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Soil Science Research, Information & Communication Technology and New Agricultural Education Policy: Issues and Perspectives

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Abstract

The present article takes a tour of research in Soil Science (as a part of natural resource management) with a mention about its past, present and probable future research agenda. Effort has been made to discuss the significance of Information & Communication Technology (ICT) as a part of educational and research agenda which could be dove-tailed in the New Agricultural Education Policy (NAEP) of India. Attempt has been made to inter-link issues of Soil Science research, ICT and NAEP and explore the possibility of their convergence on to the same page.

Key words: Soil Science, Information & Communication Technology, New Agricultural Education Policy.

Introduction

Where soil is the backbone of agriculture (and its allied branches) as the source of food and other essentials as a part of natural resources, it is imperative to understand the soil and the natural resource research for its management. In view of modern technologies available with almost everyone in the form of electronic devices, Information & Communication Technology (ICT) is making a progress by leaps and bounds. This trend of modernism could be a boon for natural resource managers to spread the knowledge of the importance of soil as a medium of ecosystem service provider to one and all. Lack of manpower in disseminating agricultural technology can be overcome with the active participation of student community armed with the latest ICT gadgets to reach the farmers and bridge the gap between State Agricultural Universities (SAUs) and farming community. This requires a shift and revision in the New Agricultural Education Policy (NAEP) with reference to Natural Resource Management (NRM) (read Soil Science) **(Figure 1)**. The policy is required to address the issues of future of NRM research so that the professors and the scientists can carry out future programmes and enthuse the students to ignite their inquisitive mind to understand the contemporary issues. The entire exercise can be made easy if ICT is utilized in a meaningful way to be a part of the mainstream NAEP (**Figure 1**) and ultimately enrich it.

For a research subject as important as NRM with special reference to Soil Science, the path it has traversed in the past carries on the reminiscences of both success and failure. This requires a looking at the yester years. This does also necessitate to see what is in store for tomorrow. The lessons of yesterday are certain as compared to the tortuous turns and twists of tomorrow. Introduction of ICT tools has an immense influence today and continues to prevail tomorrow to shape the research agenda for future natural resource managers. New Education Policy (NEP) encompasses NAEP where soil as one of the most important components of the natural resource shall have an important role.

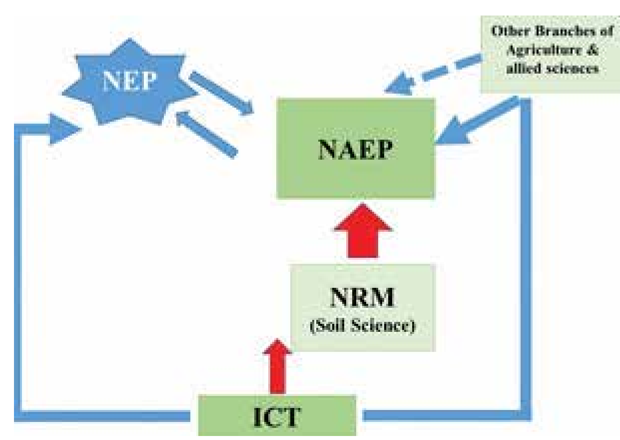

Figure 1. Suggestive link of NAEP with NEP, NRM and ICT

A. Soil Science Research

Recognition of at the UN/FAO level is documented in the form of formal establishment of World Soil Day (WSD) as a global awareness raising platform. The WSD for 2021 was themed on *halt soil salinization and boost soil productivity*. This was in continuation of the previous years' themes (**Table 1**). The appraisal of the subject of Soil Science is important since it transcends human life, expertise, experiences by many generations, even centuries. The immediate present and imminent future of the professional subjects borrow their food for thought from their respective pasts. And that's why it is good to see through the prism of time the yesterday, today and tomorrow of Soil Science for the management of natural resources.

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Table 1. Themes of World Soil Day

Year	Theme
2015	Healthy Soils for a Healthy Life
2016	Soils & Pulses: Symbiosis for Life
2017	Caring for the Soils Starts from the Ground
2018	Be the Solution to Soil Pollution
2019	Stop Soil Erosion, Save our Future
2020	Keep Soil Alive, Protect Soil Biodiversity
2021	Halt Soil Salinization and Boost Soil Productivity

An effort is made to mention a few important events related to agriculture in general, and soil in particular. Many events are available in literature. Major emphasis is shown here with an eye on the probable future events.

A1. Soil Science Yesterday

Looking back is important. It requires scientific auditing. Looking back helps in understanding a few important issues such as the, i) length travelled, ii) milestones covered, iii) laurels achieved, iv) extent of deviation from the set goals, v) corrections required, vi) level of satisfaction and happiness (with the performance), vii) level of services provided for science, society, people, farmers, and their families (for agriculture-related societies), viii) measurement of performance, ix) threshold values of satisfaction, and x) feedback of the society/stakeholders (Bhattacharyya 2021a).

Mere understanding may not help; proper comprehension of these issues is more important. The moot point is the society at large, and the students, administrators, and the parents (farmers in many cases) have huge demand from the soil scientists and natural resource managers. Their expectations and aspirations shall increase with time. To fulfill these aspirations, science and professional scientific societies and institutions need to keep pace with the new avenues of research. It is important to look back and see the path travelled to set our present responsibilities to serve the science.

The earliest evidence of agricultural activity, including manipulation of soil to promote crop growth, comes from a site near Jarmo, Iraq nearly 9000 BC. Cultivation began in modern day Poland as early as 5,500 BC; but, in general, agricultural techniques were improved in Europe by the Romans. The people of Mesopotamia recognized differences in fertility between soils, an early evidence of Soil Science. Way back in 5,000 to 1,700 BC, the Egyptians developed an organized civilization around the Nile River that lasted some 3,000 years, from about 3300 BC to 332 BC (Brevik, 2009) (**Table 2**).

The Ramayana around 7000 BP (before present) informs about the necessity of organic matter to nurture soils. Farming existed in Mexico by the 5th century BC around 401-500 BC, and included terracing and irrigation techniques. In Mexico, the Maya farmed flat valley lands with readily available water, and used a system that required a working knowledge of a number of soil properties. Kautilya (Arthashashtra 321-296 BC) refers to the application of manures in soils. In India, Neolithic (3rd to 2nd centuries BC) farming communities are recorded in areas with fertile black (*regur*) soils on the Deccan Plateau. During the 1st century BC, soil properties and optimal tillage operations are reported by Fan Sheng-chih. Early agriculture in China centred on the fertile floodplain of the *Huang He* (Yellow) river. Indian farming was expanded to the fertile floodplains of the River Ganges. Assessing soils according to their quality and location existed in China. Use of land quality in assessing taxation was reported in India also (Brevik, 2009) (**Table 2**).

The 15th century marked the beginning of the Renaissance in Europe (Brevik, 2009), a period when science began to grow. Charles Darwin, Leonardo da Vinci, Francis Bacon, and Robert Boyle glorified science and arts during this time. Concept of soil profiles and influence of earthworms on soil formation were part of soil studies during 1500 AD. Sprengel's theory on mineral nutrition of plants and the law of the minimum (Liebig's *Mineral Theory* of Plant Nutrition) came around late 1820s. Although soils were being investigated as components of chemical, geological, and biological systems during 1500 CE to 1880 CE, it was still not an independent field of study as Soil Science (Brevik, 2009) (**Table 3**).

In 1883, Russian Chernozem was published by V.V. Dokuchaev to mark the birth of modern Soil Science. Dokuchaev recognized soil as an independent natural body, and established soil forming factors to begin the study of soil genesis. He also introduced the concept of A, B, and C horizons for a soil profile (**Table 3**). National soil survey programmes began during 1880-1990 in many countries (**Tables 4** and **5**). From 1893 to 2002, various experts worked on to develop and articulated soil mapping activities in India (Bhattacharyya, 2021b) (**Table 5**).

A2. Soil Science Today

Soil Science made great contributions during the 19th and 20th centuries. Plenty of information was generated on soil properties. Generation of soil maps proved useful to prepare many thematic maps to address the contemporary agricultural and environmental issues. Subjects such as Geomorphology, Land Use Planning, Paleo-environment, Archaeology, Human Health, Soil and Water Conservation, Environment, etc. became part of soil research activities. Availability of computers, global positioning systems (GPS), Geographic Information System (GIS), remote sensing data, and

Table 2. Chronology of ancient Soil Science from 9000 BC/ B.C.E. to 1500 AD/C.E.: (Only a few selected events) (Sources: Brevik, 2009; Katyal, 2015; Velayutham et al., 2016)

Period	Events elsewhere	Events in India
11000 BP	Jarmo village (Iraq) implements for harvesting and tilling	-
9500 BC	Iraq (Irrigation evidence)	-
5500 BC	Poland (beginning of cultivation)	-
5000 -1700 BC	Mesopotamia (understanding soil fertility)	-
3300 -332 BC	Egypt (Nile River civilization/soil fertility and irrigation)	-
2,500 BC-600 AD	-	Knowledge acquired by the then agriculturists by experience has become tradition, and the same has been passed on from generation to generation.
2300 BC	China (Soil grouping on quality and location)	-
2000-1001 BC	Greece (Greek philosophers - scientists developed an understanding of soils, and their differences)	-
1577 BC	-	Land described as arid, wet (marshy), and moderate (neither too dry nor too wet) and is distinguished by six tastes through colour (Misra Chakrapani in Visva-Vallabha).
1000 BC	-	Oldest commandments of soils *Atharva Veda.* Five elements of life *viz.* earth, water, energy, sky, and air
500 BC	-	Necessity of organic matter to nurture soils (The *Ramayana*)
401-500 BC	Mexico (farming included terracing and irrigation techniques)	-
321-296 BC	-	*Kautilya Arthashashtra* refers to application of manures in soils.
322 BC	-	Measurement and supervision of alluvial deposits for revenue purposes (Megasthenes during Maurya dynasty) 300 BC - Fertile black (*regur*) soils in the Deccan Plateau
300 BC	-	Soil classification on the basis of suitability of crops
100 BC	China (fertile floodplain of the Huang He, or Yellow River)	-
300 AD	-	Fertile floodplains of the Ganga river, India included
1100 AD	China (Count Hui dividing soils according to their quality and location)	-

Notes: BC/BCE: Before Christ/Before the Common (or Current) Era; AD/C.E.: Anno Domini/ Common Era; BP: Before Present

Table 3. Chronology of ancient Soil Science (from 1500 AD/C.E. to 2002 AD/C.E.:) Only a few selected events (Source: Brevik, 2009; Anonymous 2021; Soil Survey Staff, 1975)

Period	Events elsewhere	Events in India
1500 AD	Europe (soil formation/ biology)	-
1820 AD	Law of minimum of Justus von Liebig	-
1500-1800 AD	Chemical, geological, or biological components considered	-
1883 AD	Russian Chernozem publication by V.V. Dokuchaev. He recognized soil i) as an independent natural body worthy of study in its own right, ii) established the five soil forming factors that are widely used and developed one of the first models of soil genesis, and iii) broadly introduced the concept of A, B, and C horizons.	-
1880-1990	National Soil Survey Programmes in many countries (Also see Table 4)	National Soil Survey Programmes in India (Also see Table 5)
1926	-	Imperial Council of Agricultural Research (ICAR) registered as a Society
1938	USDA Soil Taxonomy developed with three Soil Orders	-
1946	-	ICAR became Indian Council of Agricultural Research
1969	-	US Soil Taxonomy was adopted.
1967, 1970	-	Soil Test Crop Response Project, Long-Term Fertilizer Experiments Project
1975	US Soil Taxonomy : Seventh Approximation	-
2002		Soil Map (Table 5)

Table 4. National Soil Survey Programmes in countries (Sources: Brevik, 2009; Bhattacharyya, 2021a)

Country	Year
USA	1899
Russia	1908
Canada	1914
Australia	1920s
Great Britain	1920s
Mexico	1926
Sri Lanka	1930
China	1931
India	1932 (First soil map)
Poland	1935

Table 5. National Soil Survey Programmes in India (Source: Bhattacharyya, 2021a)

Year	Maps
1893	J.A. Voelcker (India)
1898	J.W. Leather (India)
1932	Schokalskaya (Soil Map of India)
1935	Wadia (Soil Map of India: Geology)
1943	B. Vishwanath and A.C. Ukil (Soil Map of India)
1963	S.P. Raychaudhuri (Soil Map of India: 16 major and 108 minor soil regions)
1971	S.V. Govinda Rajan: World Soil Map Project
1983	R.S. Murthy (Soil Map of India)
2002	NBSSLUP Staff (Soil Map of India - 1: 2,50,000 scale)

different statistical and predictive models permitted soil scientists to generate a wealth of information. Information on soil nutrients, fertilizer applications, and soil pollution were also generated (Brevik, 2009). Many models developed proved to be useful to predict climate change/global warming to assess the possible fate of natural resources. With the ever-multiplying demands of the society at large, and to address the local and global problems huge responsibilities lie now on the shoulders of the next generations to carry forward the present research agenda further. It requires to keep pace with the changing scenario of agricultural and non-agricultural issues as discussed below.

A3. Soil Science Tomorrow

For any scientific discipline, it is good to look back and make out what has been achieved, how it has been done and whether anything can be learned from the past. Although it is a respectable activity but it will not yield scientific breakthroughs. To stay in business as a science, it is healthier to look forward and fix the road map for tomorrow. Soil Science as an important component of NRM discipline has made great strides in the past and is still doing well with the active support of the talented scientists and professors in India and elsewhere. Soil Science, however, needs to take a shift from the traditional research agenda to other areas of research encompassing a few subjects such as Ecosystem Services, Soil Diversity, Pedodiversity, Biodiversity, Soil Endemism, and Geophagy (Bhattacharyya, 2021 b,c; Brevik, 2009). It is imperative that soil scientists should take a larger perspective instead of isolated approach of concentrating mostly on agriculture and forestry.

Soil scientists need to forge links to harness interdisciplinary opportunities as detailed later. There are many other contemporary issues like global warming, multifactor modelling of complex soil processes, remote sensing and IT applications for land use planning, developing technologies for genetically modified crop-based systems that also require the broadening of current paradigm of soil scientists (Minhas, 2006). Soil Science and the soil scientists need to be dynamic and should be ready to adopt midterm corrections for their research agenda depending on societal and global necessities.

A3 (1) National or International Soil Databases

Soil Science requires internationalization through its deeds and attitude. Indian soil scientists may take a lead to decide on the future of tropical soils with its vast majority of technical resources and accordingly set their research agenda. In order to be able to run regional environmental modelling as a future research programme, nationwide soil profile and analytical databases must be established following the internationally accepted methodologies to put the database in the same page. It should be carried out with NRM, ICAR and SAUs as the focal points of research. This database should be made available to researchers in India and abroad following standard protocols.

A3 (2) Fertilizer and/or Nutrient Management and Land Degradation Neutrality (LDN)

Broader perspective of nutrient research may address the burning issues like land degradation neutrality (LDN). LDN may also be conceptualized through fertilizer and/or nutrient management and ecosystem services. Since poor nutrient management leads to poor crop performance due to poor soil/land quality, it might as well invite land degradation and related ecosystem services. New range of fertilizers and amalgamations as part of various treatments in Long-Term Fertilizer Experiments (LTFEs) may be incorporated as new treatments to test their effects in soil and crops (**Figure 2**). It might be a part of future recommended doses of fertilizers (RDF). ICAR and SAUs may take appropriate initiatives in this regard.

The ICAR All India Coordinated Research Project on LTFEs may be made more contemporary and user-friendly. Findings of these studies need to reach the

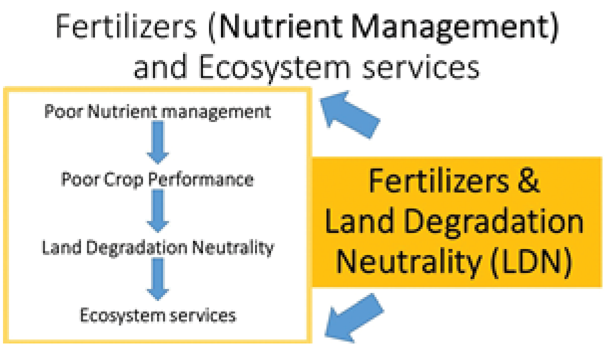

Figure 2. Link between nutrient research, ecosystem services and land degradation neutrality (LDN)

farmers through SAUs to the respective state governments. The SAUs are the channels to reach the farming community and LTFEs act as the eyes and ears of ICAR. These experiments are excellent tools devised by our predecessors. However, since agriculture has different growth engines, LTFEs may be oriented to address the issues of other sectors as well. There is a scope to revisit, reshape, and reorganize our technical programmes to address the contemporary issues to solve the problems of the stakeholders at the field level. For the LTFEs, various issues listed in **Table 6** may be considered in the future.

A3 (3) Land Degradation Neutrality and Land Use Options

Land degradation neutrality and land options could

Table 6. Revisiting long-term fertilizer experiments

S. No.	Issues	Suggestions
1.	LTFE data base	· Database should be in public-friendly domain following standard protocol to ease the data storage and sharing · Digitisation of LTFE datasets with experts from IT · Information System on Long Term Fertilizer Experiment (ISLTFE)
2.	FYM as a part of treatments and soil carbon	· To specify the OC content of FYM only · Very low active pool of OC in black soils · Passive pool: recalcitrant and useless C reserve in soils · Fresh and highly oxidised externally added FYM generates active pool of SOC for plants · Splitting FYM into at least two doses (one each for *kharif* and *rabi*) shall improve both soil and crop health · For *rabi* crops (using residual soil moisture and/or with a life-saving irrigation) a split dose of FYM shall improve the active pool of SOC
3.	Biofertilizers	· Microbial population and its influence be the part of LTFE and laboratory studies for better soils and crop health.
4.	Fertilizer applications	· Ascertaining nutrient content at the time of application for each treatment.
5.	Length of LTFE	· Documentation on length of LTFE in terms of stabilization of soils health/biotic stress/abiotic stress
6.	Methods of measuring parameters for soils	· Standardization of method(s) for measuring parameter(s)
7.	Including new fertilizer formulations	· Including new formulations with special reference to nano fertilizers and other amalgamations with carbon, etc. in the treatments to bring these in the mainstream of RDF
8.	Soil data	· LTFE datasets are skewed towards crops and fertilizers. · LTFEs should be rich in soil data. · Various parameters of soils should be regularly analysed in future. · If SOC is measured by Walkley-Black method, then a correct Walkley-Black Recovery Factors should be routinely measured.
9.	Multi-disciplinary	· LTFEs are conceptualized as the multi-disciplinary programmes. · There is a scope to make it broad-based.
10.	Predictive soil/crop models	· Predictive modelling using LTFE data are wanting in many cases weather, and soils. · It requires revisiting
11.	Doubling farmers' income (DFI) and soil health	· LTFE datasets may be oriented to address doubling farmers' income. · AESR-based crop planning is in place. · LTFEs may be oriented to fit in the concepts of bioclimatic systems BCSs in different AERs/AESRS/ACZs/BCSs in India

LTFE: Long-Term Fertilizer Experiments; SAUs: State Agricultural Universities; FYM: Farmyard Manure; OC: Organic Carbon; SOC: Soil Organic Carbon; BSR: Black Soil Region; RDF: Recommended Doses of Fertilizers; AESRs: Agro Ecological Sub Regions; AERs: Agro Ecological Regions; BCSs: Bioclimatic Systems; ACZs: Agro Climatic Zones (Also see Bhattacharyya, 2021d)

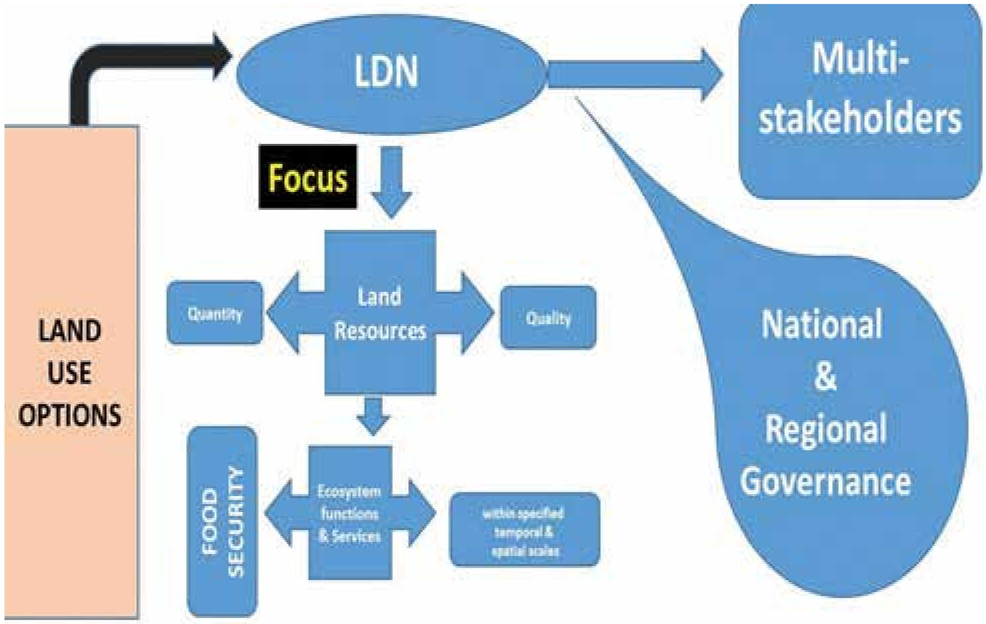

Figure 3. Land degradation neutrality and land use options: role of stakeholders (Source: Bhattacharyya, 2020)

be dove-tailed as a future exercise of land use planner to arrest further land degradation. People are thinking on the future of soil survey in this country with special reference to large scale mapping. It might be oriented to address the contemporary issues and may be demand-driven. Scientists and students will then be enthused to carry on the work both in the field and laboratories (**Figure 3**).

Climate is one of the major soil forming factors. Therefore, climate change and LDN *vis-a-vis* pedo-diversity and bio-diversity require soil as the focal point for discussion. Land area is dwindling due to many reasons among which the most important is its degradation - both natural and anthropogenic. But there are ways for research to find out how LDN may restore soil/pedo-diversity and bio-diversity. An example from the semi-arid bioclimate might help to visualize how the soils will look in the event of soil/ land degradation going on uncontrolled/unchecked (**Figure 3**) (Bhattacharyya et al,, 2016). Similar relations in other bioclimates may be constructed using new research ideas/data for all the 84 revised agro-ecosubregions of the country (**Figure 4**) (Bhattacharyya et al, 2021a).

A3 (4) Soil Ecosystems

Soil ecosystems remain firmly at the foundations of human life support systems. These are the least understood among the natural ecosystems and increasingly among the most degraded to demand attention. Soil and soil minerals are part of the natural environment. Soil studies should include many other branches of science in future research programmes to understand soil ecosystems appropriately to make it interdisciplinary, multi-disciplinary and trans-disciplinary (Bhattacharyya, 2021c). Among these branches, soil and soil minerals are an important component to provide almost all the ecosystem services (Bhattacharyya 2021d) (**Figure 5**). Four important ecosystem services which the soils provide are: provisioning, regulating, cultural, and supporting services. The provisioning services include food, raw materials and water retention, while the regulating services are climate, water regulation, carbon sequestration, and erosion and flood control. Weathering/soil formation and nutrient recycling are the supporting services provided by the soil. Cultural heritage is the important cultural service provided by the soil to the mankind. With the advancement in scientific knowledge, and novel functionalities, new services might be discovered. Research on this aspect is to be a continued effort on the part of students and researchers (Bhattacharyya 2021c).

A3 (5) Soil Carbon Research

Soil and soil minerals are part of the natural environment. Soil studies include many other branches of science. Among those, soil and soil minerals provide ecosystem services. Both organic and inorganic soil carbon influence important component of ecosystem services. These include soil fertility, and soil and clay minerals as part of natural resource management (**Figure 6**) influencing different ecosystem services.

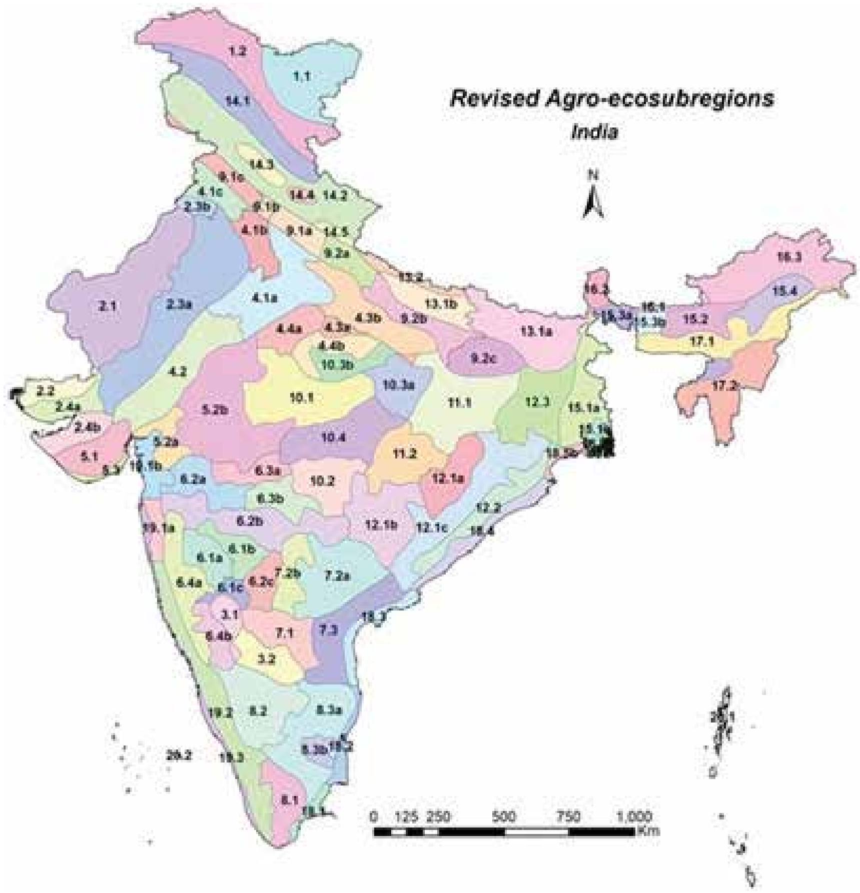

Figure 4. Revised agro ecosubregion (AESR) map of India revisited (Source: Bhattacharyya et al., 2021a)

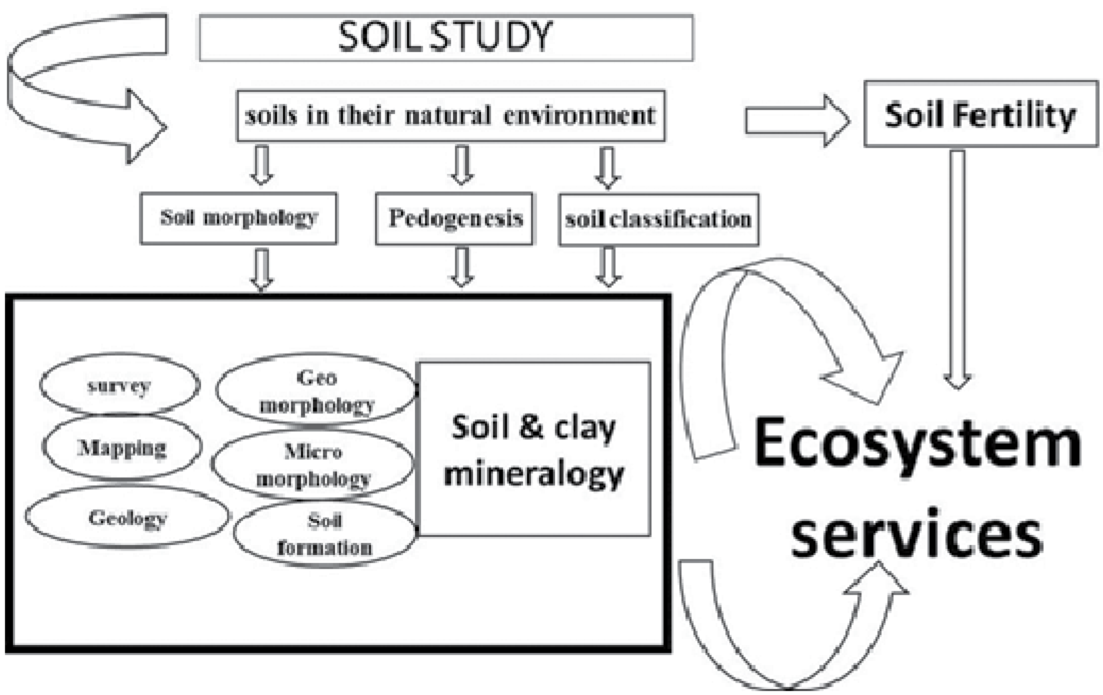

Figure 5. Relation between soils, minerals and ecosystem services (Source: Bhattacharyya 2021c)

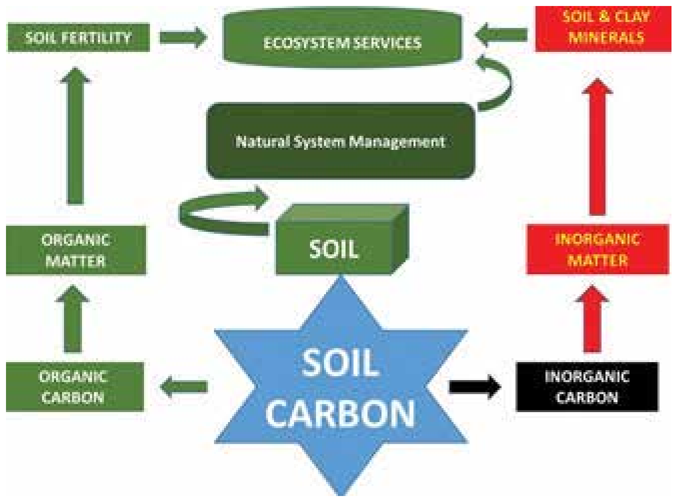

Figure 6. Soil carbon and ecosystem services (Source: Bhattacharyya, 2021d)

Soil carbon regulates services in terms of sequestration of both organic and inorganic forms. Provisioning services centre on soil quality which requires a knowledge of soil carbon reserves and the prediction of carbon stocks over years. This helps in prediction of crop yields. Both the forms of carbon in soils can help in understanding the soil and land quality through a (proposed) soil and land quality model (Bhattacharyya, 2022). Therefore, information on soil carbon will ultimately help in influencing the food, fuel, fibre, raw materials, and fresh water retention. Content of organic and inorganic carbon shall also influence the supporting ecosystem services since both these forms of soil carbon affect soil formation and nutrient recycling. Progress of nation as well as decline in civilization are results of the poor soil/land quality. Soil carbon dictates both. Thus, in both its forms carbon shall continue to maintain cultural heritage to provide cultural services to the mankind (**Figure 7**) (Bhattacharyya, 2021b, c, 2022). Research on both these forms of soil carbon and their influence on global warming may be a part of future soil carbon research.

Different pools of organic carbon require in depth investigation in all the 84 AESRs (agro ecological subregions) since these pools are influenced by climate, Since fresh farmyard manure (FYM) addition increases the active pool of soil organic carbon (very labile pool, splitting of FYM dose with one in the *rabi* season with an assured irrigation may be a subject of research. Inorganic soil carbon requires a separate

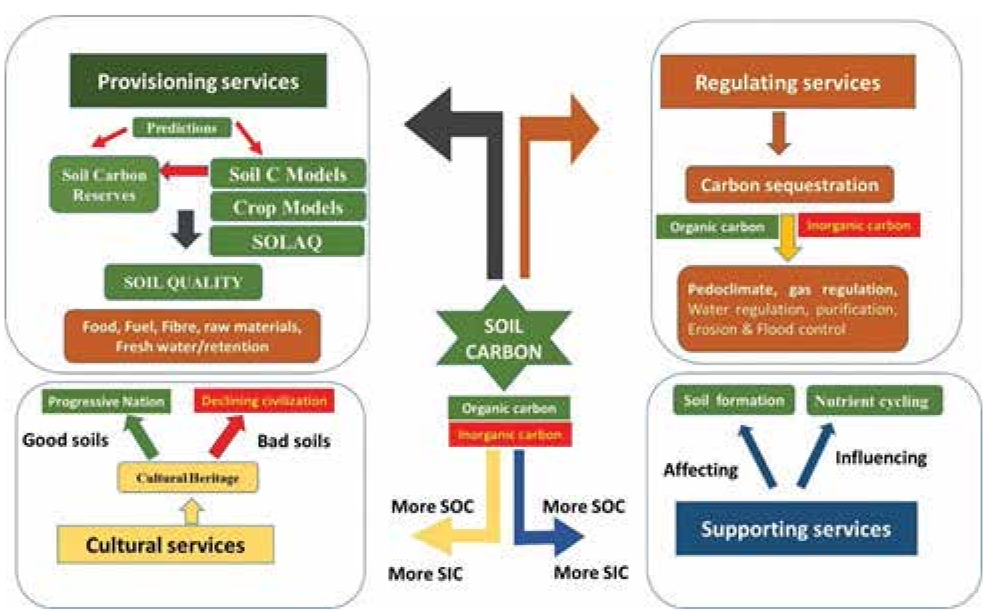

Figure 7. Soil organic and inorganic carbon, their reserves and prediction to influence ecosystem services (Source: Bhattacharyya, 2021d)
(SOC: soil organic carbon; SIC: soil inorganic carbon; SOLAQ: soil and land quality model)

research agenda for the scientists engaged in the abiotic stress management (Bhattacharyya, 2021d).

A3 (6) Soil and Human Health

Soil Microbiology and Biochemistry should be strengthened in the future soil research programme to throw more vision on biodiversity, soil-plant and soil-chemical interactions in ecosystems which affect the human life. Contamination of urban soils could be a part of the peri-urban agriculture. Majority of the world's population living in urban and suburban areas is exposed to soil-borne contaminants and pathogens through inhalation, ingestion, and dermal contact. More research may also be carried out by soil scientists to find the possible links between soils and animal/human health.

A3 (7) Soil Biology

Soil is a complex biomaterial on the planet. More than 90% of the planet's genetic biodiversity is resident in soils but less than 1% of the microorganisms have been cultured and studied. The enormous gene reserve in soils may be exploited in future by industry and pharmaceutics with the help of soil microbiologists (Rao, 2006). The future projects may be oriented accordingly.

With the advent of more sophisticated instruments, soil biologists may reveal the mystery of structure-function relation of microbial communities. A greater understanding of the functional bridges with the available knowledge of basic sciences should find some place in the agenda of future research in Soil Science (Rao, 2006). Earlier while generating soil database, biological information was made as an important component of soil information system (Bhattacharyya et al., 2014a, b). This research should be a part of both course curriculum as well as research programmes in future Soil Science programme.

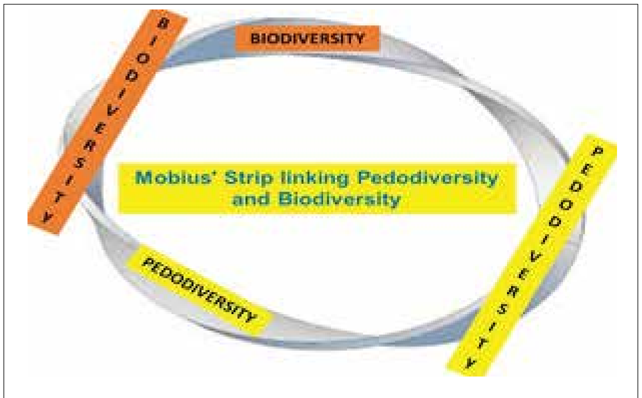

Figure 8. A Mobius strip relation between pedodiversity and biodiversity (Source: Bhattacharyya and Patil, 2022)

A3 (8) Pedodiversity and Biodiversity

It has long been recognized that biodiversity can be the mechanism behind the performance of an ecosystem, particularly in communities of above-ground organisms. In soils below ground, however, the functioning of biodiversity is not well understood. The relationship between two inter-related aspects of natural diversity namely, pedodiversity and biodiversity may be viewed in the image of a Mobius strip (Bhattacharyya and Patil, 2022). Mobius strip is a curious and intriguing object that can be created with a strip having two surfaces; but once created will give an illusion of having only one continuous surface (**Figure 8**).

Land use and its changes bring major changes in diversity. There could be changes in pedo-diversity leading to disturbed biodiversity. It requires expertise of many researchers from different branches (**Figure 9**). Contribution of various experts is paramount not only from the biodiversity point of view but also in bringing some areas under agriculture and other allied

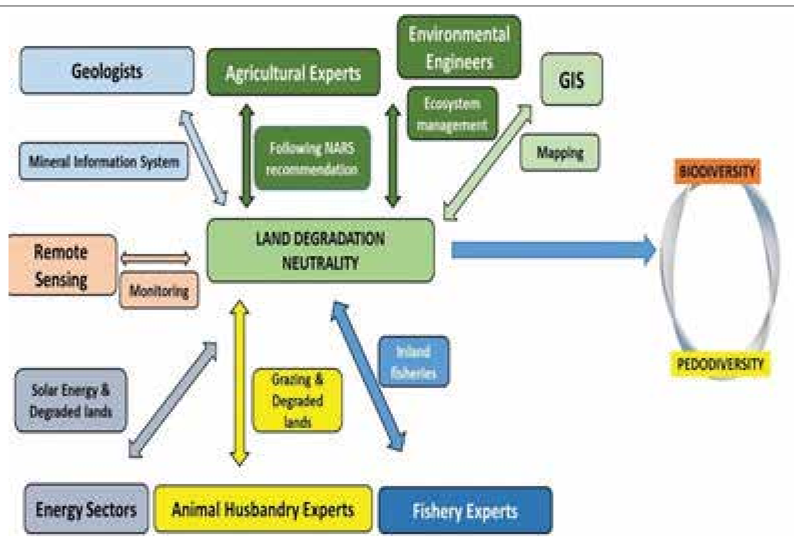

Figure 9. Land degradation neutrality maintains soil/pedodiversity and biodiversity: suggested policy (Source: Bhattacharyya and Patil, 2022)

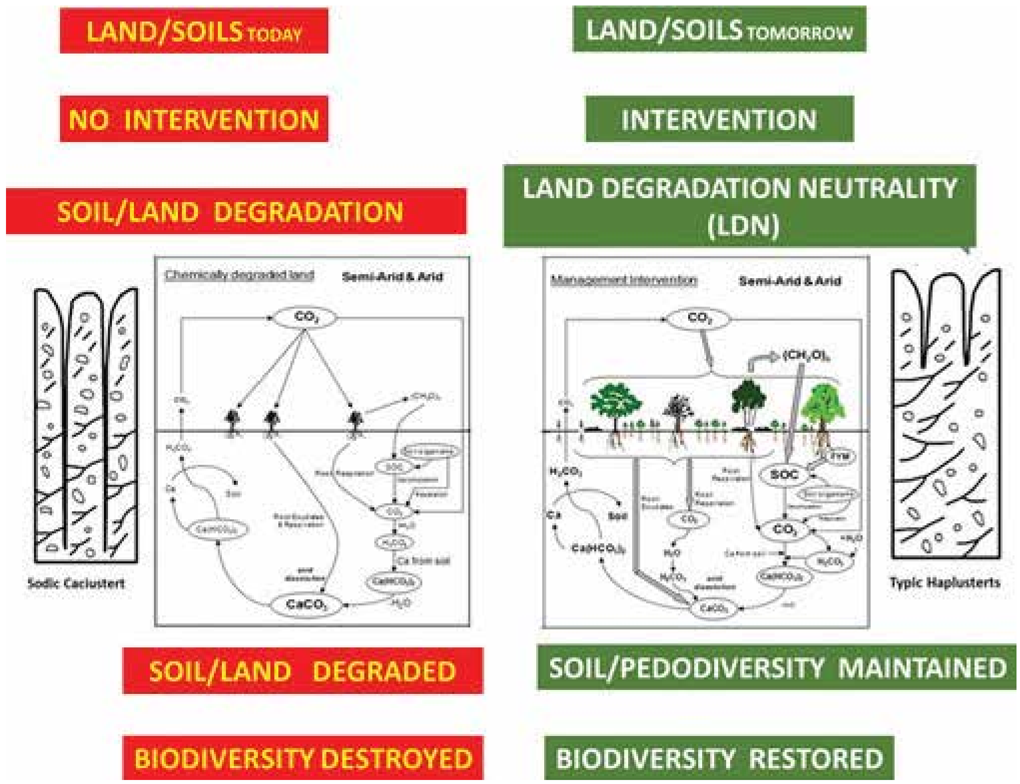

Figure 10. Addressing climate change and land degradation neutrality *vis-a-vis* pedodiversity and biodiversity (Source: Bhattacharyya and Patil, 2022)

activities. Future research in soils should focus to fulfil the target of land degradation neutrality with an acceptable policy to converge the Mobius strip of biodiversity and pedodiversity (**Figure 10**).

A3 (9) *Quantifying Relationships between Pedodiversity, and Biodiversity with Other Forms of Diversity in Nature*

Soil diversity research has been scantily carried out in India (Bhattacharyya, 2016, 2021 b,c). Soil and pedodiversity is linked so are their contributions to the key aspects of heritage such as, biological and cultural (preservation of biodiversity, ancient and traditional sustainable practices), soil monitoring (benchmark soils in monitoring programmes), prehistoric and paleontological (archive of artefacts and remnants of extinct species), bio-geosphere (archive of past environments), and geological (pedodiversity as a part of geo-diversity concept). Relationships between pedodiversity and biodiversity with other forms of diversity in nature may be considered for future research programmes for Indian soil science programme (**Figure 11**).

A3 (10) Soil Endemism

There is a necessity to preserve the plant/tree species globally through the efforts of collecting them, planting them in orchards or botanical gardens and to carry out information campaign to keep them conserved in the wild. Efforts to preserve the unique characteristics of an important fruit like mango (*Mangifera spp.*) have been made to identify the mango species under threat (**Table 7**).

Similar to plant/tree species threat to survive on earth, soil species (family or series in US soil taxonomy; Soil Survey Staff, 2006) indicate considerable soil endemism in the USA (and likely around the world). The trend towards *endemism* at the series and family

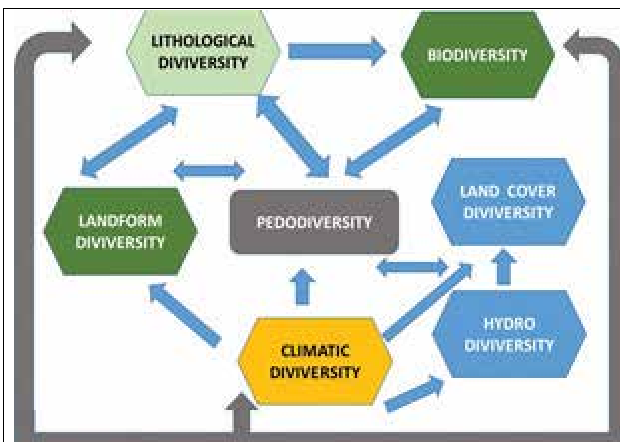

Figure 11. Relationships between pedodiversity and biodiversity with other forms of diversity in nature (Adapted from Ibáñez et al., 2012) (Bhattacharyya and Patil, 2022)

Table 7. Mango species and tree endemism (Source: Ganguli et al., 2019)

Type of threat	Mango spp.
Rare	*Mangifera andamanica, Mangifera camptosperma, Mangifera gedebe*
Endangered	*Mangifera cochinchinensis, Mangifera flava, Mangifera lagenifera, Mangifera pentandra, Mangifera reba, Mangifera superba*
Vulnerable	*Mangifera duperreana, Mangifera inocarpoides, Mangifera monandra, Mangifera timorensis, Mangifera zeylanica*

levels of soil classification is of considerable interest in conservation or preservation efforts. Soil endemism reflects, controls, and perhaps relates to the regional distribution of the plant species. And as described above, there is a jinx of the Mobius strip relation between soil diversity (read soil endemism) and biodiversity. These are complex relations in nature and need to be addressed regionally and globally for our own survival. It is a key consideration in conservation and preservation planning but is yet to find any importance in Indian Soil Science research. Future soil research programme might include this aspect. This has more relevance while mapping degraded soils in large scale to indicate the soils under threat.

A3 (11) NRM (Soil Science) and Non-agricultural Application

The contribution of NRM in areas other than agriculture in stitching the story of past may form future research programmes involving soil scientists and the experts from other disciplines.

A3 (11)a. Space archaeology and tourism: Space archaeology with the advent of GIS and other software techniques can be made open to an online platform to launch citizen archaeology for easy access of historical sites and benchmark spots. This might help in informing the monitoring agencies about the existence of new sites not yet mapped and listed. While large scale mapping soil scientists engaged in soil survey and mapping can be vigilant about these sites. The experts in soil survey and mapping, remote sensing experts and archaeologists can work together in this field of research. It will stop the extent of damage caused by vandals to stop vandalisms, and educating locals to understand the importance of these historical sites built many years ago and cannot be rebuilt (Bhattacharyya et al., 2020). This will turn the conservation and maintenance of archaeological sites into a people's movement and would serve tremendously to boost tourism and may thus generate revenues for both the Central and State Governments (**Figure 12**). Such rural tourism can be a secondary source of income for the farmers and farming community.

A3 (11) b. Petrographic, mineralogical, and geochemical studies: archaeological evidence: Natural resource managers, in addition to help finding out missing archaeological evidences (see above), may help in finding the source of various types of historical evidences through chemical, geochemical and mineralogical studies. Soil scientists may help experts of other branches working on non-agricultural aspects of soil research. Such studies may form future collaboration with soil scientists and archaeologists to find the historical truth.

There was discussion about the provenance of cannon balls in Goa on whether it was from India or brought by the Portuguese from elsewhere. Archaeological, petrographic, mineralogical and geochemical studies were carried out on samples of millstones and the quarried site at Dharavi (Uttan) (**Figure 13**). In addition, sample was also collected from cannon ball found at Arsenal (Old Goa) to find out whether stone from Dharavi (Uttan) was used. The analytical results of basalts present nearby at Bassein (Dharavi, Uttan) did not match with the composition of the cannon balls. It could, therefore, be stated that although stones from Dharavi (Uttan) were quarried for decoration of churches of Goa by the Portuguese on a larger scale, the same was not suitable for cannon balls due to their fragile nature (Ambekar et al., 2015).

B. Information & Communication Technology/ Digital India Programme

Information & Communication Technology in the Digital India Programme is an interesting area and soil scientists have a great role to play in this field of research. There are mentions of demand for the natural resource database to come in the mainstream of information technology (IT). It is all the more necessary for the national soil information system (SIS) to develop a soil information technology (SIT) and be a part of digital agriculture (Bhattacharyya et al., 2014c; Bhattacharyya, 2021 b,c) through electronic extension (e-Extension) mechanism (Bhattacharyya et al., 2021b).

The e-Extension has the potential to transform traditional farming into precision farming. Many countries rely on precision farming for increased productivity and profitability. Precision farming has economic, social and environmental benefits. It requires adoption of advanced technology. In most of the cases, technology is available, but its rate of adoption is slow. The e-Extension can play a crucial role to enhance the adoption rate of technology. The e-Devices and softwares may be used to ensure data

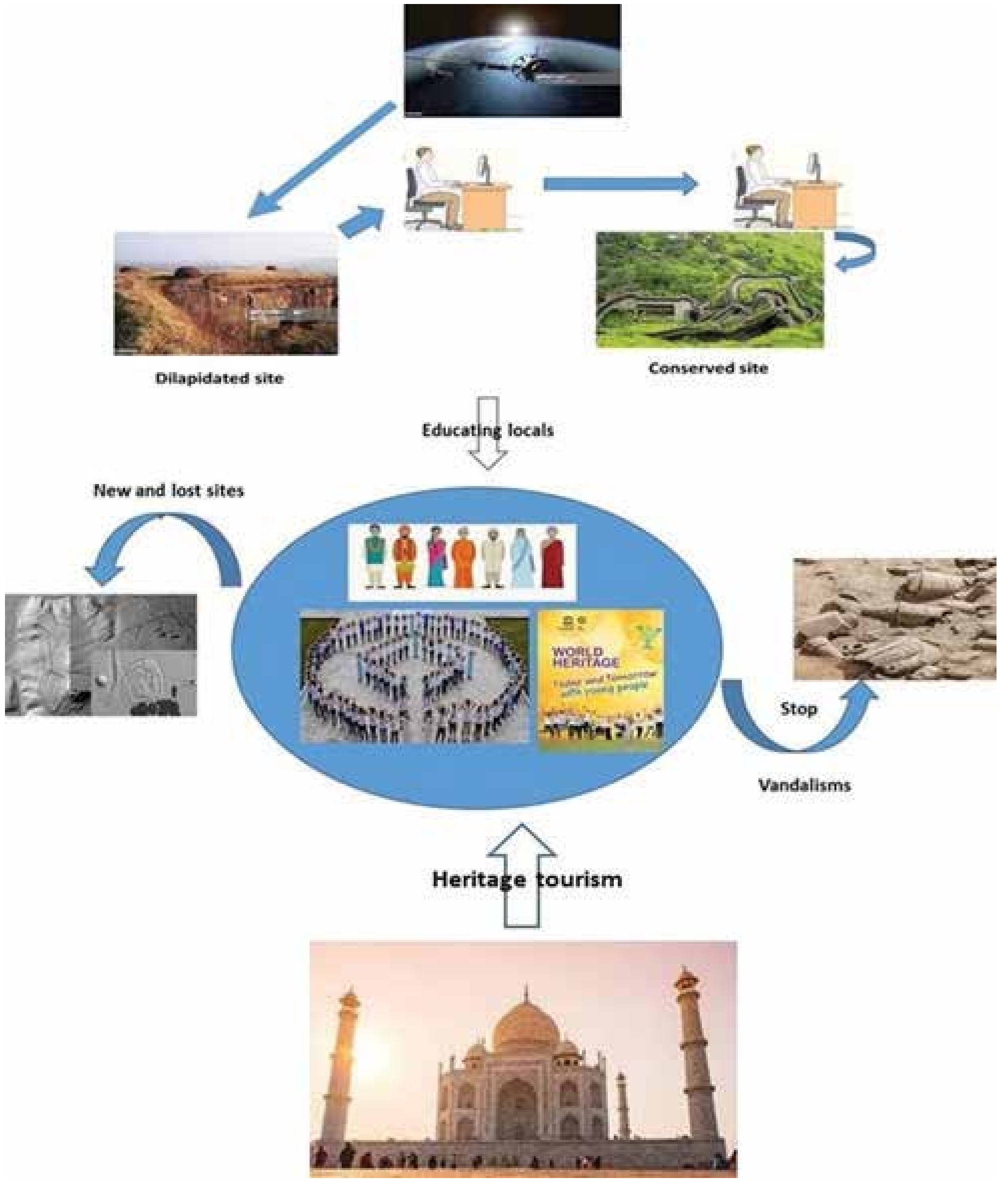

Figure 12. Space archaeology and soil survey can be complimentary (Source: Bhattacharyya et al., 2020)

logs from sensors and through feed-back. Natural resource managers including the soil scientists may be involved to enhance the access to technology, inputs and advisory to improve the rate of adoption (**Figure 14**) (Bhattacharyya et al. 2021b) by the farming community.

The involvement of both resource managers and the stakeholders (farming families) necessitates some degree of empowerment. Thus, the concept of empowerment may be a focal point of research in order that the process of project management can be put into an appropriate, and contemporary context for the soil scientists. This requires to be followed in Indian agriculture using ICT.

Relationship management influences empowerment and overall performance to accrue benefits **(Figure 15**) with special reference to India and Indian farmers. An input-conversion output paradigm is used in terms of several incentives to the Indian farmers by the Governments (Anonymous, 2020a) which determine the effectiveness of the empowerment through various stimuli for the ultimate benefits of the Society, in particular and for the Nation, at large. This scheme might be a model understanding to empower Indian farmers and may be sharpened with new concepts and case studies in days to come. Natural resource managers should put such issues in their future research programmes.

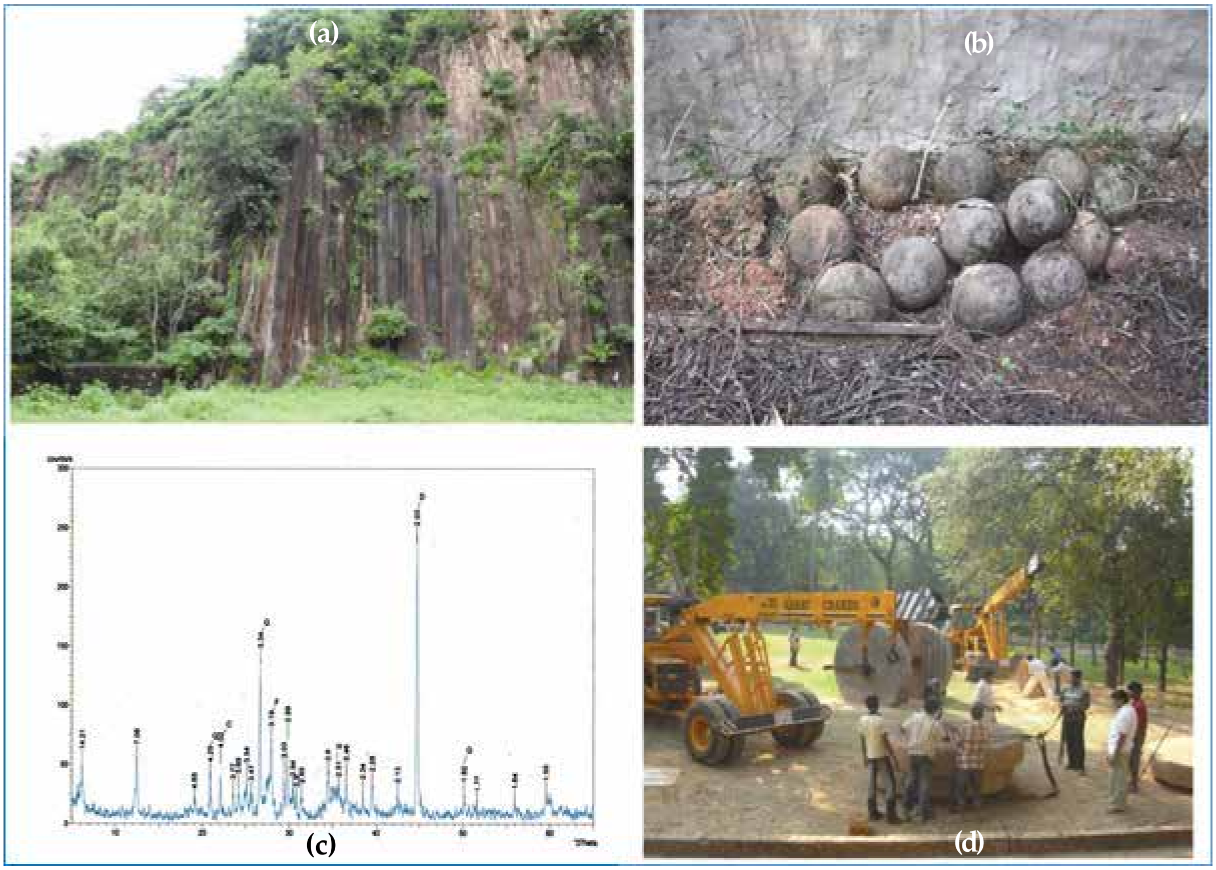

Figure 13. Provenance of rocks for millstones and cannon balls: case study (a) Cliff section of quarried site at Dharavi (Uttan); (b). Cannon balls at Arsenal, Old Goa; (c) X-ray diffractograph of powdered cannon ball sample (C, Calcite; F, Feldspars; H, Hamatite; Q, Quartz; O, Opal CT); and (d) vanished site by salvage archaeology (Source: Ambekar et al., 2015)a

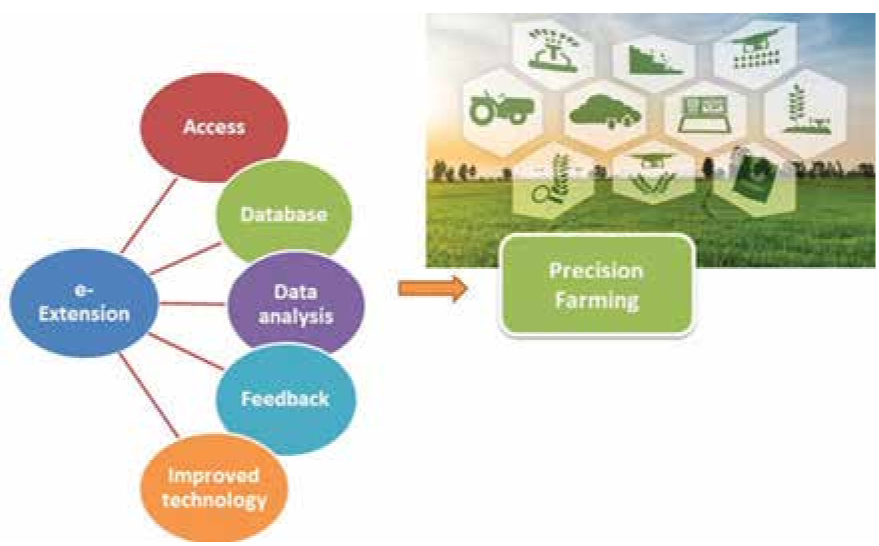

Figure 14. Utility of e-Extension for precision farming (Source: Bhattacharyya, et al., 2021b)

Initiatives of the Government of India and Indian Council of Agricultural Research for empowering Indian farmers through Digital India Programme are set to transform India into digitally empowered society and knowledge economy (**Figure 16**). This programme of digital media is one of the important tools to i) make farmers literate, ii) provide them information about modern agricultural research and

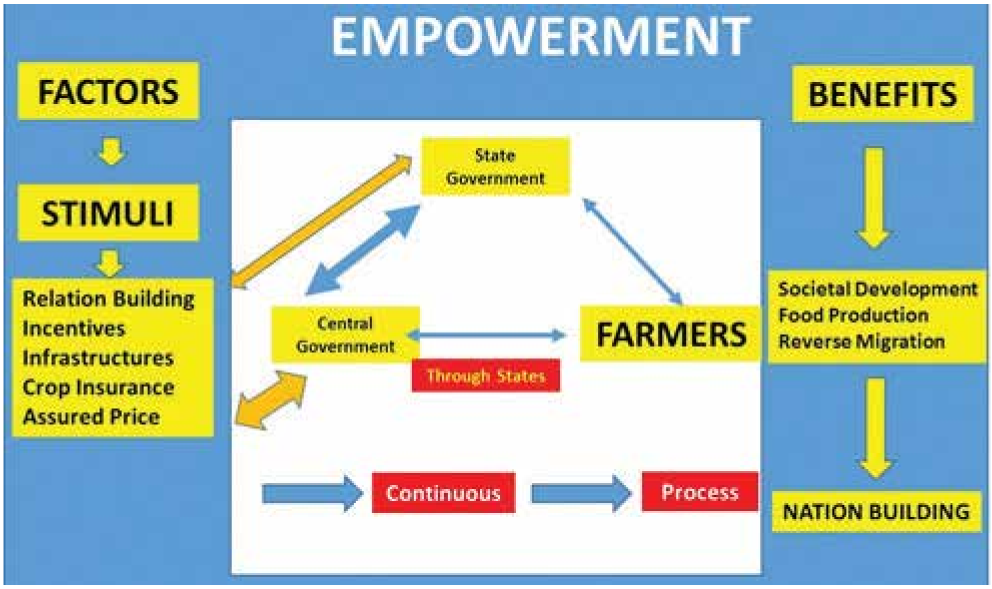

Figure 15. Empowerment model for Indian farmers as a continuous process: a schematic diagramme (Source: Bhattacharyya et al., 2021b)

technology, and iii) empower them in future days (Soni Kumari, 2016; Bhattacharyya et al., 2021b).

Nearly 160 Mha area in India needs attention in terms of better food production, resource management (Bhattacharyya et al., 2008) and scaling up research achievements to the farm level. Through the upscaling techniques using line departments, government organizations and NGOs, selected AESRs (**Figure 4**) can be brought back to the sustainable agriculture. Soil scientists must earmark the AESRs using the large scale mapping techniques to save the soils under threat as discussed above. Interestingly, many soils respond to the management interventions due to their inherent resilience. Resilience of soils of SAT (semi arid tropics) in India (Bhattacharyya et al., 2016)

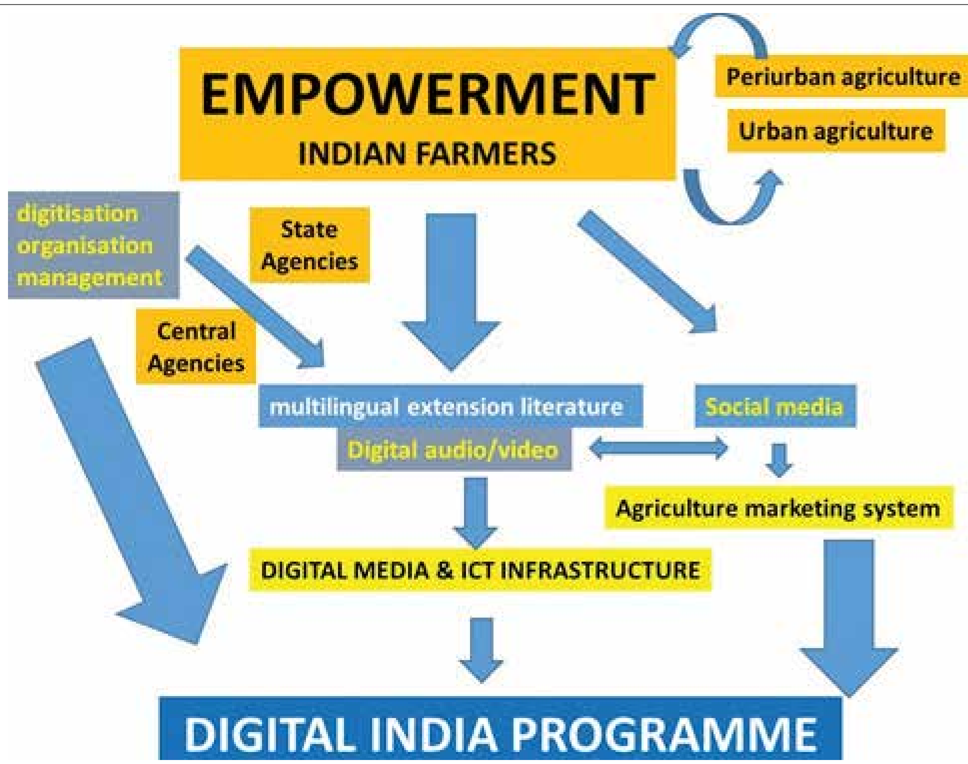

Figure 16. Empowerment of Indian farmers through Digital India programme (Source: Bhattacharyya et al. 2021b)

suggests that the chemically degraded soils could be made the vibrant crop production areas to feed the burgeoning population. The degradation in dry arid areas with desert and coastal sand dunes and other areas need to be scaled up and may form a part of the future research programmes in Soil Science.

Many soil scientists and natural resource managers are hesitant to talk on LDN, even if their research is devoted to this area. This can be overcome if future research involves multi-disciplinary experts to fulfil the target of scaling up various technologies gathered by SAUs, ICAR, Consultative Group on International Agricultural Research (CGIAR) [now rechristened as Consortium of International Agricultural Research Centers], and many other organizations directly or indirectly working in these sectors with the active participation of the non-governmental organizations (NGOs) with an acceptable policy (**Figure 17**). The contribution of various experts is paramount not only from ecological point of view but also bringing some areas under agriculture and other allied activities. This will result in not only vertical but also horizontal expansion of areas under agriculture, animal husbandry, fisheries and other non-agricultural sectors. Bringing waste land to harness non-conventional source of energy can be doubly beneficial. Firstly, it will help using alternate source of energy to reduce carbon footprints, and secondly, it shall enable farmers to utilise the energy thus generated for operating various agricultural implements (Bhattacharyya 2020).

C. **New Agricultural Education Policy**

Future programmes related to NRM (Soil Science) require a fresh talent in the SAUs and DUs for training and education. This aspect demands a special mention in the New Agricultural Education Policy (NAEP). It is important that this policy is linked with the future research agenda to benefit the students and researchers.

C1. Policy of Education

New Agricultural Education Policy is a part of National Education Policy 2020. Few important issues related to NAEP include attracting talent in agriculture to make them suitable and efficient for the stakeholders and to make them more farming-friendly. To attract meritorious students for studying in the SAUs, each and every student should be provided with incentives in one or other forms depending on merit and other social reasons. Many Deemed-to-be Universities (DUs) (*e.g.*, ICAR-IARI, ICAR-IVRI, and ICAR-NDRI) provide fellowships for each of the M.Sc. and Ph.D. students admitted by them. Such facilities are not available in SAUs because of which many meritorious students opt for DUs for

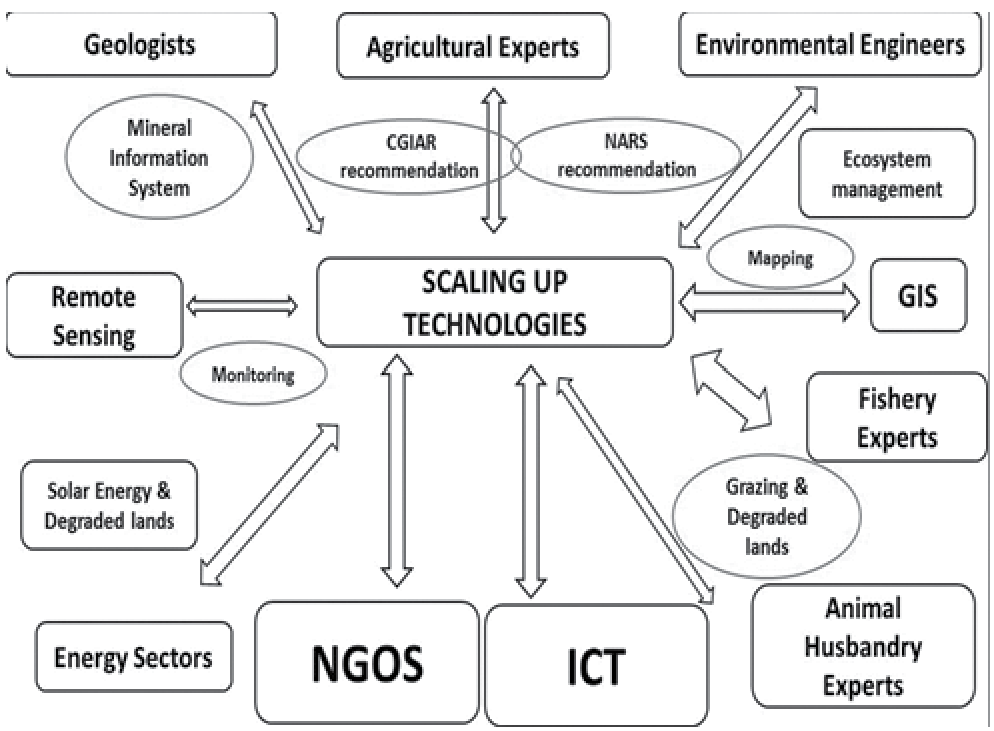

Figure 17. A tentative policy to achieve scaling up technologies (Source: Bhattacharyya et al. 2021a) (NARS: National Agricultural Research System; NGOS: Non-Governmental Organizations; ICT: Information & Communication Technology; CGIAR: Consultative Group on International Agricultural Research; GIS: Geographic Information System

higher studies and if not selected there, they go for other alternative options. This is also true for students wanting to study Soil Science, and subjects related to NRM. Even the foreign students opt for the SAUs or DUs which are located in or near the metros rather than in the remote areas of the country. This needs attention in NAEP.

Assurance of placement after completion of studies (common in many technological and management institutes) could be a way to incentivize the students. This needs to be looked into while planning educational curricula in different SAUs. Placement of students as intern in the state-run/-controlled public sector agencies such as Agricultural Produce Marketing Corporation, line departments, seed production agencies, and training centres run for farmers might help in employment generation as well as for utilization of talent and youth. Adding professionalism to agriculture and allied sciences such as Soil Science is necessary for future growth of natural resource management both from scientific point of view as well as from overall benefit of the society.

It is essential that agricultural graduates come up with start-up ventures in a big way. This requires providing special packages for graduates volunteering to practice agriculture with modern technology with special reference to ICT. Special concessions and subsidies to purchase farm machineries and equipment for setting up of custom-hiring centres are necessary to act as service providers, facilitators or mediators between farmers and industry.

Keeping in mind the above issues, the NAEP may be aligned with the NEP 2020 involving academic credit banks, integration of the campuses and distributed learning systems, by creating students' mobility within the inter- and intra- university system. Challenge of multi-disciplinarity could be an issue to begin with. Remedial courses could be a probable solution.

Indian Council of Agricultural Research (ICAR) is responsible for the quality of education across the country. It needs to be pondered over whether the ICAR should continue in its accreditation and grant-making roles. While developing the NAEP, students and their families may be consulted for their demands and aspirations. Besides, the professors who are actually taking classes, carrying out research in laboratories and fields, and are involved in extension work in field may be a part of the decision-making process.

Except a few deemed-to-be ICAR Universities, ICAR scientists spend more time in research. For SAUs, the professors in different categories are engaged in

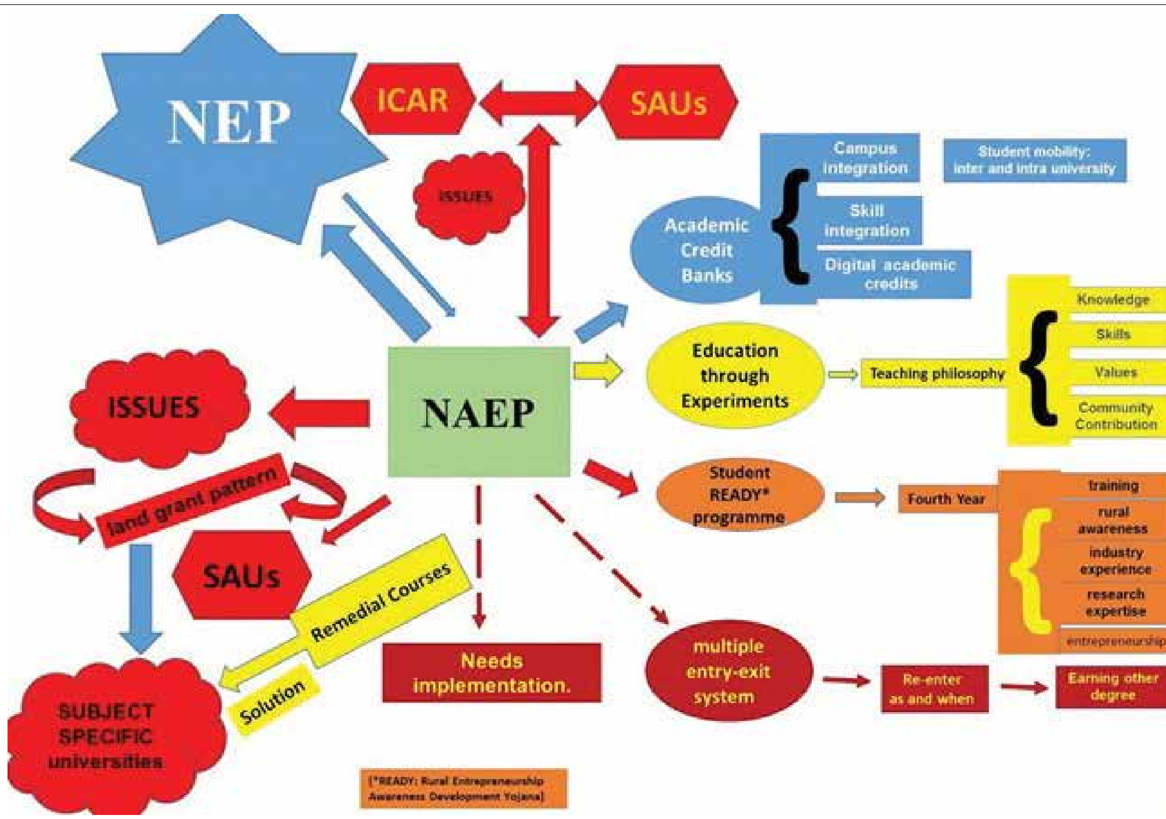

Figure 18. New agricultural education policy and course curricula

teaching, research and extension simultaneously and in most of the cases with serious resource (fund and manpower) crunch. It may be noted that in the schematic diagramme of NAEP (**Figure 18**), the dream of addressing future issues of Agriculture, Soil Science and NRM is also hidden. The entire group of professionals engaged in this field of research and education may try to liberate themselves from the traditional thoughts and embrace the call for the development of Indian agriculture.

To make the NAEP programme effective, we need to be highly motivated, and patriotic teachers and researchers selected by equally dedicated selectors with a strong motivation of nation-building. There is a scope for improved freedom for Vice-Chancellors and Chancellors of SAUs in terms of administrative, financial and developmental decision-making to make educational and research organizations more up-to-date and meaningful. This might be possible with clean, clear and fair selection of the lowest- to the highest- ranking professionals. For effective extension of agricultural research to the farming community, a completely different type of manpower may be developed with fine-tuning the existing process using the model selection procedure and a change in mind-set. NAEP should be a dynamic process with a scope for mid-term corrections.

C2. Policy of Research

Modern-day farming is heavily dependent on technologies which are born through research. These techniques are transferred to farmers through extension education and to the Gennext through agricultural education imparted in various SAUs and others. The SAUs should ideally be the hub of all such activities and should continuously be fed through other institutions related to agriculture. NRM in particular, and agriculture in general are too important subjects and should be handled by professionals only. The suggestive model (**Figure 19**) might help the planners and administrators for way forward. It may be dove-tailed with the NAEP for future research programme to give agricultural education and research policy of the country a suggestive new look. It might enable our SAUs to reach the dream level of international standard in future (**Figure 19**).

Research, education and extension education require funds. With the increased demand of the society, research and development shall be in need of regular supply of funds for development, infrastructure, recurring expenditures, etc. No organisation can function to its full capacity to meet the ever-increasing demand with low staff strength. It may be realized by the planners while preparing policy for education and research. Iceland spends 8% of gross domestic product (GDP); the corresponding figures for some selected countries are: Australia 5.6%, Canada maximum 5.4%, Japan 3.7%, USA 5.4%, and UK 5.7% (Anonymous, 2022). A comparative analysis of expenditure on education by different nation shows that there is scope for improvement on the part of

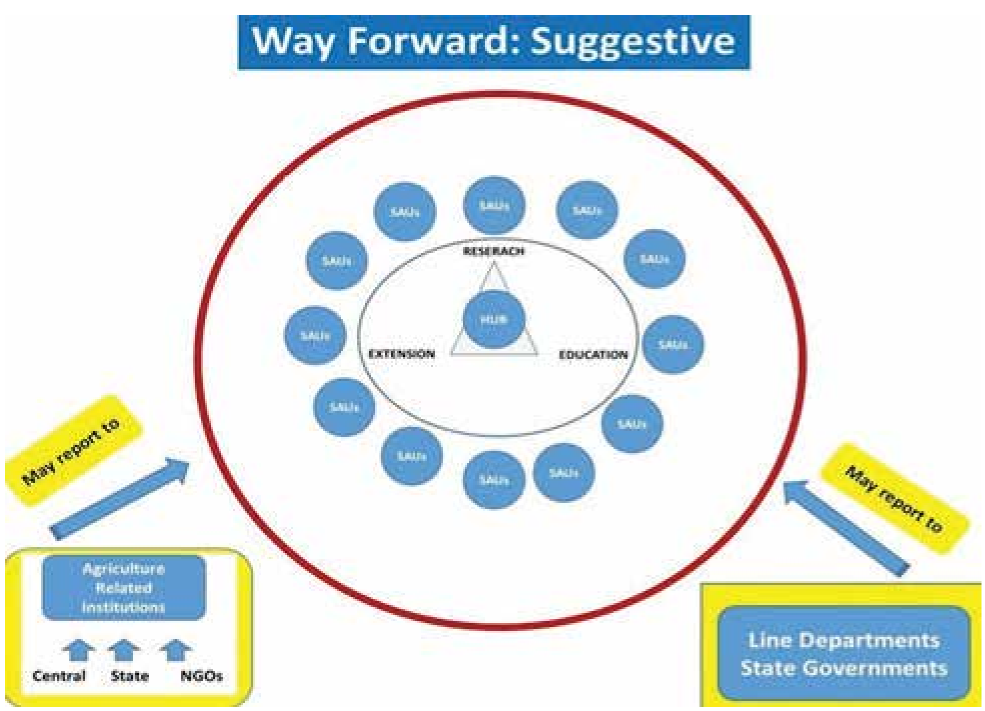

Figure 19. Suggestive plan to strengthen research, education and extension in SAUSs for empowering farmers in India (Source: Bhattacharyya et al., 2021b)

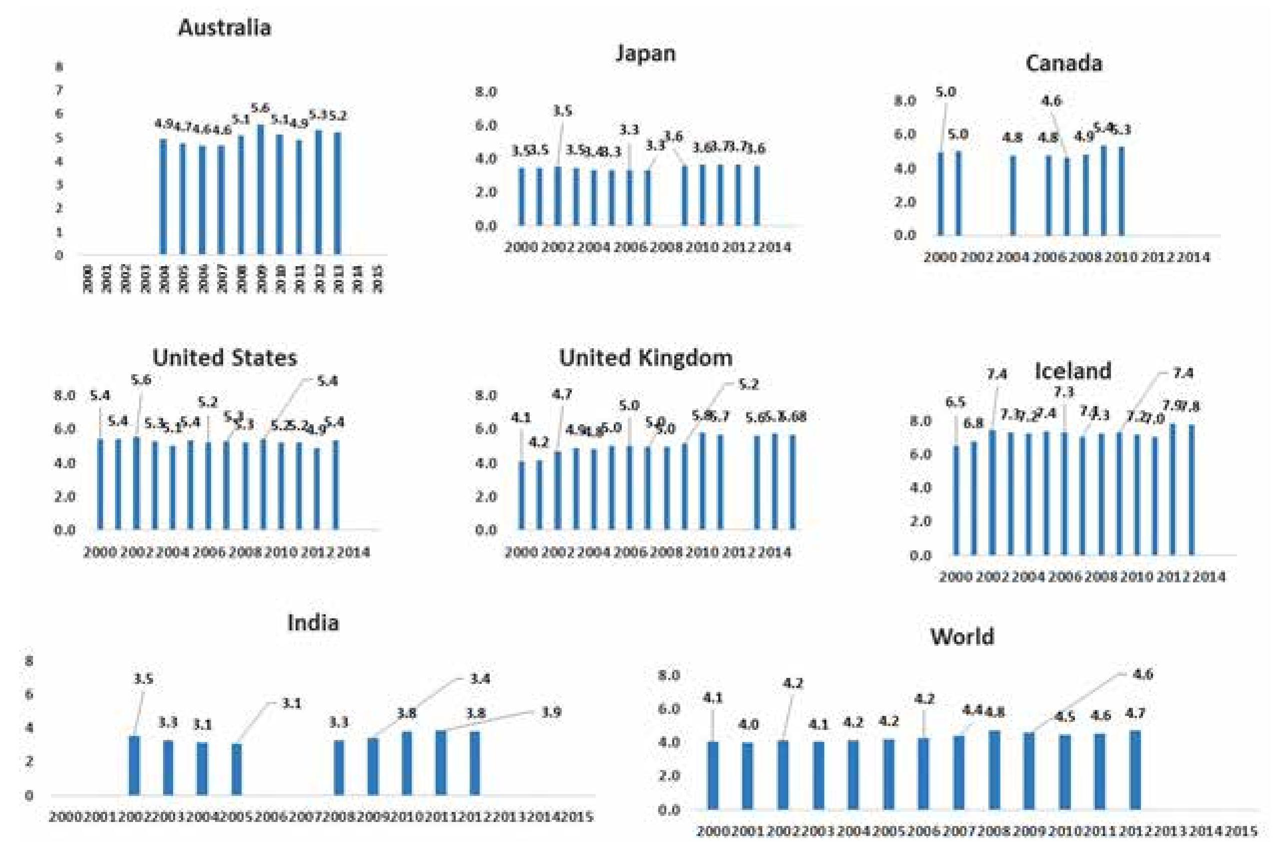

Figure 20. A comparison of expenditures on education by different countries: as % of GDP (Source: Anonymous, 2022a)

India spending nearly 3% (**Figure 20**). Nearly 0.7% of the GDP spent every year on research and development, including strengthening of science and technology infrastructure, during 2014-15 to 2018-19 (Anonymous, 2022b) in India may also be kept in mind while formulating new research agenda

Conclusions

Studying the history of any field of research provides insight into how the modern understandings and strengths have been arrived in that particular field. It does show the weaknesses inherent in that understanding. Retrospection also has the ability to point out potentially promising new areas of study by identifying areas that have not received adequate attention. It has the ability to identify past directions of study that were not fruitful. The present effort of coalescing the research and other studies related to Soil Science is only a very brief summary of major points in history of natural resource management. There is much more to be explored. A professional engaged in research and education in NRM cannot be satisfied with his/her performance. Complacency might dampen the rate of progress of the science and society. A professional cannot, therefore, afford to stop. The scientists and/professors are in a mode of searching; searching truth, understanding and comprehending nature to manage these vast natural resources. In this age of technology and communication, we need to be more communicative in replying and responding to various demands of our colleagues and students. At times, the calls may be tough but we have to express our positive mindset to make our stakeholders (students, farmers and farming community) happy and satisfied. Since the future lies in the hands of the students, it is mandatory on the part of researchers, professors and research managers to understand the demand of students and the society. Changes may be imminent in this journey in educational system, research agenda and fare selection of merit. This will help in nation building when our country will proudly be the torch-bearer for other nations.

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