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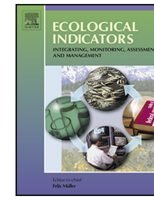

Energy budgeting and emergy synthesis of rainfed maize–wheat rotation system with different soil amendment applications

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ABSTRACT

Soil is a non-renewable resource and its preservation is essential for food security, ecosystem services and our sustainable future. Simultaneously, it is a major challenge to substitute non-renewable fossil based resources with renewable resources to reduce environmental load. In order to check soil erosion *vis-a-vis* degradation of sloppy lands of rainfed maize–wheat rotation system, fertilization with organic manure supplemented with inorganic fertilizers is required. In order to address these issues, substitution of 50% NPK through four organic manures *viz.* farmyard manure (FYM), vermicompost (VC), poultry manure (PM) and *in situ* green manuring (GM) of sunnhemp (*Crotalaria juncea* L.) were evaluated against 100% NPK through inorganic fertilizers and through FYM for energy budgeting and emergy synthesis during 2009–2014. Integrated use of FYM along with 50% NPK fertilizers could maintain the highest energy ratio (7.3), human energy profitability (142.4), energy productivity (0.22 kg MJ^{-1}), and energy profitability (6.3 MJ ha^{-1}) over other treatments. However, GM and inorganic fertilizers on equal NPK basis maintained the highest emergy intensiveness (24.61 MJ US \$$^{-1}$) and exhibited higher emergy yield ratio (2.66) and lower emergy investment ratio (0.60) and environmental loading ratio (3.74) which resulted into higher environmental sustainability index (0.71) over other treatments. Fertilization with organic manure (FYM) alone could not compete with other fertilized options to energy budgeting and emergy synthesis except specific energy. The study demonstrated that innovative integrated nutrient management of chemical fertilizers and organic manures particularly FYM for energy budgeting and GM for emergy synthesis may be considered as feasible and environment-friendly options for soil conservation, thereby benefiting a 50% saving on costly chemical fertilizers in non-OPEC countries which import most of its phosphorus and potassium fertilizers.

1. Introduction

Soil erosion due to runoff on sloppy agricultural lands causes loss of productive non-renewable soil resources, rain water and costly plant nutrients, leading to unsustainable system productivity and low energy efficiencies (Ghosh et al., 2015) which simultaneously cause adverse environmental effects (Pimentel et al., 1995; Cohen et al., 2006). Energy parameters such as, net energy return, energy ratio and energy productivity are now-a-days meaningful and common indicators for assessing or comparing the efficiency of production systems (Choudhary and Suresh Kumar, 2013; Tuti et al., 2012; Ghosh et al., 2015). However, energy consumption and output differ widely among crops, production systems and management intensity. Indeed, studies on energy use are strongly influenced by experimental plot data, upon which the computations are based, system boundaries and methodologies (Soltani et al., 2013). Therefore, agro-ecosystem productivity evaluation of any crop production system using emergy synthesis (Odum, 1996; Odum and Peterson, 1996; Hu et al., 2010) is more important and interesting over energy budgeting. One of the arguments behind this opinion is that energy budgeting does not consider soil erosion results from energy transmitted from rainfall drops which hit exposed soil with an explosive effect, launching soil particles into air and run-off itself has kinetic energy (Pimentel et al., 1995). Erosion also affects other ecosystem services like carbon emission, eutrophication, sedimentation of reservoirs etc. and finally affects national economy of the country (Lal, 1998). All of these inputs never considered in the energy budgeting. Without quantifying the intrinsic value of these services in the context of the resource basis of the economy, decision makers have no way to evaluate problem

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severity, nor any quantitative rationale to justify diverting sufficient resources to attenuate it (Cohen et al., 2006). In contrast to energy budgeting, emergy evaluation takes into account all the inputs (precipitation, global radiation, wind, soil loss, etc.) involved in a production system (i.e. renewable and non-renewable, local and imported) and transforms them into a common measure of direct and indirect solar energy requirement by means of a conversion factor called transformity (Odum, 1996; Odum and Peterson, 1996). In this way, all the flows get the same common unit for the analysis.

To assess and compare the energy and emergy indices, we have taken traditional rainfed maize–wheat rotation system of the Himalayan region of India. The primary objectives of any sustainable crop production are to reduce direct and non-renewable sources (fertilizers and fossil resources) and to raise the output of farm by either increasing the crop yield or reducing the negative impacts of soil erosion on sloppy lands. With continuously depleting resources of fossil fuels, burgeoning population and deteriorating environmental condition due to carbon emission, the search for alternate energy sources need to be initiated and implemented. In fact, the renewable energy has to play a pivotal role in meeting energy demand world over. An assessment of renewable energy technologies confirms that the improved techniques have the potential to provide with alternatives to meet approximately half of future energy needs (Pimentel et al., 1973). Another important aspect is proper energy management in production agriculture for simultaneously enhancing ecosystem services such as environmental loading ratio, environmental sustainability index, etc. This would help not only in making environmental policies for improved crop production from degraded sloppy soils but also to save environment from adverse effect of excessive and improper energy use. This can only be done by supplementing the energy intensive inputs, i.e. fertilizers with substantial investments in organic manures, soil and water conservation practices, weed management practices, etc. (Ghosh et al., 2015). These inputs and methods represent various energies that need to be evaluated so as to ascertain their effectiveness and to know how to conserve them. Among agronomic measures of soil and water conservation, integrated use of plant nutrients from fertilizers and organic sources seems to be a need of the time (Singh et al., 2013). Several studies (Ghosh et al., 2014, 2015) indicated that application of farmyard manure (FYM), vermi-compost, poultry manure, green manure, crop residues, biofertilizers and other wastes either alone or along with inorganic fertilizers reduced soil losses due to less run-off and high soil quality indices. But there is scant information on the performance of various organic manures particularly vermicompost, poultry manure and *in situ* green manuring on ecological indicators like energy and emergy efficiencies of rainfed maize–wheat rotation system. This is very pertinent because in rainfed cropping systems, balanced fertilization could contribute positively toward mitigating adverse effect on atmospheric CO_2 levels and subsequently effect on global climate change (Lal, 1998).

We hypothesized that continuous integrated application of carbon, N, P and K through different combinations of manure and fertilizers will have distinct effects on the activities of productivity, energy and emergy which in turn will depict the sustainability of the system. Keeping in view of the above hypothesis, the following objectives were derived for this study: (i) to assess the system productivity; and energy and emergy indices of different modified soil amendment application practices in comparison with traditional practices of soil fertilization in rainfed maize–wheat system and (ii) to compare the energy best treatment with emergy indicators in terms of environmental sustainability.

2. Material and methods

2.1. Site

An experiment on the rainfed maize–wheat rotation system was conducted during 2009–2014 at the Research Farm, Selakui of the ICAR – Indian Institute of Soil and Water Conservation (Erstwhile Central Soil and Water Conservation Research and Training Institute), Dehradun, Uttarakhand, India (30°20′0″ N latitude, 77°52′12″ E longitude) at 516.5 m above mean sea level on a 2% land slope. Before 2008, the plot was under the maize–wheat cropping system (with recommended mineral fertilization for both crops) for past 20 years. The climate of the study areas is sub-temperate with hot summers and cold winters. May and June are the hottest months with mean daily maximum temperature varying from 36 to 37 °C, while January is the coldest month with mean daily minimum temperature ranging from 4 to 5 °C. The mean annual rainfall is 1615 mm, of which 80% is received during the southwest monsoon from July to September, and the rest is received through the 'Western Disturbances' from December to February. Air remains moist during most part of a year. The mean wind velocity varies from 0.76 km h^{-1} during October to 2.62 km h^{-1} in May. Pan evaporation varied between 1.25 and 7.41 mm d^{-1}.

The soils at the experimental site were fine mixed hyperthermic Typic Udorthents. Before imposing the treatments, soil samples (n = 6 for each plot) were collected from all the seven run-off plots of 25 m × 15 m size of each. In order to minimize heterogeneity of soil properties, six samples from each plot was collected and composite samples were processed for initial soil properties characterization. Each sample was air dried, powdered and passed through a 2 mm sieve for determination of soil pH in a 1:2.5 soil:water suspension (Jackson, 1973), oxidizable SOC by the method of Walkley and Black (1934), available soil nitrogen by the alkaline-$KMnO_4$ method (Subbaiah and Asija, 1956), Olsen-P (Olsen et al., 1954) and NH_4OAc-K (Jackson, 1973). A 5-cm diameter sampler was used for soil bulk density determinations. Soil texture was determined using a Bouyoucos hydrometer (Bouyoucos, 1927) and infiltration rate using a double ring infiltrometer (Bouwer, 1986). The soil moisture content at maximum water-holding capacity, field capacity and permanent wilting point was 35.5, 24.8 and 11.2% respectively. The initial physico-chemical properties of experimental plot are mentioned in Table 1.

2.2. Experimental details

The field experiment was conducted with seven treatment combinations [control, i.e. without any dose of manure and fertilizers (T_1), 100% recommended dose of NPK through inorganic fertilizers

Table 1
Initial (before imposition of treatments) properties of the surface (0–15 cm) soils.

Soil properties	Mean (n = 42)	S.D.
pH (1:2.5 soil:water)	6.06	0.17
Oxidizable organic carbon, SOC (g kg^{-1})	6.6	0.7
Available N (kg ha^{-1})	224	4.6
Available P (kg ha^{-1})	16	1.9
Available K (kg ha^{-1})	170	13.4
Sand (%)	42.0	0.46
Silt (%)	35.5	0.75
Clay (%)	22.5	0.12
Bulk density (Mg m^{-3})	1.33	0.02
Infiltration rate of the soil profile (cm h^{-1})	0.92	0.03
Water holding capacity (%)	32.3	1.69
Saturated hydraulic conductivity (cm h^{-1})	1.13	0.04

n, number of soil samples; S.D., standard deviation.