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Junior Scientists Tandems
Final Report

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Title: Impact of Regenerative Agriculture on Soil Health, Greenhouse Gas Fluxes and the Nutritional Quality of Mung Bean (*Vigna radiata* L.)

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Introduction

Although soil is the literal foundation of ecosystems and agriculture, soil health has been declining globally through various degradation processes. Many of their causes are anthropogenic and directly linked to agricultural activities. More sustainable soil management practices are thus urgently needed. In this context, regenerative agriculture has been gaining attention in both research and practice as it specifically aims to improve soil health. However, the effect of such well-intended, “sustainable” practices varies drastically between different contexts, e.g. climates, soil types or combinations of practices. Further, as soils are part of a complex, interconnected ecosystem the impact of a management change is not limited to only the “target” – unplanned or even unnoticed negative modifications of other variables can occur. These potential trade-offs must be considered prior to the implementation of a new management system.

Despite the urgency of this topic, the interlinkages of regenerative soil management, soil health and soil ecosystem functions (e.g. climate regulation, food provision) are still “under-studied”. This knowledge gap is particularly persistent for tropical vegetable production systems. Thus, I was very excited to study this broad and complex topic in the frame of the “Career Exploration” scholarship of ATSAF e.V. at the World Vegetable Center for the past 7 months – thereby potentially contributing to closing the gap. The main objective of my research project was to identify the most effective combination of regenerative practices to promote soil health, reduce greenhouse gas emissions and increase the nutritional quality of the tropical legume mung bean (*Vigna radiata* L.). “Could sustainable agriculture and soil health act as tools for climate change mitigation and nutritional security?”

Methods

A field study was conducted at the World Vegetable headquarters in Shanhua, Southern Taiwan. Three factors, namely “tillage intensity”, “fertilizer” and “winter cover”, were studied. The conventional practices were “roto tillage”, “mineral fertilizer” and “no cover crop over the winter season”. Regenerative practices were “no-till”, “composted cattle manure” and a “sunn hemp (*Crotalaria juncea*) cover crop”. The combinations of these practices led to eight distinct treatments with three replicates each. The trial was established in December 2024 (sowing of the cover crop). The main crop mung bean was grown in the spring season 2025.

Figure 1: Study site at the WorldVeg campus in Taiwan

To reach the objective, an interdisciplinary approach was used, covering various parameters relevant for soil health, climate and nutrition. However, soil health itself, as the central variable, is not a single, specific parameter which can be measured directly. It is a multi-dimensional concept which combines diverse soil parameters and their interactions. For this research project, different physical, chemical and biological indicators were chosen to quantify soil health. The selection was based on recent literature as well as the availability of methods.

Soil physical structure was mainly evaluated based on soil aggregation and bulk density. For this, the traditional methods of wet-sieving (share of water stable aggregates) and sampling/weighing of an undisturbed soil core (with known volume) were used. Chemical parameters included the content of soil organic carbon, inorganic nitrogen, soil pH and plant available nutrients, among others.

For evaluation of the biological dimension, which is fundamental to the soil health concept, soil microbial biomass, root colonization by arbuscular mycorrhizal fungi (AMF) and the diversity/abundance of soil microbes were assessed. Microbial biomass was quantified via an indirect approach where soil DNA concentration is used as a proxy (Fornasier et al., 2014). For AMF colonization, fine roots of mung bean plants were destained using KOH, stained using an ink-vinegar solution and then assessed with a dissecting microscope using a modified grid-intersect method. Here, the absence or presence of AMF structures at intersections of roots and grid lines is evaluated. Fungal and bacterial diversity and abundance were assessed via metagenomic analysis (ITS and 16s primers) after extraction of soil microbial genomic DNA.

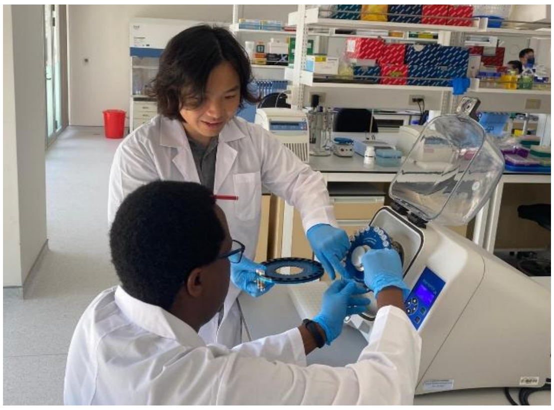

Figure 2: During extraction of soil DNA

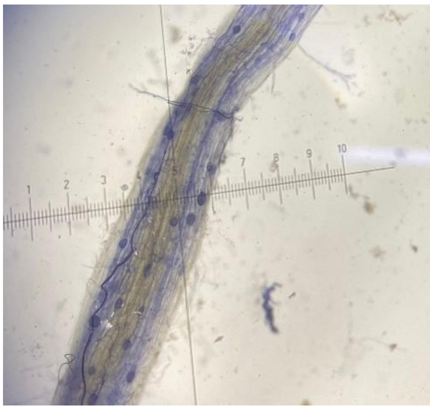

Figure 3: AMF vesicles in mung bean roots

Soil greenhouse gas emissions, namely CO_2, CH_4 and N_2O, were measured bi-weekly over the course of the growing period of mung bean (in total six measurements for each gas) using the LI-7810 and LI-7820 Gas Analyzers and the 8200-01S Smart Chamber (LI-COR, United States).

Figure 4: LI-COR Smart Chamber

Figure 5: GHG measurement in mung bean field

For the main crop mung bean, aboveground biomass as well as total and single plant yield were quantified. For crop nutritional quality, macro- and micronutrients were analyzed. This included an analysis of the amino acid profile. Additionally, antioxidants and polyphenols were quantified. In this context, the content of the flavonoids vitexin and iso-vitexin, which are major phytochemicals in mung bean, were separately assessed. As a higher AMF colonization has been associated with an increased content of the fungi-synthesized antioxidant ergothioneine (Carrara et al., 2023), this compound was also quantified.

For statistical analysis, three-factorial ANOVA and linear mixed models were used. Analyses were done with the “statsmodels” package in Python (version 3.13.) and the “lme4” package in R (version 4.5.).

Results and Discussion

Although not all parameters have been analyzed yet, the preliminary results are promising. For instance, improvements of soil structure were found under regenerative management, including an increased aggregate stability and reduced bulk density. While not statistically significant, these results indicate that structural improvements can already be detected after a single season of regenerative management. The higher aggregation, porosity and soil stability are interdependently linked to the soil microbiome and the crop plants. For instance, increased microbial exudation as well as root exudation from the cover crop support the aggregation of soil particles – but microbes and plants also benefit from the associated structural improvements (e.g. soil aeration, water infiltration).

As for soil microbial parameters themselves, regenerative practices do indeed seem to support the soil microbiome. The soil microbial biomass, estimated via the soil DNA concentration, was tendentially higher when organic fertilizer. Additionally, the mung bean roots showed tendentially higher colonization by arbuscular mycorrhizal fungi under reduced tillage. Considering the detrimental effect of soil disturbance on the fungi’s hyphae, this positive effect of reduced tillage intensity seems reasonable.

Regarding the soil-borne emission of greenhouse gases, a strong temporal variability stands out. This is potentially due to differences in soil moisture (irrigation), time since fertilization and varying plant nutrient uptake. Still, across the growing period, a clear, statistically significant decrease in nitrous oxide emissions was found when switching from mineral to organic fertilization. On average, the efflux rate decreased by 67%. Carbon dioxide, in comparison, was slightly increased under regenerative management, particularly organic fertilizer. This could be partly attributed to an increased availability of organic carbon which is then enhancing metabolization processes of soil organisms.

The main crop mung bean grew well, despite various abiotic and biotic stressors. Unfortunately, no data on yield or nutrient content of mung bean can be presented yet. Harvest and analyses are still on-going, but they will finish soon. However, differences of aboveground biomass between treatments indicate higher biomass in minerally fertilized plots (more readily available nutrients) as well as interactions between the factors “tillage” and “cover crop”. The measurement of final yield and later the analysis of nutritional quality will give deeper insights into the effects of regenerative practices on mung bean production and human nutrition.

Personal Reflections

Overall, my time at the World Vegetable Center in Taiwan was very nice. The Agroecology unit was an incredibly dynamic and fun group of people to work with. Taiwan itself surprised me with its rich history and culture, beautiful nature and sunny people. While I encountered some challenges in my research and daily life (e.g. visa, dormitory), most of them were resolved quickly. Susan Tsai, the internship coordinator at WorldVeg, was very supportive.

Figure 6: Yangmin-shan National Park

Figure 7: Lunch with colleagues

Conclusion

This research project, while still on-going, has demonstrated the diverse effects different combinations of regenerative practices can have. Especially for soil health, structural and microbial improvements were found. However, the preliminary results also show the complexity of the soil system and modifications thereof, e.g. for greenhouse gas emissions. Hence, one of the main takeaways is that the effect of a changed management is not limited to only the target parameter – the interconnectedness of the soil ecosystem must be considered.

The past seven months were a journey of continuous and active learning. Being involved in this complex research project and the dynamic “Agroecology” group allowed me to grow both as a junior scientist and as a person. Still, there is so much more to learn about soils, so much more to do. This internship was only a beginning.

Figure 8: Agroecology unit at WorldVeg HQ

Acknowledgements

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References

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