ASIA-PACIFIC NETWORK FOR GLOBAL CHANGE RESEARCH

ARCP Final Report




Project Reference Number: ARCP2016-08CMY-Dey

Impacts of Crop Residue Removal for Biomass Energy on Soil Function; Studies to Recommend Climate Adaptive Agricultural Waste Management

The following collaborators worked on this project:

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1. Project Overview

Project Duration	:	2 years
Funding Awarded	:	US$ 40,000.00 for year 1; US$ 35,000 for Year 2
Key organisations involved	:	• South Asian Forum for Environment [SAFE] India • Department of Agriculture, Central Luzon State University, Philippines • Department of Agriculture, Royal Govt. of Bhutan • Indian Council of Agriculture Research, India

Project Summary

Renewed interests in utilizing biomass energy from various agricultural wastes for local usages in countries of South Asia and as well for its removal through open burning, prompt strategic assessment of the common practice of agro-waste management in the climate milieu. In the present study, spanning India, Bhutan and Philippines, impacts of removal & burning crop residues on local environment, soil health and yield has been found to be detrimental, compared to keeping it and utilizing it more wisely as since the wastes, when used as manure or mulch, perform positive functions by controlling surface erosion, retaining soil organic matter and soil moisture, enhancing soil functions & by restoring bio-ecology of the soil. Agro-waste biomass used as raw mulch and bio-char has also improved the carbon capture and storage potentials of soil and abated loss of air quality. On-site biomass burning contributed to climate change by releasing GHGs, forming tropospheric ozone, produces smoke aerosols with adversely impact ambient air quality, temperature & health. Therefore, specific guidelines for residue harvest & utilization that are impending has been recommended for climate adaptive sustainable agro-practices in waste management and as well scientifically validated in the present action-research.

Keywords: Agricultural waste, biomass burning, soil carbon, climate adaptive farming

Project outputs and outcomes

OUTPUT:

1. The agro-ecological frontiers of intervention in all project implementation sites were finalized with identification of location and beneficiaries of the project, based on agro-farming practices and trends of agro-waste management.
2. Eco-physiological attributes, farming practices, crop range and agricultural waste residue availability is known through habitat survey for need assessment in all three sites of intervention.
3. Soil functions and local ecological traits of the agrarian habitats were estimated for all three intervention sites. Field data is retrieved and assessed to find trends and analogies. Studies on terrestrial carbon flux and surface to below ground soil carbon sequestration are initiated.
4. Primary estimates of crop residue volume, carbon content (stock), calorific value, emission potential etc are obtained from intervention sites. Dosage compensation formulation for regulated volume combustion of crop residues is prepared. Emission potentials and impacts assessed.
5. Strategic impact assessment report validating ‘residue keeping versus residue burning’ is prepared for ready reference.

6. Implicative changes in terrestrial carbon flux and emission potentials are substantially studied with reference to climate adaptive agricultural waste management.
7. Suggestive alternatives for energy resources and efficient burners are demonstrated and as well sustainable agro-waste management strategies formulated and verified from intervention sites.
8. Participatory framework for enabling decision support tools for agricultural waste management through community based intervention is completed. Results of intervention well disseminated for extended action research.

OUTCOME

1. Sustainable crop residue removal rates varying from 25% to 100% of the total waste generated from unit area of cultivated land for usage as raw waste or bio-char treatment or else for complete biomass burning is determined by the crop cycle management, yield and soil type that could be understood more rationally from the research results obtained from specific practices in diverse cropping systems and across contrasting ecological paraphernalia.
2. The perusal of experimental data suggests that locally relevant soil conservation practices like contour cropping or conservation tillage or as cover crop to compensate for the loss of erosion protection and SOM reductions must be integrated with agricultural residue removal and its reapplication as soil treatments, to get augmented impacts on soil function enhancement.
3. Energy crops like *Euphorbia*, *Arundo donax* etc as alternative sources for biomass-energy, to promote environmental and economic viability for sustainable agro-waste use is demonstrated to the direct beneficiaries.
4. A decision support research finding, establishing the need for change in agro-waste management for developing nations is propounded as reference and as well for implications in policy framework.
5. The research incubated academic deliberations in the concerned fields for in-depth evaluation of agricultural waste management practices in the climate milieu to abate the emission and pollution in open burning and adapt carbon efficient practices of wastes removal and reapplication towards enhancement of soil functions.

Key facts/figures

1. Reapplication of 75% agricultural wastes by weight of the total generated wastes per unit cultivated area as bio-char and raw waste treatment enhanced the soil functions (moisture retention and fertility) to increase average productivity by 40-45 metric tons per hectare and has also saved the additional investments of USD 120-150 per acre of land on water and fertilizers.
2. The treatment has brought qualitative changes as better Commercial Cane Sugar (CCS) content (> 120 MT/Ha) along with enriched Vitamin-C as nutritional supplements for which though the production has increased up to 60% but the earnings have increased by 90%.
3. Nearly 2700 farmers have been trained 1450-1500 farmers in India and 100-125 farmers in Bhutan have adopted the agro-waste management practices of removal and re-application of agro-wastes in the field.
4. The treatments (75-100% raw waste and Bio-char) could increase the soil carbon capture and stocking ratio thereby reducing emission equivalent of ~ 42 %.

Potential for further work

A. The research speculation was that sustainable intensification of soil ecosystem services would enhance soil functions for higher yield and thereby the opportunity costs of farmers incurred in forgoing open burning of wastes either for biomass energy or just for removal could be compensated through payments from improved soil ecosystem services. This innovative and climate adaptive approach of the research which mitigated emissions and as well increase the carbon capture and storage potentials of soil, needs to be furthered through more intensive research in various other cropping systems, agrarian ecology and practices along with a robust benefit to cost analysis for economic evaluation of payments from ecosystem services.

B. Alternative usage of bagasse and other agro-wastes for 'low-water and no-chemical' intensive farming along with introduction of energy cropping or solar power as new energy regime as alternative sources to biomass needs to be researched to cause a paradigm shift in indigenous farming practices towards climate preparedness.

C. Inclusion of biochar in soil treatment has been yet another innovative approach in a way that it optimized the usage of biomass for energy and soil function enhancement as well and leveraged a win-win situation for farmers and climate practitioners, however, impacts of bio-char and raw wastes on the microbial vegetation of soil needs to be studied more extensively, especially the impacts on nitrogen and carbon cycle bacterial vegetation present in the soil.

Publications

1. Dey, D. Gyelshen, T and Juico, P.P (2018): *Impacts of Agro-waste Biomass Reapplication against Open Burning on Soil Function and Crop Productivity – An assessment Study*. Paper accepted in 26th European Biomass Conference & Exhibition (http://www.eubce.com/).
2. Dey, D. Gyelshen, T and Juico, P.P (2017) *Reusing Crop Residues for Enhanced Soil Function and Emission Reduction towards Climate Adaptive Agricultural Waste Management.* Proceedings of Fourth 3R International Scientific Conference on Material Cycles and Waste Management (3RINCs); March 8-10, 2017, New Delhi, India.
3. http://www.apn-gcr.org/resources/items/show/1947
4. https://www.apn-gcr.org/2017/04/11/south-asian-regional-workshop-on-agricultural-waste-management/

Awards and honours

The research work has been nominated for **Fakruddin Ali Ahmed Research Award 2017** from **Indian Council of Agricultural Research (ICAR), New Delhi, India.**

Pull quote

Quote – 1: Dr Ayyandhar Arunachalam, Principal Scientists, Indian Council of Agricultural Research, New Delhi, India

> *"Research on agricultural waste disposal, especially in the context of biomass burning in agricultural fields, has been presumably less and demanding. This work has a tremendous potential in determining the practices and policies about the management of agricultural wastes in India and neighbouring countries as well. It also provides a new insight in burning and keeping agricultural biomass in the current climate change perspective."*

Quote – 2: Mr. Panchanan Matha: Sugarcane Farmer, Arsha village, Raghunathpur Block, Purulia, West Bengal, India

"We have been burning the bagasse so far openly in the field. This impacts our health and even we are unable to breath in the smoke. But we never knew that the same thing when applied as raw in the field or half-burnt in close containers can turn out to be better manure. This new technique is very helpful for us to know."

Quote – 3: Mr Baptandy Dorji: Head, Department of Forest, Royal Government of Bhutan, Thimphu, Bhutan.

"Open burning of field residues is a menace in terrace farming in Bhutan, as it often causes very disastrous forest fire. Knowing that these wastes can help improving the soil quality, without burning them is really a very desirable solution. This will have very significant impact in the forest ecology of Bhutan Himalayas."

Acknowledgments

The author sincerely acknowledges the Indian Council of Agricultural Research, New Delhi, India, Department of Forest and Agriculture, Royal Government of Bhutan and Central Luzon State Agricultural University, Luzon, Philippines for their extensive support and guidance. The contribution of National Bank for Agriculture and Rural Development (NABARD), India is also earnestly acknowledged.

1. Introduction

Crop residue burning is one among the many sources of air pollution. Burning of farm waste causes severe pollution of land and water on local as well as regional scale. This also adversely affects the nutrient budget in the soil. Straw carbon, nitrogen and sulphur are completely burnt and lost to the atmosphere in the process of burning. It results in the emission of smoke which if added to the gases present in the air like methane, nitrogen oxide and ammonia, can cause severe atmospheric pollution. These gaseous emissions can result in health risk, aggravating asthma, chronic bronchitis and decrease lung function. Burning of crop residue also contributes indirectly to the increased ozone pollution. It has adverse consequences on the quality of soil. When the crop residue is burnt the existing minerals present in the soil get destroyed which adversely hampers the cultivation of the next crop. The on field impact of burning includes removal of a large portion of the organic material. The off field impacts are related to human health due to general air quality degradation resulting in aggravation of respiratory (like cough, asthma, bronchitis), eye and skin diseases. The black soot generated during burning also results in poor visibility which could lead to increased road side incidences of accident. Punjab Government, its various Departments and other institutions like Punjab Agricultural University, Punjab Farmers Commission are all making efforts to devise some alternate economic uses of rice stubble. These include the stubble treated with urea as a fodder for animals, its use in biothermal energy production, paper manufacturing, mushroom cultivation, bedding for animals, etc. Punjab government is also providing subsidy to the farmers to promote the use of equipments which help in checking the burning of crop residues, like rotavators, happy seeders, zero–till-drills and straw reapers. While on the one hand, there is an urgent need to revitalize the research in agriculture and related activities, on the other hand, to tackle the problem of soil degradation and water depletion, a dedicated programme for promoting resource conservation technologies, such as zero tillage, deep ploughing, raised bed planting, laser land levelling etc., should be promoted. An eco friendly technology will be beneficial to the farmer community and the state by providing them a tool for improving soil health and environment for sustainable agriculture.

(https://www.researchgate.net/publication/278697280_Pollution_Caused_by_Agricultural_Waste_Burning_and_Possible_Alternate_Uses_of_Crop_Stubble_A_Case_Study_of_Punjab)

Recent references of residual biomass burning in North India and indicated air pollution in Delhi has prompted immediate reviewing the regime of agricultural waste management in the milieu of climate change in this ecoregion. Open burning of crop residues for removal or to yield biomass energy leads to emission, pollution and adversely affects soil function & nutrients (Mitchell et al. 2000). Additionally, it contributes to climate change by releasing GHGs, forming tropospheric ozone etc. and as well emission of dioxins owing to the chlorine content and presence of pesticides in agricultural waste (http://www3.cec.org/islandora/en/item/11405-la-quema-de-residuos-agr-colas-es-una-fuente-de-dioxinas-en.pdf). Nearly 500 million tons of crop residues are diverted for energy needs every year in the Indian eco-region that accounts for almost 7% of total agricultural emissions, whereas they reportedly perform positive functions like controlling surface erosion, retention of soil organic matter, restoring soil functions & soil bio-ecology (2-6). Present paper attempts to assess the practice of reusing crop residues for enhanced soil function and emission reduction towards climate adaptive agricultural waste management in sugarcane fields of Purulia district in India and horticultural fields in Hongtshu Block in Bhutan.

The committee on ‘National Waste Management Policy’ constituted by Ministry of Environment and Forest Govt. of India in 2010 (http://moef.nic.in/sites/default/files/Roadmap-Mgmt-Waste.pdf) observes that in the absence of a clear policy, waste management in India in all sectors is inadequate and ineffective in meeting environmental and public health norms. While Ministry of Environment & Forest in Bhutan emphasizes on organic farming (http://www.moaf.gov.bt/moaf/?wpfb_dl=685) in 2012 plan document for better management of agricultural wastes, there is no specific policy or management strategy for the same either in Bhutan, Bangladesh, Nepal or Philippines as yet. The state recommendations are only suggestive as it acutely lacks decision support research to formulate one such. Most research on crop residue removal impacts has concentrated on the American Corn Belt and seldom addressed other crops and regions. There is a felt need therefore for studies as proposed, especially in global south wherein crop residue removal is mainly done as on-site burning and ash residues are directly dumped to the soil. Sustainable crop residue removal rates are not the same as percent soil cover, due to which appropriate conversion is necessary and will vary by management, yield, and soil type for crop and region. Decision support researches in relation to rates of residue removal in various agro-environmental conditions are too meager to guide additional conservation practices such as contour cropping or conservation tillage etc. to compensate for the lack of erosion protection and soil organic matter reductions seen with residue removal. Policies to promote crop alternatives for biofuel are therefore not defined. Crop residue biofuel may not be a viable option in terms of energy ecology or economics. Removal rates needs to be adjusted in response to adverse changes, like increased erosion or decreased soil carbon. Thus policy implications for sustainable management of agricultural waste must be raised on

1. Strengthened decision support research to regulate on-site burning of agro-wastes and help deliver through preventive policy instruments.
2. Justifications to establish range of funding & relief mechanisms to realize the potential of agricultural mitigation and its co-benefits, related to sustainable agriculture and adaptation to climate change; capture efficiencies and cost-effectiveness to restore ecosystem services like soil functions.

Importantly burning residues for bio-energy and related aspects of emissions have not yet been quantified, neither is the understanding of the impact of crop residue removal on soil ecological functions.

Perusal of research literature suggests that on-site biomass burning contributes to climate change by releasing powerful GHG. Further, fires produce a range of smoke aerosols with temperature effects. Burning in open may affect the proportion of woody versus grass cover, with implications for the frequency or intensity of fires, changes in CO2 sink in soil and biomass. Increased N2O emissions due to burning residues for bio-energy has not been quantified yet, though ban of burning of field residues in the 1980s by the European Union for air quality purposes enhanced soil carbon, reduced N2O and CH4. Air quality legislation in China (2007) bans straw burning, thus reducing GHG emissions. So, policy regulations on open burning in countries of Asia Pacific are yet unexplored and needs immediate attention.

Smoke from agricultural waste burning causes hazardous haze pollution in South and Southeast Asian countries every year. Besides traces of a few toxic gases several persistent organic pollutants, natural, and anthropogenic emissions are released, resulting in adverse health effects. Perusal of study results carried out in northern Thailand and Punjab in India on identification of sources of PM2.5-bound polycyclic aromatic hydrocarbons (PAHs) during the non-haze and haze seasons and investigations on the concentration and toxicity of fine particulate matter, especially in the middle of biomass burning period reveal that there has been significant rise in five-to six-ring PAHs levels in the past two years between 2015 and 2017. Diagnostic binary ratios and linear regression analysis highlight the roles of vehicular exhausts and biomass burning as two major contributors of PM2.5-bound PAHs (http://www.sciencedirect.com/science/article/pii/S1309104217300399).

This intervention has three strong policy implications that are synergistic to the research findings and can be duly tabled for adoption at various stages. In alignment with the activities proposed, these policy connections are articulated as hereunder.

1. Implementation of policy directives for climate adaptive agricultural waste management towards emission reduction can be persuaded with department of agriculture and other govt. line departments, after completion of the 3rd proposed activity when postharvest emission estimates and crop residue figures are at hand. Since community participation will be ensured at field level activities, stakeholder workshop for policy framing at the district level shall be organized to sensitize the local administration on the concerned issue, who would in turn recommend adaptive management policies to authorities at the upper level. Such bottom-up approach from the direct beneficiaries would strengthen the policy move.

2. Preparation of policy guidelines for climate-smart agro-farming practices endorsing usage of renewable energy, energy efficient controlled combustion, less water intensive organic farming and rejuvenating critical environmental services like soil function towards sustainable agriculture can be advocated with the department of environment at the term-end phase of the intervention when comparable results and suggestive alternatives as well, are available. The reports and reviews would be circulated as whole or in part through various communiqués to concerned forums for policy implementation. Project leader would be sharing the same at national level meet of the planning commission of India. Similar forum, workshop or meeting platforms can be used to table the findings and discuss apposite plans for policy instrumentation in all the places.

3. However, blanket ban on open combustion of agricultural wastes to preclude GHG emission and hazardous gaseous discharge towards prevention of health exposure to air pollution can be strongly recommended with the pollution control board and department of health on valid grounds at all the stages of intervention. Health awareness camps will be held with the local beneficiaries to disseminate the research findings and sensitize them about the health implications in regard to this. Such camps can also be linked with and health assessment survey and the reports can be shared with the media for escalating the issue to fetch necessary policy remediation.

Increasing agricultural emission footprints in global south, explicitly owing to unsustainable agro-farming practices in smallholder agriculture, is a prime concern and is also responsible for its current status by which the benefits of ‘Carbon Markets’ are not yet reaped. However, the uncertainty issues associated with agricultural soil carbon sequestration in view of its high mitigation potential, if resolved, can be the driver of change to the advantage of smallholder agriculture. This can be realized under future global climate change agreements, too. Owing to unsustainable fertility-mining practices in agro-farming like crop residue removal, excessive grazing and imbalance in application of plant nutrients etc, rate of soil organic carbon (SOC) sequestration has gone down below 200 kg per hectare per year. Recent researches show that SOC concentration in most agricultural soils in South Asian countries is as low as 0.001%, impairing many soil functions. To this end, the present proposal brings in a double pronged climate adaptive intervention in which both emission reduction and retrieval of soil function is attempted through integrated agricultural waste management. The direct impacts would further fetch additional benefits of introducing such farming practices that will enhance soil carbon, further reduce agricultural emission footprints and as well promote the wise-use of natural energy resources.

Further, from another stringent climate perspective, sustainable management of terrestrial carbon flux is being proposed as an important means of increasing the amount of carbon sequestered in the terrestrial biosphere. It is therefore, a matter of great concern that the potential for rapid, disturbance-induced losses may be much greater than is currently appreciated, especially with the complex and threshold-like nature of disturbances – like fire and drought. This calls for increased considerations and research on the mechanisms by which rapid 'disturbance-induced losses' or 'practice-influenced gain' of terrestrial carbon could occur. Present proposal propounds exactly similar decision support research to adjudge the impacts of 'residue-keeping versus residue burning' on soil characteristics and agriculture in the perspective of climate change. Consequently, scientists need to research more to improve quantification of these potential losses or gain to integrate them into sound, sustainable policy options.

Another significant climate connection in the proposal is the search for climate-smart agro-farming strategies that needs to be place-based for downscaling impacts of climate change, because assumptions relating compensatory dynamics to ecological stability needs to consider complementarities in responses to environmental change along with seasonal complementarities, as well, among cultivars and species. The research design therefore accommodates climate contrasting sites for the intervention so as to present pro-climate paradigm, conducive for agro-environmental conservation.

All these issues and concerns have been cited by various researchers and authors, but comprehensive work is still needed with special references to the smallholder agriculture in the Indian ecoregion of Asia.

The proposed project aims to strengthen global change research by articulating problems / inappropriate practices in crop residue removal for biomass energy production and knowledge gaps in understanding post-harvest carbon emission from residue burning. These are integral to climate efficient agricultural waste management, based on research synthesis and applied assessment. These are particularly aligned with the APN thematic area of Resource Utilization and Pathways for Sustainable Development. Empirical evidences will help prescribe policy and implementation options for climate adaptive residue management strategies. These will create the context for regional cooperation for sustainable development amongst initiatives in comparable circumstances. It also directly relates to climate variability, soil microbe diversity and agro-farming practices and local relevance of practices that are important thematic areas of APN, in varying ecological domains with location – specific integrated decision support research. In the courses of research, mutually reinforcing capacity enhancement and awareness programmes shall also emerge. Further this will contribute to sound scientific basis for policy formulation and decision making in regard to agricultural waste management and develop scientific capacity and improve the level of awareness on its climate adaptive implications. These are well known and central tenets for benefits of studies on global change.

In alignment with APN's Institutional Agenda, the proposed project involves close collaboration with organizations in the global change community like Coordinated Regional Climate

Downscaling Experiment (CORDEX) of World Climate Research Programme, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Global Environmental Facility – Scientific and Technical Advisory Panel (GEF-STAP) and UNEP along with such national level organizations as the Indian Council for Agricultural Research (ICAR), National Council for Climate Change & Sustainable Development (NCCSD) and Renewable Natural Resource Research Centre in Bhutan & Depts. of Soil Sciences Central Luzon University Philippines, to achieve shared goals in the region. It will proactively seek collaboration with organizations that are providing in-kind contributions like Central Research Institute for Dry-land Agriculture (CRIDA), National Bank for Agricultural and Rural Development (NABARD) in India, ICIMOD, SANDEE, National Adaptation Programme for Adaptation to Climate Change (NAPA), & other Climate Change Networks.

Literature Review: On-site biomass burning contributes to climate change by releasing CH_4 & N_2O, hydrocarbon and reactive nitrogen forming tropospheric ozone, while fires produce smoke aerosols which have temperature effects (Andreae et al., 2005; Jones et al., 2003; Venkataraman et al., 2005; Anderson et al., 2003; Menon et al., 2002) and modulate warming (Beringer et al., 2003). Crop residue burning in the open may affect the proportion of woody versus grass cover, with implications for the frequency or intensity of fires and CO_2 sinks in soil (Scholes and van der Merwe, 1996). The ban on burning of field residues in the 1980s enhanced soil carbon, reduced N_2O and CH_4 (Smith et al., 1997; 2000). Only some agricultural systems showed lower yields with high crop residues due to diseases & poor germination (Linden et al., 2000), while others reported higher yields when soil moisture is limiting (Power et al., 1986). Residues do not contribute significantly to soil carbon (Gale et al., 2000) and additional N fertilizer is needed when residues are left on soils to avoid N uptake from soil or allow for soil carbon accrual (Clapp et al., 2000). A review by five USDA Agricultural Research Service (ARS) scientists, Wilhelm et al. (2004) acknowledged the complexity of interactions between soil type, climate, and management when considering crop residue effects on soil. These correlates have to be established in systems unique to the locations proposed in the present study.

2. Methodology

The intervention apropos research planning and finalizing the experimental design, was carried out in three places viz Purulia in India (23’34’’21.97’N 86’31’’14.60’E),Hongshu near Thimphu (27.556696N, 89.699581E) in Bhutan and Luzon (16.532014N & 121.256352E) in Philippines with ecologically contrast features and varying practices of agro-waste management. The intervention followed the following methods of experiment.

Experimental Design and sampling methods

A randomized complete block (RCB) with four treatments and three replications along with one control set will set the design. Experimental plots (3m × 5m) and 0.5m between plots and 1m between replicates have been treated with three different forms of crop residues generated per hectare as particulate BIOCHAR (<2mm), burnt ash (ASH) and raw agricultural wastes (RAW) along with another plot without treatment, as the control. Different forms of crop residues have been mulched at the rate of 5 ton/hectare (as recommended by ICAR 2010). Analysis has been carried out on soil samples (in 5 replicates) collected randomly from each experimental plot, mulched with different forms of treatments viz. crop residues, residual ash, and chemical fertilizing after residue removal, using a steel corer (6.5 cm inner diameter) from two depths (0–15 and 15–30 cm) for consequent seven sampling periods (7, 14, 35, 56, 77, 98 and 112 days after treatment) throughout the experimental cropping period. All the samples were collected tri-monthly for 30 months.

Analytical methods:

Replicates, their mixing and sieving were processed for all physico-chemical analyses as proposed in Allen et al. (1974) and Anderson & Ingram (1993).Standard laboratory procedure was used to determine physical properties of soil samples. Carbon stock estimation in crop residues & soil were done by destructive & allometric methods as recommended in IPCC standards. Soil Carbon Sequestration (SCS) rating in post and pre ante interventions were measured in terms of Soil Organic carbon, Total carbon and carbon density etc. Soil organic carbon was determined using the Walkley-Black chromic acid titration method (Mod. 2007). Macro-Kjeldahl method was used to determine total nitrogen and the calculation of organic matter was done using the following formula [Agbenin 1995] as

(a) Organic Matter (%) = Soil Organic Carbon (%) x 1.72;
(b) Carbon density (t/ha) per soil layer is calculated [CSE, Indonesia 2011] as CaD = % C x bulk density (cm3) x soil layer depth (m) x 10000(m2/ha).

Soil Health Test & analysis:

Biological health of soil environment was assessed with Calico-Strip Test (CST) (Latter & Walton 1988) and observational evidences from the same were recorded. CST is a simple qualitative assay for general activity involves inserting a strip of unbleached calico into the ground and examining it three weeks later for decay, the greater the decay, the greater is the biological activity.

Other tests (Reid & Cox 2005) conducted for soil health were

(a) Nematode Analysis: This involved microscopic counting of different nematode types. Nematode populations include fungal, bacterial and root feeders, parasites and predators. The ratios of these population groups correspond with the level of soil disturbance, nutrient cycling and microbial diversity.
(b) Earthworm Count: Earthworm numbers are highly variable between soil types but this simple indicator is sensitive to organic matter supply, low soil pH and high copper levels.
(c) A simple method to measure soil ATP by the luciferin-luciferase system is described. The ATP is extracted from the soil by vigorous shaking with a sulfuric acid-phosphate solution for 15 min. An aliquot of the soil suspension is neutralized with a Tris-EDTA solution and mixed with a special ATP releasing reagent (NRB). ATP is measured after a 10s exposure to the NRB reagent, followed by addition of luciferin-luciferase and integration over 10s in a Lumacounter M 2080.

Growth and production analysis:

The impact of various treatments on growth and production was analyzed by measuring simple growth indicators like intermodal length, DGR%, leaf area indices etc. Gompertz functions were fitted to the available field data, as one of simple sigmoid growth models, with four parameters that is:

Y = A + C exp(-exp(-B(X-M))) where Y is referred to sugarcane plant height, A is often assumed to be 0, so there are just 3 parameters to fit; C is final height (also said as height potential), B is relative growth rate at time M and M is time at which absolute growth rate is maximum and time which relative growth rate is B. Lavenberg-Marquardt method is used to obtain estimates of the unknown parameters of a non-linear regression model that is widely used for computing nonlinear least square. The accuracy of models was determined by Mean Square Error (MSE) and coefficient of determination (R2). Based on the analysis of the models, it was verified that R2 value is above 99%, indicating a good fitting model.

Statistical Analysis:

Data has been analyzed using SPSS & Excel. Three-way ANOVA were used to compare soil properties amongst different treatments, soil depth and sampling days. Simple correlation matrix helped in understanding the relationship amongst different soil properties (Zar, 1974). The level of significance (p) in all the cases was held at 0.05.

3. Results & Discussion:

The intervention reviewed and evaluated agricultural waste management in diverse geo-ecological scenario viz. eastern plains of India, hilly terrains of central Bhutan and coastal areas of central Luzon state in Philippines to find that it is impaired by practice and policy, as since removal of agricultural residues mainly by burning or else to haul out biomass energy is predominant in these areas, which are highly vulnerable to climate impacts. In Purulia district of Eastern India, mono-cropping of sugarcane is predominantly practiced and post extraction of juices, the bagasse is used for boiling it to make brown sugar and as well used as cooking fuel by the communities. The ash is discarded in the agricultural field, which deteriorates the soil functions and causes massive air pollution in the locale. In Central Luzon, Philippines the hay stocks from rice is burnt in the field for removal and matured sugarcanes are burnt in open for cleaning up the canes posing a similar impact. This is experienced in two cropping cycles per year. In Hongtshu Bhutan, rice and maize is cultivated in terrace farming intermittently with smaller horticultural crops. The agro-wastes are burnt in open and this is a major cause of forest fire. Impacts on soil function are comparatively less than the other two sites. Perusal of data retrieved from the fields of all three intervention sites are collated, analyzed and interpreted in following paragraphs.

A. Results from Purulia, India:

- *Soil analysis (Physical properties):*

The soil samples collected from the ‘control experiment’ plots of Purulia showed a gradual increase of water holding capacity (WHC) up to 57%in a span of seven to eight weeks whereas in the experimental plot treated with raw agricultural waste showed a slower rate of increase in water holding capacity reaching up to 50% only. In bio-char treatment, the trend is just reversed and there was a consistent decrease of water holding capacity by 14% to 20% compared to ‘control’ whereas the decrease was even more pronounced by 37% -40% in plots treated with ash. These seemingly suggest that there is a gradual reduction in the particulate space in soil that holds the water capillaries due to application of biomaterials or ash. It is observed that the maximum impact of raw waste and ash was with a treatment of 50% and 75% of waste and ash respectively.

Similarly, the soil moisture content got doubled (almost 98% increased) compared to ‘control’ with the application of 75% raw agricultural waste in the experimental plots, whereas the moisture content halved with 75% of bio-char and reduced by 60% compared to control after the application of 75% of ash by weight. The water retained by raw waste and adsorbed by bio-char expectedly made the difference in moisture content of the samples.

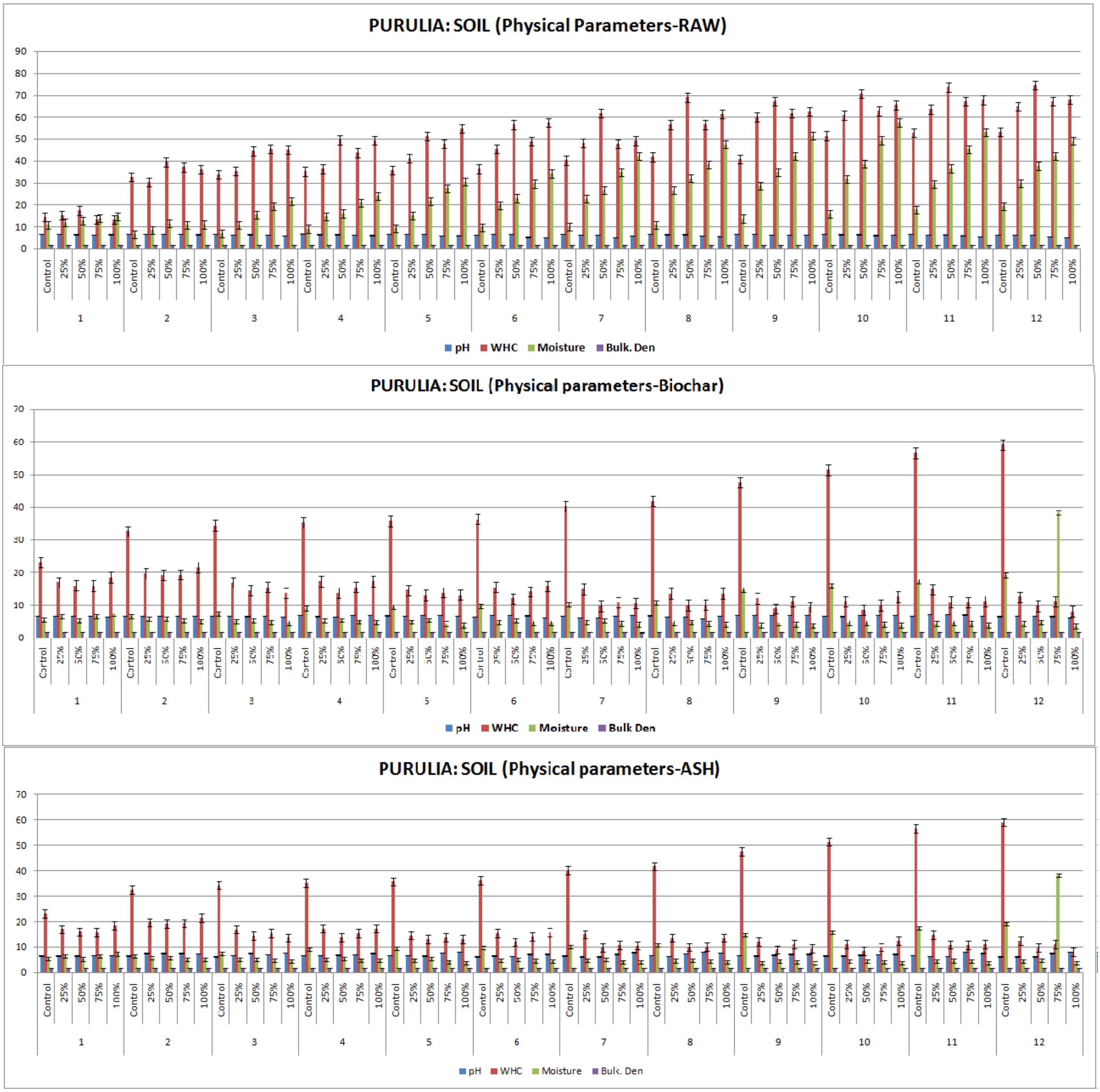

Fig – 1A: Physical Parameters of Soil (Purulia, India)

Interestingly, the application of raw agricultural waste gradually decreased the bulk density of soil of the experimental field from 1.67 to 1.52 in a span of thirty months whereas it gradually increased from 1.67 to 1.79 with the application of 75% and 100% of ash by weight. However, biochar did not have much of an effect on the bulk density across this period.

Soil analysis (Chemical Properties):

The pH of the soil in 'control' plots ranges between 6 to 6.5 but it gradually falls after application of 75% and 100% raw waste by weight whereas it shows a sharp increase with application of 75% biochar after 22nd and 24th month. There is a general decrease in pH value during monsoon and increase in winter period whereas after the application of 75% to 100% of ash the PH gradually neutralizes and turns alkaline in the 24th to 30th months.

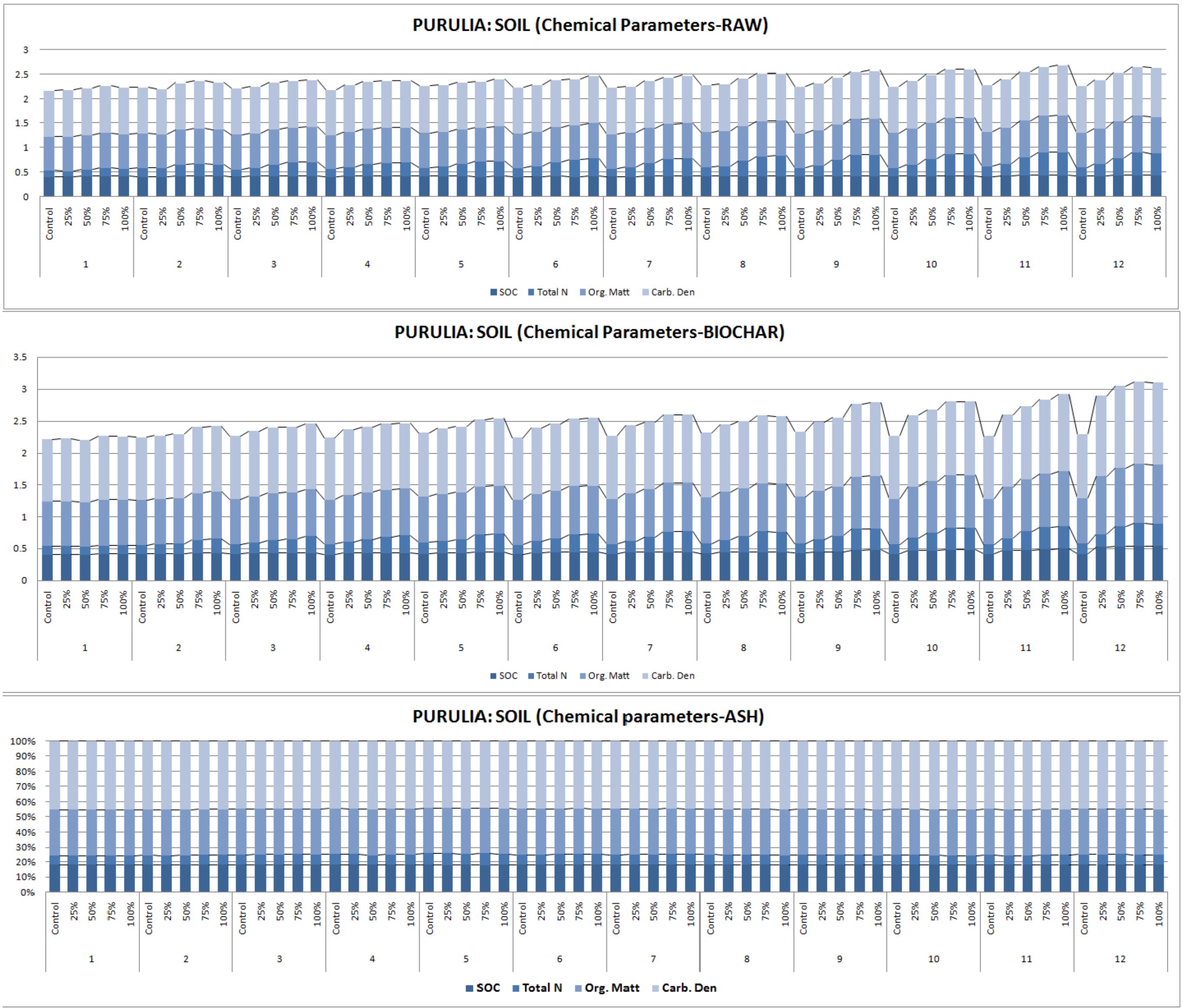

Fig – 1B: Chemical parameters of Soil (Purulia)

Total nitrogen in the 'control' plot was found to be 61.5%, which shows sharp rise by 115% after the application of raw waste for the first 15 months. In the last 15 months the rise in

total nitrogen sublimes further and comes to 138.8%. Application of biochar shows a better elevation in total nitrogen but the pace of increase is more steady compared to raw waste reaching up to 140.33% whereas with application of ash the total nitrogen content shows an increase of 44.61% in the first 15 months and therein it rapidly decreases in the last 15 months by 10% to 12%.

Organic matter in soil increased in the 'control' experiment by 3.44% normally across 30 months, whereas the maximum increase was observed in application of 75% biochar by weight showing 32.28% increase followed by raw agricultural waste with 8.89% increase and ash with 5.59% increase. Soil organic carbon showed a similar trend with the organic matter only the rate if increase was very gradual and effective with 50% to 75% biochar and raw waste application only. The impact of ash on organic matter and soil organic carbon was limited.

B. Results from Hongthsu, Bhutan

- Soil analysis (Physical properties):

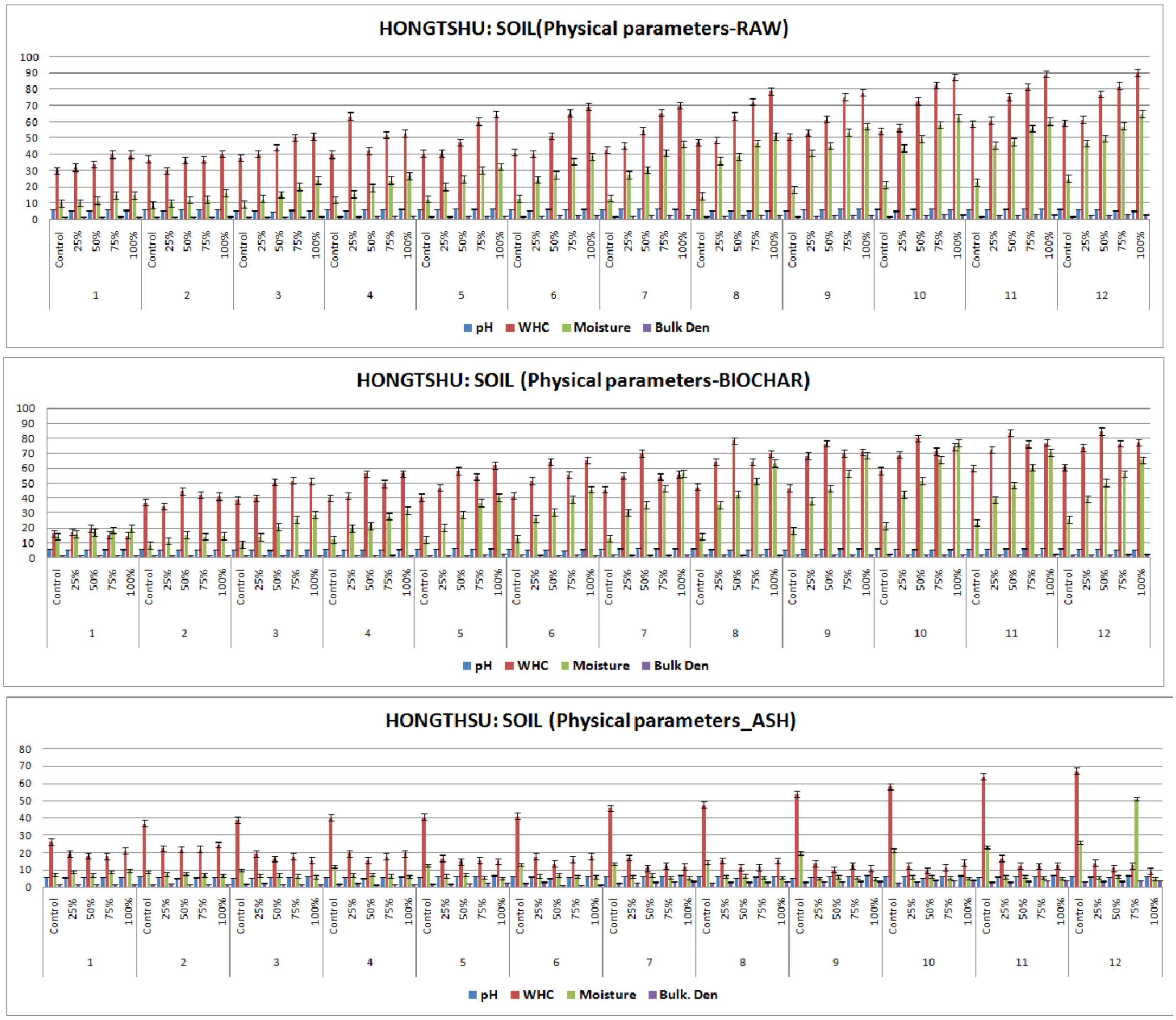

Fig – 2A: Physical Parameters of Soil (Hongtshu, Bhutan)

In Bhutan the geo-ecology being different, perusal of results show that in control plot the water holding capacity is increased by 45-50% in a span of 10 to 12 weeks after sowing of seeds, whereas after the application of 50-75% of raw agro-waste and biochar by weight, the water holding capacity is doubles in the same span of time. However, it decreases sharply further by 17-20% from the control after application of ash. 25% and 100% raw waste and biochar has no marked effects on the water holding capacity per se. Similarly, the moisture content also gradually increases with the application of 50-75% waste and biochar reaching up to 65% with raw waste and up to 27.5% with biochar, whereas the moisture content decreases sharp and rapidly with application of ash above 50% by weight. Bulk density increases from 1.6 to

2.6 in 30 months with application of 50-75% raw waste and 75-100% biochar, whereas it increases even up to 3.92 with 75-100% ash by weight.

- Soil analysis (Chemical Properties):

Total nitrogen was found to increase by 39.23% in control plots of Bhutan, which is much lower than that of Purulia, as since the pattern of cultivation is totally organic in nature. However, the impact of application of raw waste and biochar was almost same. First 15 months there have been an increase by 136.24% to 146.15% in 50-75% raw waste and biochar respectively, whereas with same doses of ash the nitrogen decreases by 31.54% in the first 15 months followed by another 21.54% decrease in the next 15 months.

Organic matter and Soil Organic Carbon increased by three folds up to 48.96% with application of 75% biochar and with 75-100% raw waste an increase of 33.18% and 25.64% was recorded for organic matter and Soil Organic Carbon respectively. However, application of ash above 50% could only increase these by 15-16%, whereas below 50% application of ash by weight had no impacts on these.

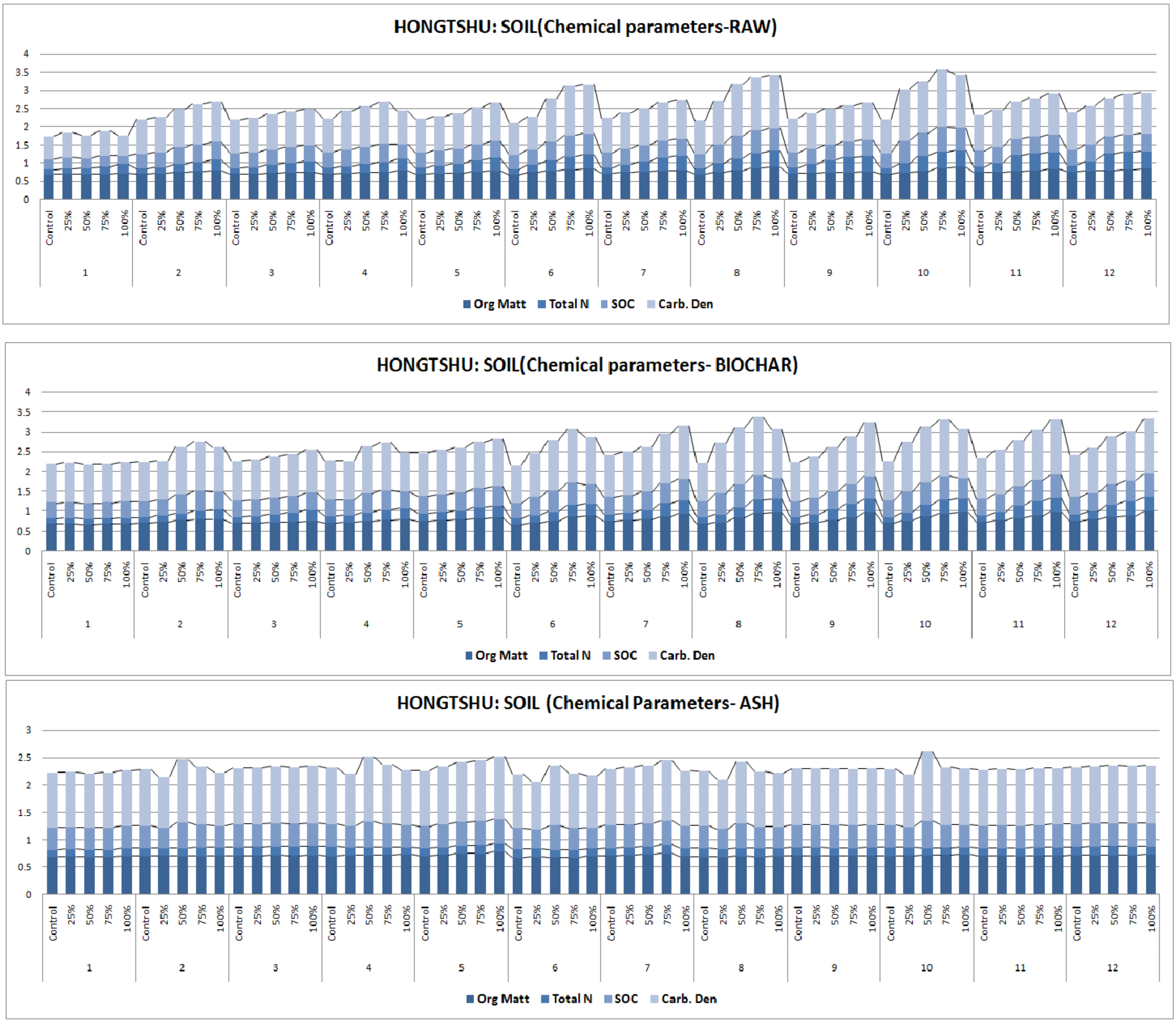

Fig – 2B: Chemical Parameters of Soil (Hongtshu, Bhutan)

C. Results from Luzon, Philippines

In Philippines, the experimental plots were drawn out in Department of Soil and Agriculture, Central Luzon State University campus. However, the treatment plots could be maintained from 18 months in continuation and the results were similar to that of Purulia, with some interesting changes as may be found hereunder.

- Soil analysis (Physical properties):

Water holding capacity increased by 47-50% with the application of 75% to 100% raw agro-waste and biochar, though more quickly within 4-5 weeks, whereas in control experiment it only reaches up to 37% at the maximum in 7-8 weeks. Moisture content doubles up (56% increase) with the application of 50% agro-waste and biochar by weight

The samples collected from the experimental plots of Purulia shows a gradual increase of water holding capacity in the control experiment of about 57% in a span of seven to eight weeks whereas in the experimental plot treated with raw agricultural waste there is a slower rate of increase in water holding capacity reaching up to 50%. In biochar the trend is just reversed and there was a consistent decrease of water holding capacity by 14%- 20% whereas the decrease was pronounced in plots treated with ash by 37% -40%. These seemingly suggest that there is a gradual reduction in the particulate space in soil that holds the water capillaries due to application of ash. It is observed that the maximum impact of raw waste and ash was with a treatment of 50% and 75% of waste and ash respectively.

Similarly, the moisture content got doubled with the application of raw agricultural waste by 75% of the total waste generated in the plot. Whereas the moisture content halved with 75% of biochar and reduced by 60% compared to control after the application of 75% of ash by weight. The application of raw agricultural waste gradually decreased the bulk density of soil of the experimental field by 1.67 to 1.52 in a span of thirty months and it gradually increased from 1.67 to 1.79 with the application of 75% and 100% of ash by weight. However, biochar did not have much of an effect on the bulk density across this period.

- Soil analysis (Chemical Properties):

The PH of the soil gradually falls after application of 75% and 100% raw waste by weight whereas it shows a sharp increase with application of 75% biochar after 22^{nd} and 24^{th} month. There is a general decrease in PH value during monsoon and increase in winter period whereas after the application of 75% to 100% of ash the PH gradually neutralizes and turns alkaline in the 24^{th} to 30^{th} months. Total nitrogen in the controlled field was found to be 61.5% which shows sharp rise by 115% after the application of raw waste for the first 15 months. In the last 15 months the rise in total nitrogen sublimes and comes to 138.8%. application of biochar shows a better elevation in total nitrogen but the rate of increase is more steady compared to raw waste reaching up to 140.33% whereas with application of ash the total nitrogen content shows an increase of 44.61% in the first 15 months whereas it rapidly decreases in the last 15 months by 10% to 12%.

Organic matter increased in the controlled experiment by 3.44% whereas the maximum increase was observed in application of 75% biochar by weight showing 32.28% increase followed by raw agricultural waste with 8.89% increase and ash with 5.59% increase. Soil organic carbon showed a similar trend with the organic matter only the rate if increase was very gradual and effective with 50% to 75% biochar and raw waste application only. The impact of ash on organic matter and soil organic carbon was limited.

Soil Microbial Health

Enhancement of microbial activities with application of organic matter and biochar is well studied earlier (Dolling and Ritchie 1985; Ameloot et al 2013). This was hinted by the increased nematode and earthworm counts, ATP content and Calico Strip Test (Fig – 4) within 4 to 16 weeks of treatments given in the soil. The pictogram below is prepared on the grades of soil microbial health as perused after the treatments exposures, which suggests that the microbial activities gradually increased with application of agro-wastes and biochar.
However, there was maximum impact of waste treatments in Hontshu Bhutan, followed by Purulia in India and Luzon, Philippines. Application of ash deteriorated the microbial health of soil and also decreased ATP contents in most of the cases. The ATP content in soils treated with 75% Bio-char, which had been stored at 5°C for 90 days and then incubated at 25°C for 5 days, ranged from 0.37 to 7.52 µg ATP g−1 dry wt, which was the maximum activity with standard deviations less than 10%. There was a close (*r* = 0.96) linear relationship between ATP content and biomass C determinate by fumigation for this group of soils. The soil biomass contained 4.2–7.1 µg ATP mg−1 biomass C. The ATP content of the biomass declined during storage at 5°C for 180 days. Raw agro-wastes produced a lower content of ATP, ranging from 0.25 to 6.04µg ATP g−1 dry wt.

TABLE – 1: IMPACT OF AGRO-WASTE TREATMENT ON SOIL MICROBIAL HEALTH

Location	Treat	Nematode & EW					Calico Strip Test					ATP Content				
		0 W	4 W	8 W	12 W	16 W	0 W	4 W	8 W	12 W	16 W	0 W	4 W	8 W	12 W	16 W
PURULIA	CON	0	0	0	1	1	0	2	2	2	2	0	2	2	3	3
	RAW	0	0	3	3	4	0	2	3	4	5	0	3	3	5	5
	BCH	0	1	1	1	1	0	2	3	5	5	0	2	3	3	3
	ASH	0	0	0	0	1	0	0	0	0	1	0	0	1	1	2
HONTSHU	CON	2	3	3	3	4	0	3	3	4	4	0	3	3	4	4
	RAW	2	4	4	5	6	0	4	4	6	6	0	4	4	5	6
	BCH	0	3	4	6	6	0	2	2	3	6	0	1	3	5	6
	ASH	0	0	0	0	1	0	1	1	1	1	0	1	2	2	2
LUZON	CON	0	0	0	1	2	0	0	0	1	2	0	0	0	1	2
	RAW	0	0	2	3	4	0	1	2	2	3	0	1	1	2	2
	BCH	0	1	1	1	1	0	3	3	4	5	0	2	3	5	6
	ASH	0	1	1	1	1	0	2	2	3	3	0	2	2	2	3
SCALE (++)		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14

Growth and Production
The scatter plots of the sugarcane stalk height were measured from the field and the same could be analyzed by nonlinear regression. Parameter estimation using iterative process based on Gompertz model of plant growth (height) with no treatment shows that: Y = -5.73 + 280.1 exp(-exp(-0.001234(X-101.15))) and the first derivative is (3.456434 exp (-0.01234 X +1.24819)*(exp(-exp(-0.01234 X+1.24819))) with R2 of 99.3% and Mean Square Error (MSE) = 31.47 . The growth analysis and the first derivative of plant given bio-char treatment is: Y = -34.7 + 408.9 exp(-exp(-0.00712(X-124.19))). To draw the trend of the growth rate, we found the first derivative as (2.911368exp (-0.000712 X +0.884233)*(exp (-exp(-0.000712X+0.88423))); R2 is 99.5% and MSE = 17.53. Based on the growth model we can draw the trend of the growth model, where the X-axis is time (in days) and Y is plant height (cm), as shown below (Fig – 3):

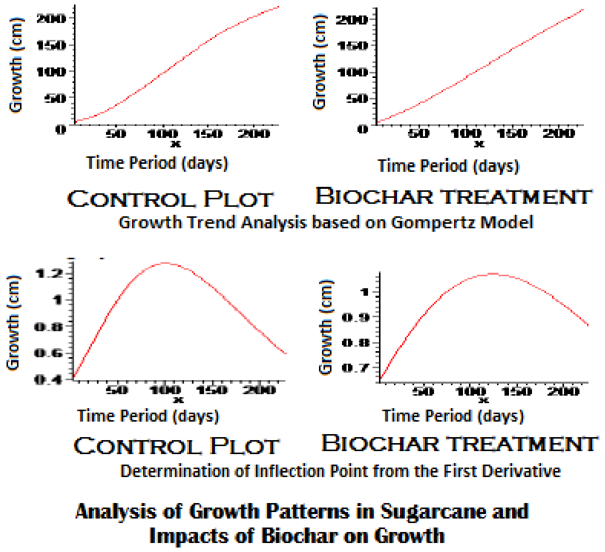

Fig – 3: Analysis of Growth Patterns in Sugarcane

Fig – 4: Calico Strip Test

Productivity enhancement: The enhancement in sugarcane productivity is graphically presented hereafter from field records in the Indian context.

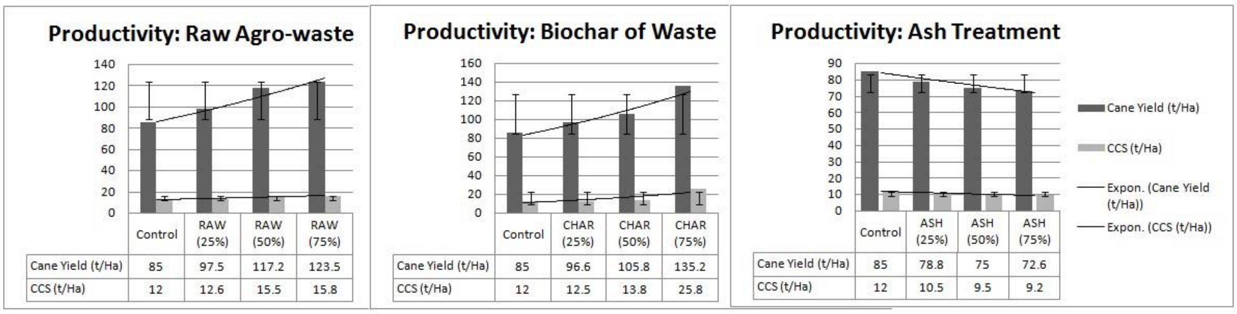

Fig – 4: Impact of agro-waste treatments on crop productivity

At least 35-40 farmers who volunteered for the experimental treatment and replicated the measures in 2nd and third year had experienced an excellent increment in returns on investments. The details are given below in the table. However, some assumptions on this is essential for consideration, like

i. The treatment has brought qualitative changes (better CCS), for which though the production has increased up to 60% but the earnings have increased up to 90%.
ii. The enhanced soil function (moisture retention and fertility) has also saved the additional investments on water and fertilizers.
iii. Better seeds and cultivars would respond much better to the treatments and can save the health of farmers from local air quality deterioration due to burning of agro-waste.

TABLE – 2: Impacts of agro-waste treatments on yield quantity & quality

PARTICULARS	Rate (INR) / MT		Previous		Post Treatment (RAW 75%)		Post Treatment (CHAR 75%)	
			Production (t/Ha)	Earnings (INR)	Production (t/Ha)	Earnings (INR)	Production (t/Ha)	Earnings (INR)
Yield (t/Ha)	(CCS<120t/Ha)	1750.00	85	148750.00	123.5	259350.00	135.2	283920.00
Increment (%)	(CCS>120t/Ha)	2100.00	n.a	n.a	45.3	74.35	59.12	90.87

DISCUSSION

Agriculture plays a significant role in economies, lives and livelihood of South Asia. Over 70% of its population live in rural areas, the majority of whom make their living by depending on the natural resources that surround them —land, freshwater, coastal fisheries. Agricultural waste management is beyond any traditional farming practices in South Asian countries wherein the crop residues are usually burnt in open for biomass energy, leading to emission pollution and loss of soil function & nutrients (Mitchell et al. 2000; Lehman et al 2015). However, reapplication of crop residues in the cultivable land may augment soil functions, favourably alter the physic-chemical properties of soil and Good management of field residues can increase efficiency of irrigation too.

Perusal of results from all three intervention sites in Purulia (India), Hongshu (Bhutan) and (Luzon) Philippines (Fig – 1A, 1B, 2A, 2B) shows that application of raw agro-waste and bio-char augmented soil functions and had pronounced impacts on the physic-chemical characters of soil, soil microbial vegetation and as well it enhanced organic carbon contents whereas the application of ash was detrimental to soil health and had no similar impacts on the carbon profile of soil. The applications also increased organic matter, bulk density of soil and its porosity thereby making it more conducive to support biological growth. This has a concurrence with earlier reporting from Nigeria (Ndor et al 2015).

Chen et al. (2010) studied the influence of bio-char use on sugarcane growth, soil parameters and ground water quality of 'Shimajiri-maji' soil. They indicated that bagasse charcoal reduced soil dry density and increased available moisture, which in turn increased the yields and sugar content of sugarcane. Results from Hongtshu, Bhutan shows that application of raw crop residues in horticultural fields and hand crushed biochar augmented the soil organic matter and nitrogen content of the soil depicting a positive correlation and as well increased soil moisture and helped in increasing the productivity. The present observation is also in parity with the inferences of Kameyama et al 2012, that raw agro-waste and bio-char increased soil moisture and as well the residence time of nitrate in the crop root zone providing greater opportunity to absorb nitrate, which restored soil fertility in calcaric dark red soil. Application agricultural residue not only disposes of waste material but also can improve crop production by increasing the supply of nutrients in the soils where the material is applied. Mitchell et al. (2000) studied the loss of nutrients from the immediate area, when sugarcane residues are burnt. Graham et al. (2002) studied the effect of fertilizer applications, burning and trash retention on the soil organic carbon and quality in a long term sugarcane application in South Africa. They revealed that soil organic matter content in the top 10 cm increased with increasing inputs of crop residues, which is also being observed in our interventions in Purulia and Hongshu. Inyang et al. (2010) investigated the effect of anaerobic digestion on the biochar production from sugarcane bagasse. They concluded that the pyrolysis of anaerobic digestion residues to produce biochar may be an economically and environmentally beneficial use of agricultural waste. Mohan and Ponnusamy (2011) addressed the challenges of sugarcane trash decomposition through effective microbes. In this study, they have tested effective microbes prepared through fruit wastes, which were found to be very effective in converting sugarcane trash into compost in 60 days. Herein the application of raw bagasse and bio-char improved the soil microbial health greatly as may be inferred from TABLE (1).

Our findings on improved quality and productivity in sugarcane, in India, are substantiated by previous studies herein. Singh et al. (2007) studied in the yield and soil nutrient balance of a sugarcane plant-ratoon system with conventional and organic nutrient management in subtropical India. They concluded that the sugarcane crop responded well to different organic manures in a multiple rationing system with a better economic output. Vallis et al. (1996) did the simulation modeling of the effects of agro-waste and N-fertilizer management on soil organic matter levels and yield of sugarcane. They revealed nitrate leaching was sensitive to N fertilizer, and was greater with trash blanketing than trash burning because of less evaporation of soil water early in the growing season. Ball-Coelho et al. (1993) studied on the residue management effects on sugarcane yield and soil properties in North-Eastern Brazil. In their experiment mulching was proved to be an alternative to traditional burning system. Robertson and Thorburn (2007) worked on the decomposition of sugarcane harvest residue in different climatic zones in Australia. They concluded that variation in the rate of agro-waste dry matter and C decomposition between sampling dates was partially related to temperature and rainfall at 2 of the 3 sites, but was considered to be influenced by other factors (such as soil, trash, and management) as much as by climate. This is an important factor for observing the impacts under varied conditions of weather, which is a promising area of furthering this research, as since the micro-climatic regime in these South Asian countries are highly unpredictable. Wood (1991) worked on the management of crop residues following green harvesting of sugarcane in north Queensland. They stated that rapid transition from burnt to green harvesting of sugarcane in north Queensland has been accompanied by a reduction in tillage, the retention of crop residues as a surface trash blanket, and a change to surface applications of fertilizer. Field trials have established the long-term effects of these new practices indicating increased ratoon crop yields, a suppression of weed growth, increased soil moisture and organic matter and a reduction in soil loss from sloping areas, which are also evidently viewed in our intervention too.

Enhanced water holding capacity with the application of raw agro-waste can now be used to estimate with reasonable accuracy, the water retention characteristics depending on particle-size distribution, percentage of organic matter, and bulk density. This will be of particular help in water budgeting and modelling salt and water flow in soils and in estimating available water capacities, especially in coastal areas like Philippines, with saline water intrusion possibilities in stormy weather and sea level rise. Water retention curves may also be used to approximate hydraulic conductivity-water content relationships [Gupta & Larson 1979, Green and Corey, 1971; Campbell, 1974]. As opposed to the usual assumption, fertilization was of little, if any, benefit for soil C sequestration (Mack et al.,2004), addition of N or P is reportedly found to be more effective for stimulating mineralization of SOC in subsurface horizons, as compared with surface soil layers (Khan et al 2007, Soon and Arshad, 2002;). However, application of additional external fertilizers was beyond the scope of this intervention.

Bio-char has the potential to increase conventional agricultural productivity and enhance the ability of farmers to participate in carbon markets beyond traditional approach by directly applying carbon into soil. (McHenry 2009) bio-char addition to agricultural soil has been suggested to mitigate climate change through increased biogenic carbon storage and reduction of greenhouse gas emissions. Earlier studies reveal that bio-char addition increased CH_4 uptake (96% increase in the average cumulative CH_4 uptake), but no statistically significant differences were observed in the CO_2 and N_2O emissions between the bio-char amended and control plots. Added bio-char increased soil water holding capacity by 11%. Further studies are needed to clarify whether this may help balance fluctuations in water availability to plants in the future climate with more frequent drought periods (Karhua et al 2010). Another major benefit associated with the use of bio-char and raw crop residues as a soil amendment is its ability to sequester carbon in the soil thereby mitigating climate change [Lehmann et al 2006]. The increasing Carbon Density after the application of Bio-char and crop residues is evident from the results. The sequestration potential for biochar in this study is highly significant; which is in agreement with report of [Gaunt et al 2008]. It is noteworthy, that carbon content in raw bagasse to charcoal, reduced from 43.89 ± 9.56 % to 33.27 ± 18.30 %, whereas in the ash, it reduced to only 1.92 ± 0.89. This data, suggests that if raw bagasse mulch can be used in the agricultural field, instead of burning as fuel, it can reduce emission of ~ 42 %.

All litter types and organic residues have similar carbon fraction chemistries at the end of the first phase of decomposition described here and also exhibits narrow range of changes in nitrogen concentration per unit weight loss. Studies have concluded that the length of time required to convert litter or residues into soil organic matter and the chemistry of the material produced by this process can be predicted from initial litter chemistry and (or) relatively short-term litter decay data (Aber et al 1990). This study would therefore be significant in understanding the soil carbon sequestration potential enhancement abilities of crop residues. Results show that SOC concentration in the top 20-cm soil layer increased at an average rate of 0.035% each year, and at the same time, the mean bulk density of the top 20-cm soil layer decreased significantly with an average rate of 0.0032 g cm^{-3} $year^{-1}$ (Zhou et al 2006), which is comparable to our findings from the intervention fields.

This study also suggested that the carbon cycle processes in the below ground system of these agricultural fields are changing in response to the changing environment. This result directly challenges the prevailing belief in ecosystem ecology regarding carbon budget in old-growth forests (Odum 1969) and supports the establishment of a new, non-equilibrium conceptual framework to study soil carbon dynamics. Our study further highlights the need to focus on the complexity of the below ground processes, as advocated in previous research (Johnston et al 2004), and the importance of establishing long-term observation studies on the responses of below ground processes to global change.

4. Conclusions

It is pertinent to conclude from the achieved results and inferences drawn from the discussions herein that the research in the present intervention could substantiate the impacts of reapplication of agro-waste and crop residues to the field soil for enhancement of soil functions and restore its primary productivity potentials to the favour of farmers. Additionally, it improved the soil microbial environment and resumes the stocking potentials of organic carbon, thereby impacting the soil carbon sequestration and flux. This proves to be significant in the climate milieu, especially when the agro-waste management procedures and policy are not suitably drawn up for mitigating emissions. The inferences vividly demonstrate that sustainable crop residue removal rates for bio-fuel production will vary with management, yield, and soil type. The results help determines specific practices in diverse cropping systems. It also redeems the appropriate proportions and form of agro-waste (raw or bio-char) for re-application depending upon the crop cycle, soil type and other factors. The results validated that locally relevant Conservation Practices like contour cropping or conservation tillage to compensate for the loss of erosion protection and SOM reductions can be effectively adjoined with residue removal and re-application as an adaptive strategy for abating climate impacts. Since, the study has opened the windows for adaptive management of agro-wastes, the study needs to be furthered with more cropping patterns, in varied geo-ecology. There are few important segments of research that can be led ahead and these include the soil microbial dynamics and bio-geochemical cycles, impacts of agro-waste treatments on the soil carbon pool and microbial vegetation etc. However, the study has attracted good peer focus and has initiated a new paradigm in climate smart agriculture in the South Asian context.

5. Future Directions

The baseline metadata that this intervention has created, shall open multiple avenues of research findings, of which few prior areas are identified hereunder

(a) The complexity of the below ground processes needs to be researched to understand the soil carbon dynamics in agrarian ecosystems, as this can be a turning point for climate smart agro-farming of marginal communities in developing south.

(b) The interlink of soil microbiology and bio-geochemical cycles in altered agrarian ecosystem, like alteration due to re-application of agro-wastes and bio-char etc, that impacts primary productivity, needs to be studied in-depth as this can be vital in mitigating climate impacts and as well assure food security for agrarian communities

(c) Research related to enhancement of water retention characteristics of soil with applications of crop residues in relation to particle-size, organic matter content and bulk density, will be of particular help in water budgeting and modeling salt and water flow in soils and in estimating available water capacities, especially in coastal areas with saline water intrusion possibilities due to sea level rise. Such water retention paradigms may also be used to approximate hydraulic conductivity-water content relationships towards integrated water management in drought prone areas.

6. References

1. *Aber,J. D.,Ijllo. J. M and Mcclaughertcy, A. (1990). Predicting long-term patterns of mass loss, nitrogen dynamics, and soil organic matter formation from initial fine litter chemistry in temperate forest ecosystems. Can. J.Bot. 68: 2201-2208.*
2. *Ameloot, N., Graber, E. R., Verheijen, F. G. A. and De Neve, S. (2013), Interactions between biochar stability and soil organisms: review and research needs. Eur J Soil Sci, 64: 379–390. doi:10.1111/ejss.12064*
3. Anderson CR, Condron LM, Clough TJ, Fiers M, Stewart A, Hill RA et al (2011). Biochar induced soil microbial community change: implications for biogeochemical cycling of carbon, nitrogen and phosphorus. Pedobiologia 54: 309–320.
4. *C. A. Johnston et al (2004)., Front. Ecol. Environ. 2, 522.*
5. *Campbell, G. S.(1974), A simple method for determining unsaturated conductivity from moisture retention data, Soil Sci., 117, 311-314,*
6. Chen, Y, Shinogi ,Y & Taira, M (2010), ‘Influence of biochar use on sugarcane growth, soil parameters, and groundwaterquality’, *Soil Research, vol.* 48(7) pp.526–530.
7. *Dolling, P and Ritchie, G. S. P. (1985). Estimates of soil solution ionic strength and the determination of pH in West Australian soils. Aust. J. Soil Res. 23, 309-14*
8. *E. P. Odum (1969), Science 164, 262.*
9. *Green, R. E., and J. C. Corey (1971), Calculation of hydraulic conductivities: A further evaluation of some predictive models, Soil Sci. Soc. Amer. J., 35, 3-8,*
10. *Guoyi Zhou, Shuguang Liu, Zhian Li,1 Deqiang Zhang,1 Xuli Tang,1 Chuanyan Zhou,1 Junhua Yan,1 Jiangming Mo1 (2006);* Old-Growth Forests Can Accumulate Carbon in Soils*SCIENCE, 314(1): 1417*
11. *Gupta, S.C & Larson, W.E (1979) Estimating Soil Water Retention Characteristics From Particle Size Distribution, Organic Matter Percent, and Bulk Density. Water Resource Research. 15(6), 1633-1637.*
12. Inyang, M, Gao, B, Pullammanappallil, P, Ding, W & Zimmerman AR (2010), ‘Biochar from anaerobically digested sugarcane bagasse’, *Bioresource Technology*, vol. 101, pp. 8868-8872.
13. Kameyama, K, Miyamoto, T, Shiono, T & Shinogi, Y (2012), ‘Influence of sugarcane bagasse-derived biochar application on nitrate leaching in calcaric dark red soil’, *Journal of Environmental quality,* doi: 10.2134/jeq2010.0453.

14. *Kristiina Karhua, Tuomas Mattilab, Irina Bergströma, Kristiina Reginac (2010), Biochar addition to agricultural soil increased CH4 uptake and water holding capacity – Results from a short-term pilot field study. Agriculture, Ecosystems and Environment 140 (2011) 309–313.*
15. *Mack, M.C., E.A.G. Schuur, M.S. Bret-Harte, G.R. Shaver, and F.S. Chapin,III. 2004. Ecosystem carbon storage in arctic tundra reduced by long term nutrient fertilization. Nature 431:440–443.*
16. *McHenry, M.P. (2009) Agricultural bio-char production, renewable energy generation and farm carbon sequestration in Western Australia: Certainty, uncertainty and risk. Agriculture, Ecosystems & Environment, 129 (1-3). pp. 1-7. (http://researchrepository.murdoch.edu.au/3675)*
17. Mitchell, RDJ, Thorburn, PJ & Larsen, P (2000), 'Quantifying the loss of nutrients from the immediate area when sugarcane residues are burnt', *Proceedings of Australian Society of Sugarcane Technology*, vol.22, pp.206-211.
18. *S. A. Khan,* R. L. Mulvaney, T. R. Ellsworth, and C. W. Boast (2007)The Myth of Nitrogen Fertilization for Soil Carbon Sequestration. Journal of Environmental Quality, 36: 1821-1832*
19. *Soon, Y.K., and M.A. Arshad. 2002. Comparison of the decomposition andN and P mineralization of canola, pea, and wheat residues. Biol. Fertil.Soils 36:10–17.*
20. Wood, AW (1991), 'Management of crop residues following green harvesting of sugarcane in north Queensland', *Soil and Tillage Research,* vol. 20 (1), pp. 69-85.