should be able to simply produce the desired function or product and also to stop at a predefined spatiotemporal point.

As is known, RNAPs (RNA polymerases) flowing through a DNA are compared to that of the electrons flowing in an electrical wire, where again an electrical wire being static, the count of electrons per second through a wire could be analysed, which just involves a simple knowledge of the material content of the wire, for example, copper, silver, etc. But the same cannot be possible (at least in the near future) to determine the number of RNAPs flowing through a point in the DNA, called as PoPs (polymerases per second)[7]. In the wake of all these challenges, analog circuitry models and systems thereof could get wider attention over digital circuitry models and systems because the analog circuitry is analogous to the chemical kinetic models and systems.

It could be possible to realize the full potential of a digital biological circuitry only after attaining the same in the analog biological circuitry, as was materialized in the discipline of physics from classical to the quantum world.

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Grains for ecosystem carbon management in North East India

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Preamble

North East India (NEI) comprises of eight states (Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura) and covers 26.3 million hectare (M ha) or ~8% of total geographical area (TGA) of India (329 M ha)[1]. However, it has 17.2 M ha under forest cover, which is ~25% of India's total forest area[2]. Of the total forest cover, 1.5 M ha is currently managed by shifting cultivation in NEI[2]. Shifting cultivation, an integral part of culture and tradition of tribes of NEI, is presently unsustainable because of the population-driven reduction in the duration of the fallow cycle (3–5 years)[3]. Reduction in the fallow cycle has accelerated soil erosion and other ecosystem disservices across NEI. Deforestation and accelerated erosion have severely depleted the soil and ecosystem carbon (C) pools[4]. Ecosystem C management is a priority area of national and international programmes to decelerate climate change. Therefore, this note discusses the feasibility of introducing the 'grains for ecosystem carbon management' (GECM) in NEI through providing food grains to the shifting cultivator as an alternative to shifting cultivation. GECM can be a win-win-win option because it is envisaged to accomplish (i) land restoration: land degradation neutrality under the zero net land degradation (ZNLD) proposal of United Nations Convention to Combat Desertification (UNCCD); (ii) food security: through provisioning of grains under GECM and poverty alleviation under the Sustainable Development Goals (SDGs) of the United Nations through payment for ecosystem services (PES), and (iii) climate change mitigation: restoring soil organic carbon (SOC) for critical ecosystem functions and services.

Land degradation and shifting cultivation in NEI

Land degradation refers to the deterioration or total loss of the productive capacity of soils for present and future use[5]. It is caused by accelerated erosion by wind and water and decline in soil chemical and physical quality. Shifting cultivation (Jhum cultivation), the oldest farming system and intricately interwoven in the culture of the hill people[3], is now among the most severe anthropogenic perturbations exacerbating land and ecological degradation. Shifting cultivation and related bush fallow systems prevail in the tropics and are practised on ~30% of the world's uplands in Africa, Latin America, Oceania and Southeast Asia[6]. The system involves clearing of land by cutting the vegetation (tree or bushes), leaving biomass *in situ* for drying and finally burning the biomass for production of charred material for soil fertility enrichment. Subsequently, one or more crops are grown for 2–5 years until soil fertility is depleted and farmers move to a new forest patch and repeat the process[7]. The time difference between two subsequent cultivations in the same land, earlier extended to 20–30 years has now reduced to 3–5 years[6]. Such a dramatic shortening of the fallow cycle has raised concerns about the sustainability of shifting cultivation because of soil erosion, nutrient loss, decline in productivity and reduction in biodiversity which ultimately leads to ecosystem disservices[8]. As a consequence of shortening the fallow, crop yields are as low as 130 kg ha^{-1} $year^{-1}$ under short fallow cycle in comparison to 2600 kg ha^{-1} $year^{-1}$ under long fallow cycle jhum lands[9]. The vicious cycle can lead to irreversible degradation of the soil and disintegration of the ecosystem[6]. In NEI, shifting cultivation is practised in all the eight states between 22°05′–29°30′N lat. and 87°55′–97°24′E long. NEI covers ~8% of the TGA of India and represents around one-fourth of forest cover of the nation[1]. The region is situated at the confluence of Indo-Malayan, Indo-Chinese, and Indian bio-geographical realms. Because of its geographical location, it represents diverse ecosystem types dominated by mountains and is endowed with rich forest resources. Forest cover of NEI is 66% in comparison to national forest cover of ~21% (ref. 1). Very dense, moderately dense and open forests constitute 15%, 44% and 41% respectively[1]. An indiscriminate practice of shifting cultivation and other biotic pressures decreased the forest area by ~627 sq. km over a short period between 2010 and 2012 (ref. 1). The area under current and abandoned shifting cultivation between 2010 and 2012 was ~6% and 12% of TGA of NEI[2]. Therefore, land area measuring 1.5 M ha, currently under shifting cultivation is prone to ecological degradation. Annual loss of SOC from area under shifting cultivation in NEI[4] is 6 Tg (1 Tg = 10^{12} g).

Income and poverty in NEI

Physiographically, NEI is mostly a hilly terrain (70% of geographical area), and is dominated by rural populace (80%)[10]. Per capita annual income in NEI is US$ 1126 in Arunachal Pradesh, US$ 1025 in Meghalaya, US$ 1015 in Nagaland, US$ 879 in Mizoram, US$ 609 in Assam and US$ 584 in Manipur, which is much lower than the average per capita annual income in India[11]. For the 72 districts in NEI, poverty level is high to very high for 34%, moderate for 23% and low to very low for 43% of the districts[11].

Zero net land degradation of UNCCD

The concept of ZNLD is the achievement of a state of land degradation neutrality. Achieving it involves a combination of reducing the rate of further degradation of land and offsetting newly occurring degradation by restoring the productivity and other ecosystem services of currently degraded lands[12]. ZNLD is best achieved by the introduction and promotion of sustainable land management (SLM) practices on a global basis. In effect, this means reducing land degradation globally to negligible levels while also restoring the quality and productivity of degraded lands[12]. The ZNLD concept can be used in the NEI region where shifting cultivation is being practised.

Food grain production in India

The annual production of rice, wheat and pulses in 2012–13 was 105, 94 and 18 million tonnes (Mt) respectively. Total production of rice, wheat and pulses in 2012–13, was 13%, 23% and 29% higher respectively over that in 2006–07 (ref. 13). Total food grain production estimated at 263 Mt (2013–14) is higher by 6 Mt than that of the 2011–12 production of 257 Mt. During 2013–14, grain production increased by 20.50 Mt over the average production during the last five years[13]. The current rate of India's food grain production is 5–11 Mt higher than the envisaged target rate for 2013–14. Thus food grain production in India is a success story. The rate of increase of food production has kept ahead of the population growth. However, the food produced has neither been adequately stored nor properly used.

Wastage of food grains in India

Regrettably, some 23 Mt of food grains, 12 Mt of fruits and 21 Mt of vegetables are lost each year because of poor storage facilities, with a total monetary loss of 240 billion rupees[14]. Some estimates show that agricultural produce worth 580 billion rupees is wasted in India each year[15]. Reduction in the loss of food grains would increase the food availability for human consumption and help in combating ecological degradation caused by some inappropriate agricultural practices.

Societal value of soil organic carbon

The societal value of soil C refers to the monetary equivalent of ecosystem services provisioned by a unit amount of SOC[16]. The monetary equivalent of inherent cost or societal value of SOC[16] is US$ 0.13 kg^{-1}. Monetary cost of SOC was calculated based on international prices of all inputs (fertilizer, hay, etc.)[16]. Moreover, international prices are widely applicable as is the case with any Intergovernmental Panel on Climate Change (IPCC)-based assessments. Therefore, it is logical to use reported monetary cost of SOC in the present case study. Considering the soil C sequestration rate of 0.61 Mg ha^{-1} year^{-1} with conversion of shifting cultivated area to a fallow land of NEI[9], total C sequestration in 1.5 M ha of shifting cultivation land should be around 1 Tg year^{-1}. Therefore, societal value of 1 Tg of C sequestered is around US$ 130 million year^{-1}. The SOC thus stored can be traded to create another income stream for land managers in NEI. In addition to SOC, C sequestered in the biomass in successional fallows of restored shifting cultivation landscape can bring additional income to the land managers of NEI. Therefore, additional research is needed to assess the rate of accretion of biomass C in the fallow land to estimate the cumulative gains in the ecosystem C pool through change in landscape. Furthermore, during the regeneration phase of the forest, hill farmers can pursue their traditional semiperennial and perennial crop cultivation understorey of the re-growing vegetation. Such cultivation system will fulfil their additional food, fodder and other daily life requirements without slashing and burning the native forest.

Payment for ecosystem services

Carbon farming is rapidly becoming the new agriculture where C sequestered in soil/trees/wetlands could be traded just as any other farm produce[16]. Three mechanisms of compensating farmers are: (1) C credits based on cap and trade, (2) C maintenance fees and (3) payments for ecosystem services. All three mechanisms must consider the inherent value of soil C[16]. Therefore, farmers can be compensated for sequestering C in soil/biomass. Assuming total number of shifting cultivators in NEI at 443,000 (ref. 17), each family can earn US $294 per year (total societal value of SOC/no. of shifting cultivators). The SOC stored in soil can be traded under national and international schemes. Internationally, C credited is traded in the voluntary C markets like the Kyoto Protocol: Clean Development Mechanism (CDM) and Joint Implementation (JI), EU Emissions Trading Schemes (EU ETS), New South Wales Greenhouse Gas Reduction Scheme (GGAS), Chicago Climate Exchange (CCX), and Voluntary Over-the-Counter (OTC) Offset Market. The market mechanism for C trading is well developed in India, and is evident from development and implementation of about 3000 projects till December 2012, out of which ~40% has been registered with UNFCCC (Carbon Market Roadmap for India 2014)[18].

Feasibility of GECM in NEI scenario

Considering the socio-economic situation of the NEI people, consequences of land degradation and other ecosystem disservices from 1.5 M ha of current shifting cultivation land, it is important that soils under shifting cultivation are restored and any new soil degradation is prevented. As an alternative to shifting cultivation, farmers can be provided with food grains as a part of PES that they otherwise grow by shifting cultivation. Rather than a subsidy, food grains provided are an in-kind payment for ecosystem services for restoration of degraded lands. Providing food grains at the rate of 2000 kg/ha of current shifting cultivation land will require 3 Mt of food grains that can be used from the surplus being currently wasted every year. Therefore, there is a need for Government-driven policy to implement the proposed scheme. Under a successful GGP in China, 1500–2250 kg of grain is subsidized annually for each hectare of farmland converted to forest land use[19]. While increase in total food grain production to 264 Mt $year^{-1}$ is commendable, there is no justification to waste 10–30% of the total production[20]. Therefore, introducing GECM in NEI and providing food grains is an appropriate use of surplus food grains, while achieving restoration of degraded land, strengthening ecosystem services, and earning C credits from ecosystem C sequestration as an income source through PES. The proposed GECM will help in improving the socio-economic status of the hill farmers now practising the subsistence system of shifting cultivation. Social consequences of many schemes have been debated for their negative effect on society[21]. However, in the proposed scheme the food grains that will be provided are not the subsidy but a payment for their contribution in managing the native forest. This strategy will ensure continuous engagement of hill farmers in native forest management. Moreover, during the regenerating phase of native forest women members may be encouraged to take up floriculture activities to develop another income stream.

Conclusion

To achieve the goal of National Mission for a Green India under the National Action Plan on Climate Change 2011, the proposed GECM for restoration of fragile degraded ecosystems of NEI may be a viable option. This strategy will provide multiple benefits in social, ecological and economic aspects, viz. (i) reducing the rate of land degradation to achieve land degradation neutrality (ZNLD)[12] and Vision 2020 for NEI[22], a Government of India initiative to return NEI to the position of national economic eminence; (ii) promoting the United Nations SDGs of poverty alleviation by involving the hill farmers in restoration programmes and securing their earnings through PES, and (iii) restoring SOC for critical ecosystem functions and services. Therefore, successful implementation of GECM in NEI will be a triple-win option.

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