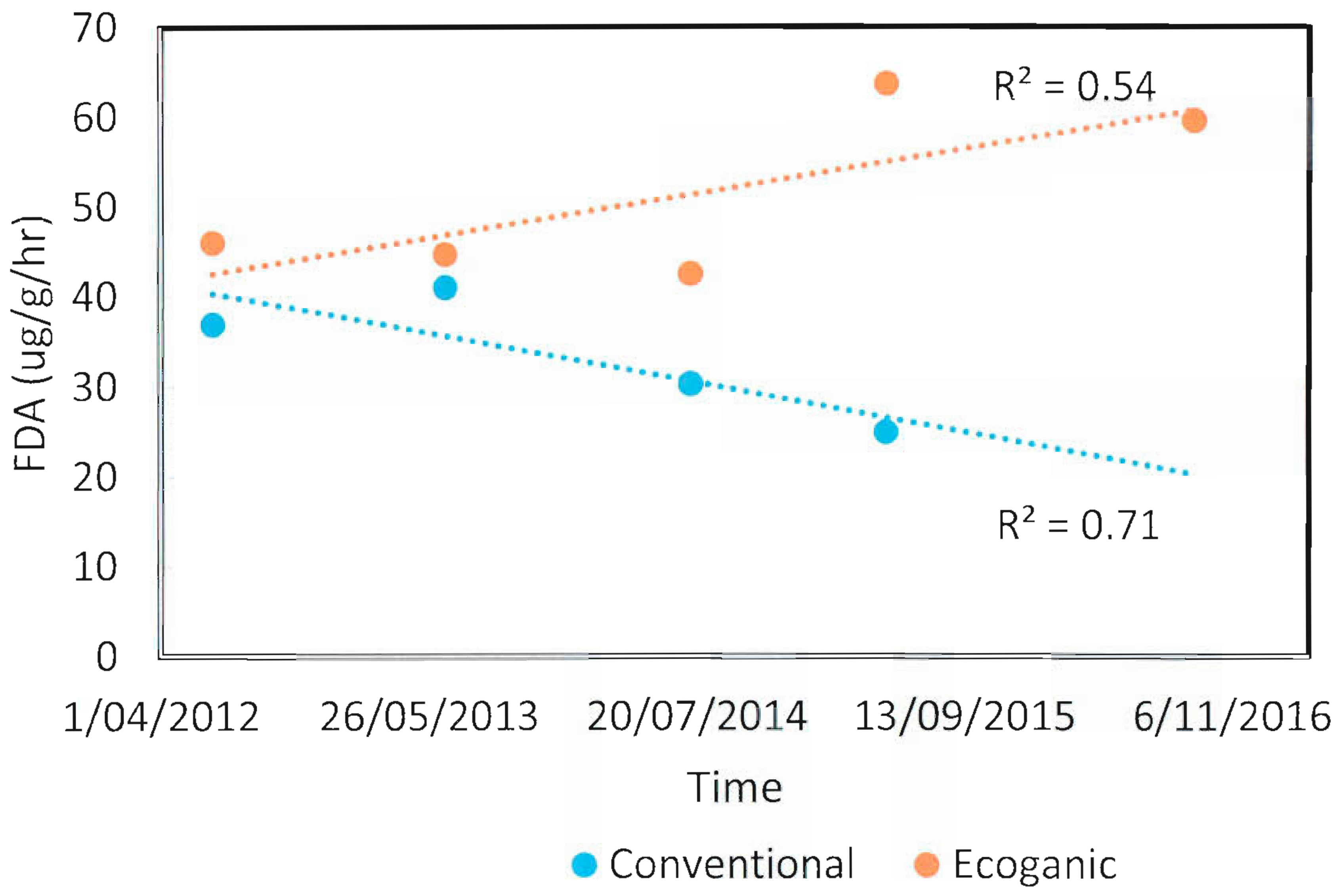
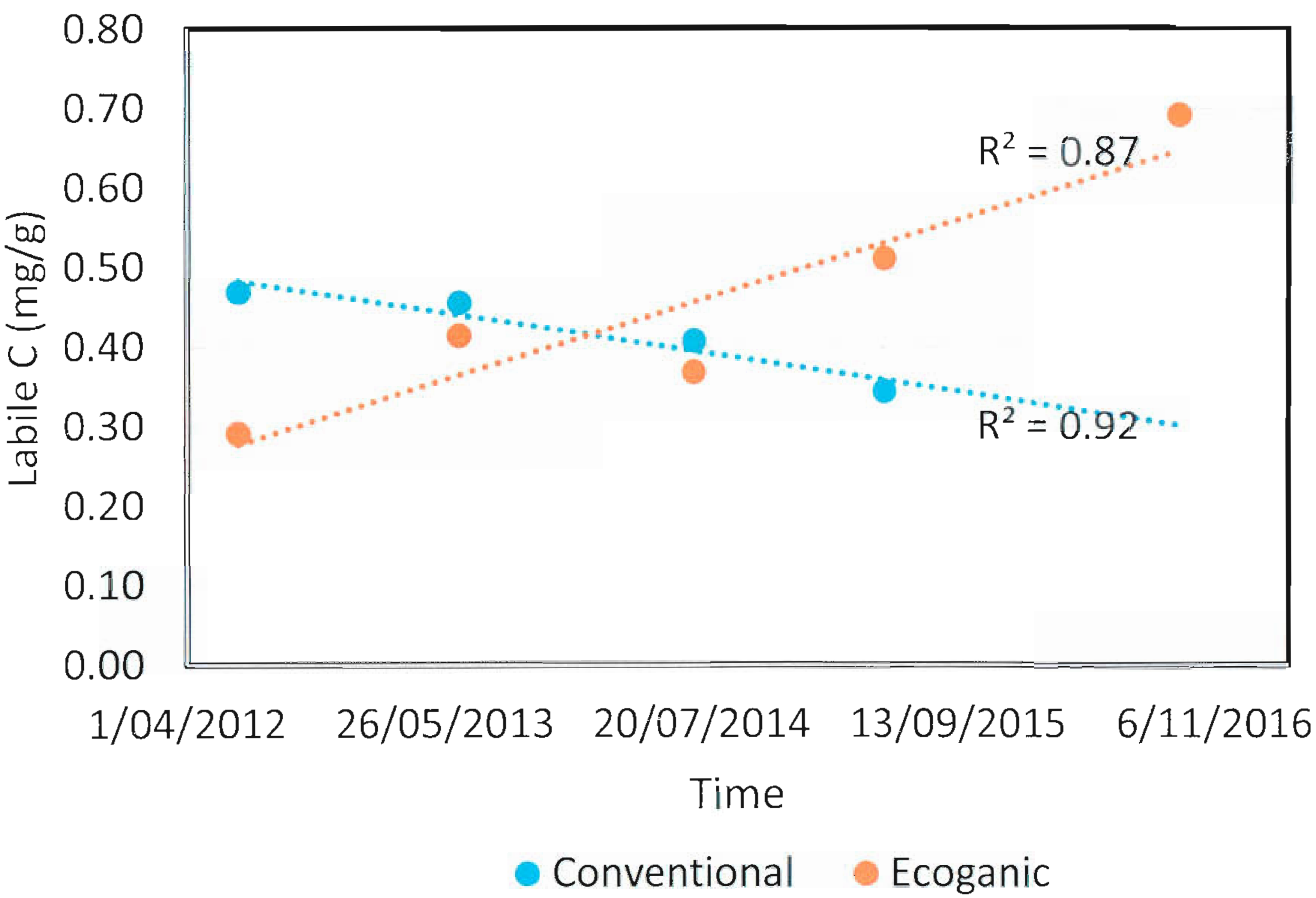





FDA (ug/g/hr)
70
60
50
40
30
20
10
0
R² = 0.54
R² = 0.71
1/04/2012
26/05/2013
20/07/2014
13/09/2015
6/11/2016
Time
Conventional
Ecoganic


0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Labile C (mg/g)
R² = 0.87
R² = 0.92
1/04/2012
26/05/2013
20/07/2014
13/09/2015
6/11/2016
Time
Conventional
Ecoganic