Soil Compaction in Tropical Organic Farming Systems and Its Impact on Natural Soil-Borne Disease Suppression: Challenges for Management

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Abstract**—**Organic farming systems still depend on intensive, mechanical soil tillage. Frequent passes by machinery traffic cause substantial soil compaction that threatens soil health. Adopting practices as reduced tillage and organic matter retention on the soil surface are considered effective ways to control soil compaction. In tropical regions, however, the acceleration of soil organic matter decomposition and soil carbon turnover on the topsoil layer is influenced more rapidly by the oscillation process of drying and wetting. It is hypothesized therefore, that rapid reduction in soil organic matter hastens the potential for compaction to occur in organic farming systems. Compaction changes soil physical properties and as a consequence it has been implicated as a causal agent in the inhibition of natural disease suppression in soils. Here we describe relationships between soil management in organic vegetable systems, soil compaction, and declining soil capacity to suppress pathogenic microorganisms.

Keywords**—**Organic farming systems, soil compaction, soil disease suppression, tropical regions.

I. Introduction

A concern regarding the incidence of soil compaction in Organic farming systems around the world is related to its long-term effects on soil structural degradation [1]. Flowers and Lal [2] reported that soil compaction induced by heavy load traffic (machinery) has degraded around 68 million hectares of the total cultivated land worldwide. The area degraded by soil compaction in Asia was about 10 million ha [1] and about 4 million ha in Australia [3]. The dependency of Organic farming systems on the use of heavy machinery for soil tillage has caused substantial compaction within soil layers [4].

Soil compaction has incited direct and adverse changes in soil physical parameters which influence soil health [5]. Supporting evidence from field and laboratory studies emphasizes the fact that compaction increases soil bulk density and soil strength [6], [7] and reduces soil pore size and distribution [8]. Soil compaction at moderate levels can be beneficial [9], but heavy soil compaction can limit air permeability, soil respiration and oxygen diffusion [5]. Through a combination of these factors, soil compaction will influence the stability of microbial structure and functions. Changes in microbial community structure and function influence the capacity of soil to ‘naturally’ suppress disease.

II. Soil-Borne Disease Suppression

Soil-borne disease is the major production constraint confronting intensively-managed agricultural systems [10], [11] Soil-borne disease outbreaks are considerably more frequent in the tropics [10], and are expensive to manage in Organic farming systems. The prevalence of soil-borne disease in the region is the result of the interaction between climatic factors and soil management factors. Climatic factors including hot temperature and high rainfall facilitate short generation times and increased virility of pathogenic organisms, whilst soil management factors in association with the climate of the region lead to soil structural decline and a further build-up of pathogens [12], [13].

Every soil in tropical regions has a natural level of resistance or capacity to control disease, called *natural disease suppression* [11], [14], [15] whereby very low levels of soil-borne disease occur at the paddock scale even when the disease and susceptible host plants are present. Soils which continuously deliver disease suppression naturally are often termed “healthy soils”. The suppressive capacity can, however, decrease in some soils, which allow crop roots grown in the soils to be attacked by disease pathogens.

The soil suppressive capacity has been distinguished into two types: general and specific suppression [16]. General (‘natural’) disease suppression, pertains to soils with high microbial biodiversity that create conditions unfavorable for a broad range of plant disease [17]. Conversely, specific suppression can occur when a beneficial organism is present in soil and directly suppresses a known pathogen [16]. This suggests that microbial interactions are primarily involved in both types of soil-borne disease suppression and are therefore considered an important aspect in developing biological control methods for soil health management purposes [14]. In addition, understanding the relationships between maintenance of soil health, soil biological community function and disease suppression is pivotal to ensure future food security and Organic farming sustainability [18], [19].

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III. Challenges for Management of Compaction in Organic Farming Systems

Adopting reduced tillage combined with organic matter retention on the soil surface is considered an effective way to control soil compaction [20]. Various studies have shown that the reduced need for tillage has had a considerable influence in the establishment of 'better' soil macro-aggregates [21]; the increase of soil organic carbon [22]; and water infiltration [23]. In addition, such a condition can persist for several planting seasons [21]. Thus, reduced tillage provides 'good' soil physical conditions and to support cropping systems and has recently been promoted as a strategy to enhance soil health in Organic farming systems [24].

The use of reduced tillage and stubble retention in tropical region, however, can have adverse implications for soil health. Higher temperature and heavy rainfall throughout the year produces a consecutive drying-wetting cycle in the soil, this affects soil physical conditions [21], [25]. Six, Feller [21] suggested that an alternation of wetting and drying taking place rapidly can disrupt the soil structure and detach the aggregates into small particles. Within the climatic oscillation process, the particles are then rearranged to bring them into closer contact with one another leading to stronger binding. This induces a compaction process rapidly within the soil layers. Therefore, reduced tillage could actually result in increased compaction in Organic farming systems.

Organic farming systems use organic matter inputs, which when combined with the effects of the tropical climate, may cause a rapid reduction of organic matter. The consecutive drying-wetting cycle influences the acceleration of soil organic matter decomposition and soil carbon turnover in the topsoil layer [21], [25]. Feller and Beare [26] reported that soil carbon turnover rate is twice as rapid in tropical soils compared to temperate soils. Therefore we suggest challenges associated with reduced tillage and stubble retention in tropical Organic farming systems – in fact, these management strategies may induce high compaction and hence low organic carbon; both of which will influence soil microbial communities.

IV. Challenges of Heavy Compaction When Facilitating Natural Disease Suppression in Organic Farming Systems

Organic farming systems use tillage and organic amendments. However, tillage causes compaction, especially in the tropics. Increased compaction will affect soil microbial community structure and functions including microbial abundance, functional diversity and activity which are measurable indicators for soil health and are highly sensitivity to abrupt environmental changes [27]. Several authors have outlined the effects of soil compaction on soil microbial biomass and activity and fungal and bacterial populations. For example, total bacteria and fungi in soil decreased by more than 40% with the increase in compaction level from bulk density of 1.10 Mg m^{-3} to 1.40 Mg m^{-3} [28]. The same researchers also found that microbial community structure in soil changed with compaction as well. In addition, heavy compaction has reduced some enzyme activities including dehydrogenase, phosphatase, arysulphatase, and amylase from 41 to 75% [29]. Similar results were found by Pupin, Freddi [30] with dehydrogenase and phophatase activity, which reduces significantly in increased compaction level. Thus, changes in microbial structure reduce microbial activity which has significant implications on the inhibition of soil microbial functions.

Adopting reduced tillage is still a problem in the tropics, and thus combined with organic amendments may not only enhance the level of compaction but also soil moisture content. High soil moisture content in wetter compacted soils can impair aeration [5] leading to anaerobiosis [31]. Reduction of the total soil pores as a result of heavy compaction may decline the proportion of air-filled porosity indicated by low O_2 availability, which can restrict the growth and activity of aerobic microorganisms [8], [32], [33]. Limitation of the enzyme activities are associated with the reduction of aerobic microbial community [34], [35] followed by an increase in anaerobic microbial community (e.g. denitrifying bacteria community) which facilitates denitrification in soil [36]. This phenomenon is highly likely to occur in cultivated soils under tropical climatic conditions [21]. The anaerobic condition can shift soil microbial structure and functions.

Microbial communities are affected by compaction, soil water fluctuations, and the substrates provided by organic matter amendments, and therefore a challenge for Organic farmers is to continue to undertake or modify their practices to favor certain types of microorganisms in the soil. If Organic farmers can do this, then they may be able to promote natural disease suppression. This process is likely to be complex, and there are a number of challenges associated with doing so. Nonetheless, Organic farming systems are so susceptible to disease, that this area is worthy of further investigation.

V. Conclusion

The extent to which compaction affects soil biology and the subsequent relationships between the remaining favorable soil biota and the incidence of soil borne disease remains an area that is poorly understood. It is known that management practices that lead to compaction affect the population dynamics of various soil microorganisms, including those with a propensity to cause disease. Given the prevalence of disease in tropical Organic farming systems, there is a need to investigate causal links between compaction, soil biology and disease suppression. There exists an opportunity for land managers and practitioners to adopt techniques that facilitate the growth and diversity of '*beneficial*' or disease-antagonistic microorganisms. Altering soil biological communities to favor beneficial microorganisms should enhance inherent or 'natural' soil disease suppression.

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