University of Jaffna

Prof.Somasundaram Kandiah Memorial Lecture-2023

(First Dean of the Faculty of Agriculture
and Professor in Agronomy)

“Approach to sustainable soil use to feed a growing world population”

by

Dr. Koki TOYODA,
Professor,
Institute of Agriculture,
Tokyo University of Agriculture and Technology.

on

Friday, 22nd September 2023 at 10.30 a.m

at

**Main Auditorium, Faculty of Agriculture,
University of Jaffna,
Ariviyal Nagar, Kilinochchi.**

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22.09.2023

Prof. Somasundaram Kandiah

Message from the Vice Chancellor

It is an immense pleasure to commemorate Late Prof. Somasundaram Kandiah who was appointed as the first Dean of the Faculty of Agriculture, University of Jaffna in October 1990. Prof. S. Kandiah was born on 9th September 1936 in Ariyalai, located to the East of Jaffna Peninsula. He went to St. John's College, Jaffna for his secondary education and from where he entered to the University of Colombo for his Bachelor of Science degree programme. Late Prof. S. Kandiah followed his doctoral research, which was mainly focused on developing dwarf types of apple trees through plant breeding, and earned his doctoral degree from University of London. Then, late Prof. Kandiah returned to the country as young PhD holder and joined as a research officer at Tea Research Institute of Sri Lanka. Due to his outstanding research and academic qualifications, late Prof. S. Kandiah selected and started his academic career as Senior Lecturer in Botany at the Faculty of Science, University of Jaffna in 1978. At the Faculty of Science, he served as the Head of the Department of Botany and later promoted as associate Professor in Botany.

In 1990, late Prof. Kandiah has accepted to serve as a Professor in Agronomy for the newly established Faculty of Agriculture in Kilinochchi although many of the Tamil academics were leaving from the country as the civil war was worsening in the region. Thereafter, he was unanimously elected as the first Dean of the Faculty in October 1990. Many of his very first batch students of the Faculty of Agriculture remember him as humble, simple and noble academician as a dedicated teacher, outstanding researcher, committed administrator. He was very keen to understand and solve students' problems. He has supervised many research students on the areas of improvement of horticultural crops and initiated the dwarf palmyrah breeding program in the Northern, Sri Lanka.

During the hard times of Sri Lankan civil war, he used to travel by bicycle from Kilinochchi to Jaffna through Poonakary road with the few other faculty academics. On 23rd March 1991, Prof. Kandiah has met an untimely death to a cardiac arrest while he was cycling back to Kilinochchi after attending the senate meeting at the University of Jaffna. The Faculty of Agriculture was upset and suddenly lost an excellent academic while on service. His dedication and commitment to the Faculty of Agriculture, is ever remembering by the University of Jaffna.

The Faculty of Agriculture was planning to hold the memorial lecture annually to appreciate the services of its first dean late Prof. Somasundaram Kandiah and I am happy that it has been materialized from last year onwards. This year, we are delighted to have Japanese eminent scientist Dr. Koki TOYODA from Tokyo University of Agriculture and Technology to deliver this 2nd memorial lecture of Late Prof. Somasundaram Kandiah under the title of "Approach to sustainable soil use to feed a growing world population".

Dr. Koki TOYODA is a Professor of Soil Biology at Tokyo University of Agriculture and Technology. Dr. TOYODA graduated in Agricultural Chemistry from Nagoya University in 1988, and completed a PhD in ecology of soilborne plant pathogens at Nagoya University in 1993. He was then appointed as Assistant Professor at Nagoya University in 1994 and moved to Tokyo University of Agriculture and Technology in 2000. He has published more than 190 research papers in Q ranking Journals and more than 50 books, book chapters and review papers and 3 patents. His prime research area is Soil Biology, Environmental Microbiology, Crop Protection. He is a Vise-President of Japanese Society of Soil Microbiology and Chairman of division of Soil Biology of the Japanese Society of Soil Science and Plant Nutrition. He is an

Editor-in-Chief of the Journal Sago Palm, Senior Editor of the Journal Microbes and Environments. He is in the editorial board of the journals Biology and Fertility of Soils and Nematological Research, Biology and Fertility of Soils, Applied Soil Ecology, Nematological Research, Soil Science and Plant Nutrition.

For the continuous contribution to the field of expertise, Dr. Koki TOYODA has won prestigious British Council Fellowship award in 1995, Inoue Research Award for Young Scientists (1995), Young Scientist Award for Soil Science and Plant Nutrition (2003) and Award for Soil Science and Plant Nutrition (2019). Moreover, Dr. Koki TOYODA is decorating as member of Scientific Committees of the Japanese Society of Soil Science and Plant Nutrition, The Japanese Society of Soil Microbiology, The Japanese Society of Soil Zoology, The Japanese Nematological Society, The Japanese Society of Sago Palm, The Japanese Society of Microbial Ecology, The Japanese Society of Pesticide Sciences.

University of Jaffna would extend its appreciation to Dr. Koki TOYODA for agreeing to deliver the late Prof. S. Kandiah memorial lecture for the year 2023 from his expertise area of research. I hope his talk will add new knowledge and open new regional agricultural research plan focusing to UN's SDG goal of zero-hunger in year 2030.

All Glories to Almighty

Prof.S. Srisatkunarajah,
Vice-Chancellor
University of Jaffna
Sri Lanka.

Approach to sustainable soil use to feed a growing world population

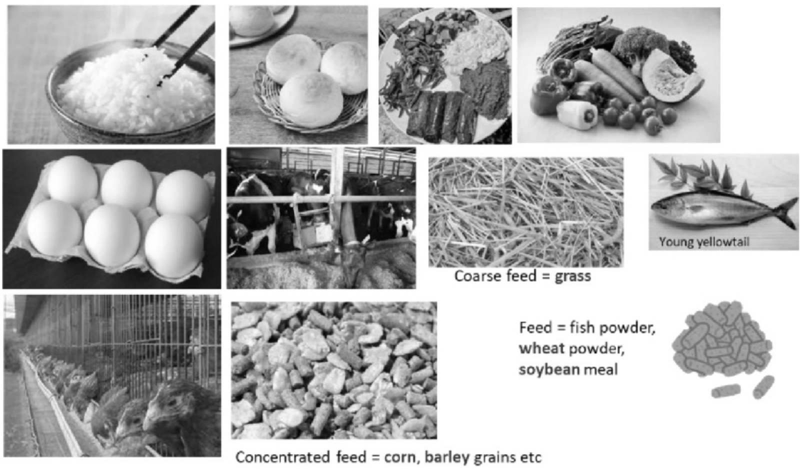
I. Introduction

According to the latest projection, the global population could grow to around 8.5 billion in 2030 and 9.7 billion in 2050 (United Nations, 2022). It is essential to increase crop production to support the growing population. By 2050, global agricultural produciton may need to be increased by 60% to 110% to meet these increasing demads (Ray et al. 2013). In general, there are two ways to increase crop production: to increase crop land area and crop yield per unit area. Global crop land area has not increased greatly in the last decades and the current estimate for crop yields is insufficient to feed a world's population by 2050 (Ray et al. 2013). Food crisis could occur in the near future.

Another global concern is global warming and climate change. According to the IPCC report, global warming, reaching 1.5℃ in the near-term, would cause unavoidal increases in umltiple climate hazards and present multiple risks to ecoystems and humans (IPCC 2022). To minitigate global warming, we need to bring multiple climate mitigation actions. The main actions that we can do in the field of agriculture are to increase soil carbon sequestration and reduce greenhouse gas emissions, synthetic agrochemicals and fertilizers. Consequently, one of the primary challenges of the world is to feed the growing and more demading world population with reduced synthetic inputs and minimal environmental impacts (Pittelknow et al. 2015). In this memorial lecture, various approaches to sustainable soil use are introduced and discussed.

2. Agricultural productivity and its relation to soil function

There are five essential elements in crop production; sunlight, water, temperature, carbon dioxide, nutrients. If even one of these lacked, crop production would become minimum. In addition to



these essential elements, soil is also very important, since soil provides 98.8% of calories which human beings consume every day (Kopittke et al. 2019). We eat a variety of foods coming from the land, river, lake, ocean, factory etc. Our staple foods are rice, wheat, potato, maize and all these crops are cultivated predominantly in soil. In addition, meats are produced by feeding mainly plant-based foods and in acquaculture, the main feeds are of plant-origin. Soil supports our lives via its ability to support the growth of plants (Fig. 1).

Fig. 1 Our daily food: among calories human beings consume every day, 98.8% derive from soil (=plants) (Kopittke et al. 2019)

Various soil functions contribute to the agricultural productivity: 1) nutrient supply, 2) water retention and supply and 3) support root eonvironment. These soil functions are essentital to support plant growth and listed among other important factors affecting agricultural productivity, such as climate, topography, fertilization, cultivation technique and kinds of crops and varieties (Matsunaka 2003) (Fig. 2). *"We need healthy soils to achieve our food security and nutrition goals, to fight climate change and to ensure overall sustainable development (José Graziano da Silva, FAO Director-General)"*.

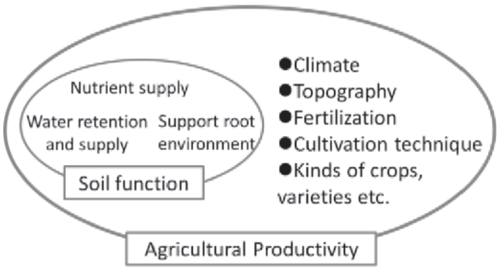


Fig. 2 Soil functions contribute to agricultural productivity (Matsunaka 2003)

However, there are many threats to the healthy soisl and resultant sustainable crop production. Firstly, nutrient deficiency is of prime importance. N, P and K are the major fertilizers and Ca, Mg, S are included in macronutrients. Fe, Mn, Zn, Cu, B, Mo, Cl, Co, Ni are also essential micronutrients. Since crops do not grow healthy even if one element lacks, we need to manage soil nutrient status properly. Secondly, various pests consisting of animal pests, diseases and weeds threaten crop production. For example, damage caused by plant parasitic nematodes has been estimated $US 80 billion per year (Nicol et al. 2011). Since soil itself has more or less natural suppresiveness to pathogens and animal pests, it is desirable to utilize or improve the natural property of soil for sustainable pest management. Thirdly, salinity control is another important issue. Approximate 7% of the world's agricultural lands are affected by either salinity or salinity-related sodium toxicity (Schroeder et al. 2013). Salinity problems are often observed in dry areas. However, these are also seen in greenhouses in wet areas like Japan having a plenty of precipitation if management is improper. Fourthly, erosion also threatens crop production, in particular in slope agricultural lands and a fallow period in dry season. Since erosion deprives the nutrient-rich top soil, erosion control is another important issue for sustainable soil use.

3. Current situtaions of nitrogen fertilizers and environmental impacts of nitrogen fertilizers

Chemical fertilizers have been needed to produce enough food for people in the world. However, a large amount of CO2 is emitted in the process of fertilizer formation, e.g. 1.6 kg CO2 is emitted to produce 1 kg of urea-N. In addition, only around 40% of the N fertilizers applied to agricultural land is taken up by crops, indicating about half is lost to the environemnt through gaseous emissions of nitrogen compounds and the leaching and runoff of disolved N compounds to water bodies (Xia and Yan 2023). The resultant pollution threats are observed in various places, e.g. dead zones in coastal waters, harmful algal blooms, terrestital and aquatic biodiversity loss, nitrate contamination of drinking water, air pollution, stratospheric ozone depletion and climate change (Schulte-Uebbing et al. 2022). Agronomists are endeavouring to find a “win-win” strategy to produce more crops with less N pollution (Fig. 3).

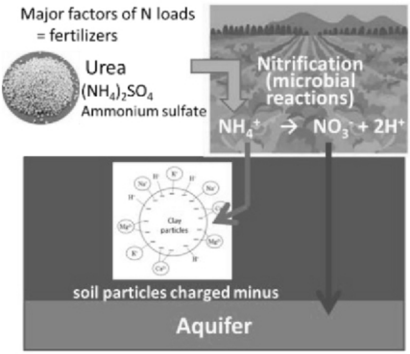


Fig. 3 Mechanisms for nitrate pollution of underground water

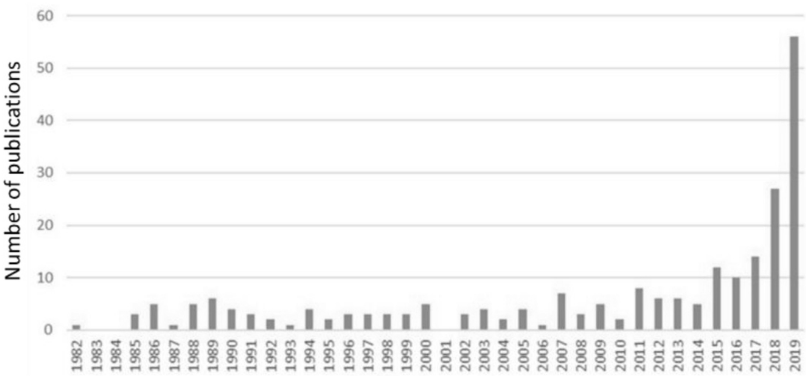
An option to mitigate nitrate leaching is to introduce green manure in a fallow period. In some agricultural land in Japan, a summer period is left fallow and such a field is vulnerable to wind and water erosion. We are recommending farmers to grow mung bean (*Vigna radiata L.*). This idea originates from nematode control. We reported that the density of the soybean cyst nematode *(Heterodera glycines)* in soil was suppressed by mung bean incorporation (Chikamatsu et al. 2021). The soybean cyst nematode forms cysts, which have a high environment tolerance ability and survive in soil for a long time in the absence of host plant. Hatching of the nematode is stimulated by growing mung bean, but the nematode does not multiply in mung bean. Thus, an option to control the soybean cyst nematode is to grow mung bean in a summer fallow period in green soybean production areas. We set up collectors for soil particles both in a fallow field and in a field sown with mung bean. The result clearly showed that wind erosion was markedly suppressed in the mung bean field. In addition, nitrate remaining in soil after harvest of the previous crop was easily leached out from the soil layer in a fallow period, because there is a lot of precipitation in Japanese summer (Toyota 2021). By contrast, nitrate leaching from an upper layer to a lower layer was suppressed by growing mung bean in a summer fallow period. In addition, mung bean cultivation augments soil carbon and nitrogen through incorporation of plant biomass and biological nitrogen fixation.

4. Eco-friendly agricultural systems - organic agriculture and regenerative agriculture

Organic farming is an agricultural system that uses fertilizers originating from organic matter, such as compost manure, green manure, and bone meal, and places emphasis on techniques such as crop rotation and companion planting (Wikipedia). Organic farming is a system aiming at producing food with minimu harm to ecosystems, animals or human (Suefert et al. 2012). Thus, organic farming attracts attention world wide and the global sales of organic food and the land area devoted to their production is readly increasing for the last decades (Weil and Brady 2017). However, the ratio of organic farms to total agricultural land is very low, 0.4% in the word average, 0.2% in Japan and 1.6% in Europe (FiBL report). Organic agriculture has various advantages, such as less pollution on produce and less adverse environmental effects, but the yields of organic agriculture are over 20% less than those of conventional agriculture (Seufert et al. 2012). The low yields are considered as a main reason that organic farming is less common in the world.

Regenerative agriculture is a type attracting much attention in recent years (Fig. 4). *It is an approach to farming that uses soil health as the entry point to regenerate and contribute to multiple ecosystem services, with the aspiration that this will enhance not only the environmental, but also the social and economic dimensions of sustainable food production* (Schreefel et al. 2022). The key processes are 1) reduced (no-) tillage, 2) rotation or use of cover crops, 3) use of natural pest control and no synthetic pesticides, 4) use of organic fertilizer and no synthetic fertilizers. Next, outcome-based definitions are 1) increase biodiversity, 2) increase C sequestration, 3) reduce greenhouse gas emission, 4) maintain or improve farm productivity, 5) improve the social and economic wellbeing of communities. In regenerative agriculture, declining crop yields are a well-known symptom and economic profitablity is prioritized over environmental and social objectives of food production.

One of the debates on organic and regenerative agriculture is the adoption of non-tillage. It is well known that non-tillage increases soil animals and microorganisms (Weil and Brady 2017). However, yields of non-tillage are on average 5.7% lower than those of conventional tillage systems (Pittelknow et al. 2015). The yields increased up to -3% if crop residue was returned and crop rotation was adopted, but decreased to -10% without residue return and rotation. In many Asian countries, it is hot and humid and weed problems are much greater than those in the other parts of the world. Tillage is a good practice to control weeds and thus it is not feasible to propagate non-tillage agriculture in many parts of Asian countries.



5. Role of soil function in supporting plant growth

Soil quality is assessed with regard to the capacity of a soil to perform 6 functions, which are intimately associated with biological, chemical and physical soil processes (Brady & Weil 2017). (1) cycle nutrients: this function provides essential plant nutrients at appropriate times and amounts. (2) regulate water: absorb, store and release water to plant roots. (3) provide physical support and maintain stability. (4) exhibit resistance and resilience function that minimize the degree and duration of impacts from major disturbances such as fire or combustion. (5) filtering soil particles and buffering toxic compounds. (6) provide habitats for soil organisms and nurture biodiversity. These soil functions are evaluated by the following twelve soil quality indicators to determine soil quality (Fig. 5). For example, in the case of nutrient-cycling function supporing plant productivity management goal, the soil quality indicators include such measureble properties as potentially mineralizable N, available phosphate level, soil pH, cation exchange caacity, soil depth.

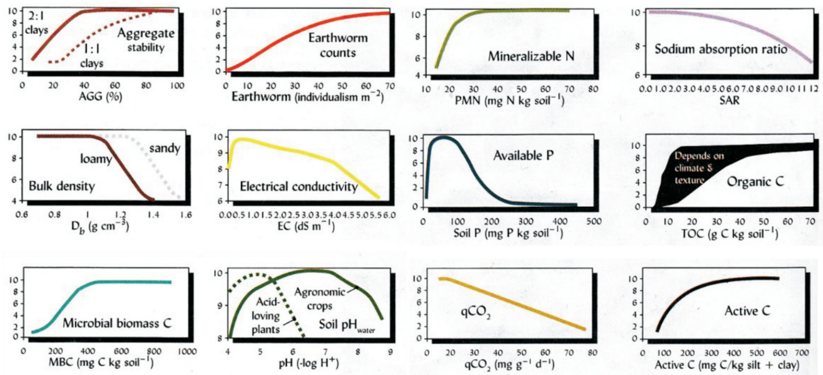


Fig. 5 Twelve soil quality indicators (Weil & Brady 2017)

Among these indicators, the most important parameter would be soil organic C content, which is directly and indirectly associated with many other parameters, including aggregate stability, earthworm counts, mineralizable N, bulk density, microbial biomass, qCO_2 which is defined as CO_2 emission per unit of microbial biomass C. In general, soil organic C is closely related with crop yields, although there are exceptions. In a study by Kanchikerimath and Singh (2001), 10 treatments with different kinds and rates of chemical fertilizers and manure were set up and crop yields were monitored for 26 years. Yields of three crops (cowpea, maize and wheat) showed significant correlations (R2 values ranged from 0.47 to 0.82) with the soil organic C content. In a study by Liu et al. (2014), a total of 26 soil parameters were evaluated: physical properties; soil texture (a ratio of sand, silt and clay), bulk density, soil aggregate stability, chemical properties; soil organic matter, total N, pH, cation exchange capacity, available N, available P, available K, available Si, available Zn, biochemical and biological properties; dehydrogenase, β-glucosidase, acid phosphatase, urease, microbial biomass C and N, Gram(-) bacteria, Gram(+) bacteria, actinomycetes, arbuscular mycorrhizal fungi, total bacteria, total fungi. Among these parameters, arbuscular mycorrhizal fungi, microbial biomass C, total N, available Si and K are the best combination to estimate rice yield. Consequently, nutrient input is the most important in soils which lack in some of essential nutrients and otherwise total C and microbial biomass C are the most important indicators in estimating crop yields.

6. How to improve soil function

As described above, the most important parameter in soil quality is organic C content. There are two ways to improve soil organic C. One is organic amendment. Crop residue after harvest should be returned to soil. Organic materials such as animal manure and municipal biowaste are recommended to apply to fields after composting, since fresh organic matter often causes inhibitory effects on plant growth. Composting is an aerobic decomposition process of organic matter, in particure manure, litter and straw.

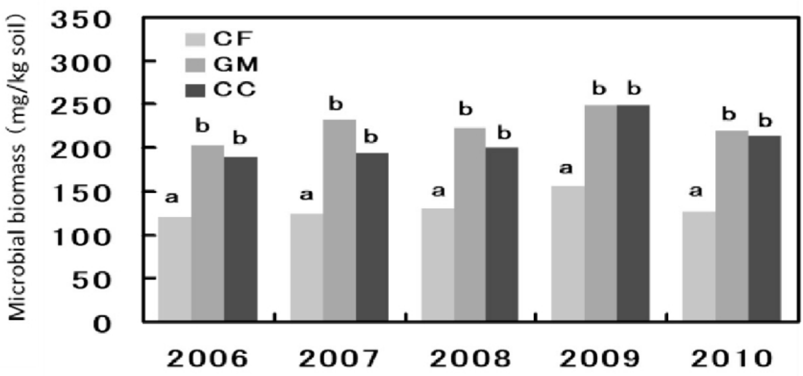


Fig. 6 Effect of green manure (GM) and compost (CC) on soil microbial biomass carbon in a field in Okinawa Prefecture. CF: chemical fertilizer, GM: green manure (Sesbania 25 t/ha), CC: cow manure compsot (25 t/ha). Different fertilization management started in 1986. Miyamaru et al. (2012).

Another way is the introduction of green manure, which has a similar meaning to cover crop. Crops are grown for a certain period in field and incorporated into the field without any harvest. A variety of crops are used as green manure, such as plants belonging to Poaceae (sorghum, oat, rye etc.), Fabaceae (milk vetch, hairly vetch, sunn hemp etc.), Asteraceae (marigold, sunflower etc), Brassicaceae (mustard, rapeseed). Among these, Poaceae crops have a feature of high biomass and provide a large amount of C to soil. Facaceae crops provide organic N fixed by symbiotic N fixing bacteria. Some green manure crops, such as sunn hemp (*Crotaralia*) and marigold (*Tagetes*), are famous for their nematicidal property. Soil microbial biomass C is markedly increased by amending compost or green manure for a long period (Miyamaru et al. 2012) (Fig. 6). Microbial biomass contains a variety of bioelements, most of which are essential elements for crops. Thus, microbial biomass provides crops for nutrients via thier turnover, which is estimated to range rom 0.3 to 4 years.

7. Nitrogen supplying capacity of soil

Nitrogen is the most limiting element for crop growth in many cases and therefore, N fertilizers are frequently used in agricultural fields. Crops uptake a part of N applied as fertilizer, but its contribution to total N uptake by crops is less than half. The remaining part of N uptake derives from soil N. For this reason, nutrient cycling is an important soil function and we measure mineralizable N, which is an organic N fraction that is readily mineralized, as a soil quality indicator. Soil microorganims mainly consisting of bacteria and fungi directly mineralize organic N into mineral N. Activities of soil animals accelerate nutrient mineralization in soil. It is well known that a litter decomposition rate is faster in the presence of diverse soil fauna. A rate of N mineralization is faster in the presence of free-living nematodes and protoza, which feed on soil microorganisms. An indicator for nutrient supplying capacity is soil respiration. Soil organic matter has a given C/N ratio, ca. 10, indicating that N is mineralized along with the decomposition of soil organic matter, which resulted in CO_2 emission.

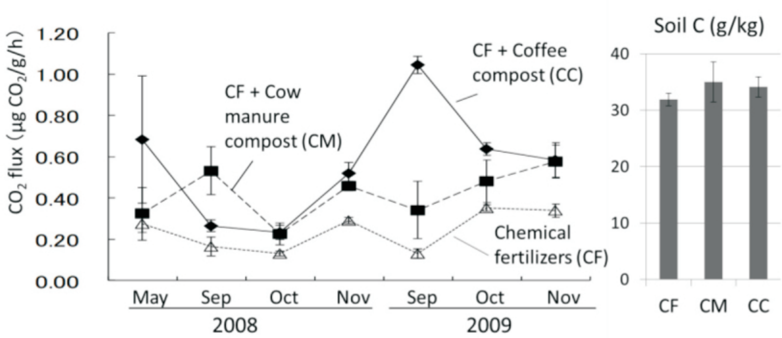


Fig. 7 Effect of chemical fertilizer and compost amendment on soil basal respiration and organic matter content. Cow manure compost and okara-coffee compost had been applied at rates of 8 and 3 t/ha, respectively, since 1995. Unpublished data.

In a field in Kanagawa Prefecture, Japan, cow manure compost or okara-coffee compost had been applied with a compound fertilizer. Soil organic matter content was not significantly increased by the compost amendment, however, soil respiration was markedly higher in soil with organic amendment (Fig. 7). This result indicates an important role of compost amendment in increasing the soil nutrient-supplying capacity.

8. Biochar as a key player in sustainable agriculture

Biochar has become a hot topic in recent years because it has been suggested as a potential tool to mitigate climate change by sequestrating its C in the soil. In the famous textbook in soil science "The Nature and Properties of Soils", there was no section dealing with biochar in the 14th edition published in 2008. Biochar frstly appeared in the 15th edition in 2017 as "Biochar: hype or hope for soil quality". Biochar has been reported to exhibit many benefical efects on soil health and plant growth. In general, biochar amendment shows on average 5-10% increase in crop yields, although effects range from 30% yield increase to 20% yield decrease (Weil & Brady 2017). Biochar has common properties such as high pH, high surface area, high CEC, and thus shows a liming effect in acid soils and provides nutrients especially N, P, S. In a study using a saline rice paddy soil (pH (H2O) 7.6, EC 1.8 mS/cm), biochar application at a rate of 50 g/kg of soil markedly increased the infiltration rate in the soil and rapidly removed the soil salinity (Phuong et al. 2019). Biochar obviously ameliorates the soil physical properties, although its application rate is high and it is not economially feasible in most cases. In another field study conducted in the Mekong Delta, Viet Nam, biochar application at a rate of 10 t/ha/crop decreased soil Na content and improved ESP (exchangeable sodium percentage), an indicator for salt toxicity (Phuong et al. 2020). After a total of 5 times application, soil total C content significanlty increased and the rice grain yield was also increased. Interestingly, the direct cause for the higher yield was considered the supply of available P by rice husk biochar, in spite that the field had been applied P fertilizer at a rate of 60 kg P2O5/ha/crop (Linh et al. 2023) (Fig. 8). How to obtain biochar at a profitable price is a key issue.

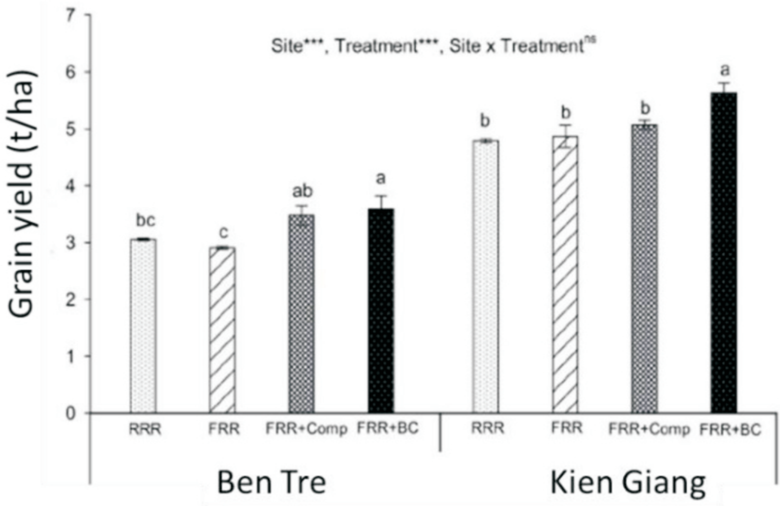


Fig. 8 Effects of cropping patterns and organic amendment on the rice grain yield in fields in two locations in Vietnam. RRR; triple rice cultivtion in a year, FRR; fallow and doube rice cultivation, FRR+Comp; FRR + sugarcane filter cake compost at 3 t/ha/crop, FRR+BC; FRR + rice husk biochar at 10 t/ha/crop. Linh et al. (2023).

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Dr. Koki TOYODA is a Professor of Soil Biology at Tokyo University of Agriculture and Technology. Dr. TOYODA graduated in Agricultural Chemistry from Nagoya University in 1988, and completed a PhD in ecology of soilborne plant pathogens at Nagoya University in 1993. He was then appointed as Assistant Professor at Nagoya University in 1994 and moved to Tokyo University of Agriculture and Technology in 2000. He is one of the renounced researchers in the field of ecology of soil microorganisms and his research mainly focusing Soil Biology, Environmental Microbiology, and Crop Protection. He has published more than 190 research papers in reputed indexed Journals and holding 3 patents in his name. Further, Dr. Koki TOYODA disseminated his findings and innovations by writing more than 50 books, book chapters and review papers.

For the continuous contribution to the field of expertise, Dr. Koki TOYODA has won prestigious British Council Fellowship award in 1995, Inoue Research Award for Young Scientists (1995), Young Scientist Award for Soil Science and Plant Nutrition (2003) and Award for Soil Science and Plant Nutrition (2019). He is a Vice-President of Japanese Society of Soil Microbiology and Chairman of division of Soil Biology of the Japanese Society of Soil Science and Plant Nutrition. He is an Editor-in-Chief of the Journal Sago Palm, Senior Editor of the Journal Microbes and Environments. He is in the editorial board of the journals Biology and Fertility of Soils and Nematological Research, Biology and Fertility of Soils, Applied Soil Ecology, Nematological Research, Soil Science and Plant Nutrition. Moreover, Dr. Koki TOYODA is decorating as member of Scientific Committees of the Japanese Society of Soil Science and Plant Nutrition, The Japanese Society of Soil Microbiology, The Japanese Society of Soil Zoology, The Japanese Nematological Society, The Japanese Society of Sago Palm, The Japanese Society of Microbial Ecology, The Japanese Society of Pesticide Sciences.

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