

Innovative Application of Scientific Fact for Nutrient Recovery from Waste Water Streams for Sustainable Agriculture and Protection of Environment: A Review

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Abstract

Organic manure is an essential component of nutrient management for sustainable agriculture, where in use of slurry extracted from the waste water streams becomes a reliable, accessible and cheap source of such nutrient rich materials. This study presents a scientific fact of sulphur cycle that governs aerobic and anaerobic decomposition of wastes which have adverse impact on environment. Working of scientific fact is substantiated in the study. Review was carried out on use of the scientific fact in the existing practices for nutrient and water use and capitalizing the waste materials. It is found that although benefits are realized, the working of scientific fact of sulphur cycle is not visualized. Relevant application of the scientific fact of sulphur cycle viz. aerobic decomposition works well in practice of NADEP composting prevalent in India. Further, usage of the innovation of aerobically decomposed green manuring will serve as an engine for driving the recovery of nutrients from waste streams. The innovative products so far developed still have some limitations of use. Several manifestations of the scientific fact are presented that are in practice and some in perspective to bring sustainable agriculture. It warrants conducting studies on optimization under generation II (2G) of factors those found promising under generation I (1G). Some prominent research areas are also chalked out whose results when implemented will bring sustainable agriculture and promote clean and green environment conservation.

Keywords: Aerobic and anaerobic decomposition; Puddling in standing paddy crop submerged fields; Residue management; Sewage sickness; Sulphur cycle and sustainable agriculture

Introduction

Some wastage always occurs in all biological and industrial processing. These wastes are utilized and/or discarded. When the kitchen wastes are disposed off through water it is called as sullage and the wastes comprising of excretory disposal is called sewage. Besides these two categories any kind of refuse from animal or industries when disposed off through water in decomposed or semi decomposed form, it is in the category of waste water [1]. The organic matter and mineral constituents are found in high concentration. The general practice has been to treat the waste water to revert back to its nearly useable quality [2-4]. The waste water under stagnant condition undergoes decomposition by the decomposing agents such as bacteria and fungus etc that generates detritus food chain. The later consumers of detritus food chain such as insects, flies and mosquitoes etc cause environmental nuisance. The scenic and odour condition inhibit the activities of recovery of valuable constituents from the waste streams, especially from the sewage streams. Thus, there has been in general lack of innovative method for recovery of valuable substances from the sewage and waste water streams. The solid wastes so recovered from the waste water streams are treated further by decomposition as composts under anaerobic condition. There occurs some magnifications in nitrogen, phosphorous and potassium content in the composting. However, the anaerobic composting produces methane, which is one of the green houses gases known to cause global warming.

Another way of decomposition is aerobic decomposition, which is popularly known as NADEP composting in India. Although, the NADEP composting was known for about past two decades, its application becomes popular in India in the recent years. The industrialized composting of solid wastes in the United States of America was based on fast and promoted aerobic decomposition [5]. Aerobic decomposition

of wastes is the right approach of processing of wastes derived from waste water streams. The decomposition by oxidation releases CO₂ and anaerobic decomposition by methanogenesis produces methane (CH₄). Methane produces 20-23 times more warming effect than the carbon dioxide.

Benefits from the NADEP composting have been realized but its scientific reason has not been fully known. This black box knowledge situation exists/prevalis and no innovative method for extraction/recovery and use of the nutrients from the waste water streams came in existence. Accordingly, field experiments have been conducted on the nutrient (N P K) of the composts prepared from the slurry recovered from the sewage/wastes to compare the efficacy in terms of enhancement in yields etc.

The scientific reason and interpretation have not been applied further to refine the yield responses. The results on performance of such experiments have largely been very site specific and no universal applications emerged in this domain. While N, P, and K shortfalls are supplemented by application of higher doses of chemical fertilizers, no thinking infused in to the on-spot management of available resources in sludge/sewage slurry from waste streams and dung gas plants, dung

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alone, in residues, trashes and refuges containing cellulose etc, which after decomposition becomes a form of sulphur (hydrogen sulphide or sulphate). The hydrogen sulphide dissolves in and moves with water that causes serious problem [6]. Yadav and Srivastav, [7] presented innovative application of the scientific facts for residue management in conservation agriculture.

The objective of this study was to analyze facts of practices, its limitations and suggest improvement by application of scientific facts of sulphur cycle to make the better use of the recovered nutrients for sustainable agriculture and promote indirect benefit to the environment. The cases of agricultural practices involving aerobic or anaerobic decompositions are suitably devised to go, as far as possible, aerobic to eliminate adverse impact of formation of hydrogen sulphide and also release of methane. Review study on implication of bio-fuel on ecosystem [8], associated resistance in to arable weed management [9] and hydrological and erosive consequences of farmland abandonments in Europe [10] provide comprehensive knowledge on their topics of studies. This review study in addition to presenting existing knowledge in the domain of nutrient recovery and waste utilization goes beyond for finding solutions to cases and entire domain for sustainable agriculture and protection of environment.

Scientific Fact

The sulphur cycle

The organic manures, be directly incorporated in field or as a part of amendment through manure of different kinds, contains cellulose and plant tissues in dried form. Trends of researches in various domains where it involves application of scientific fact of sulphur cycle are given in table 1 (Data shown as supplementary). The decomposition reduces to sulphate or sulphide (Figure 1). The knowledge of sulphur cycle [11] has not been adequately applied in devising practices of universal application of such management of waste and residue of any kind. The decomposition in the sulphur cycle goes both aerobic and anaerobic. During the aerobic decomposition the sulphur content of residue gets converted in to sulphate, which is directly taken up by the plants for promotion of growth. The sulphur, taken in sulphate form, is a constituent of amino acids such as cysteine, cystine and methionine involved in chlorophyll production, which is required for

protein synthesis, plant function and structure, is significantly affected by its available doses [12]. On the other hand, the anaerobic reaction occurs under prolonged flooding in lowlands, following irrigation and rain and produces hydrogen sulphide, which causes detrimental effect on plants. A physico-chemical process developed to transform and enhance lingo cellulosic waste in liquid humic extracts: humic-like substances (HLS) [13], showed that HLS do not increase the percentage and rate of germination, but enhance the root elongation of seeds, thus treated, while plant growth as well as on root, shoot and leaf biomass were positively improved. These effects can be related to the high water and mineral consumption of plants undergoing this treatment. The high water use efficiency indicated that such plants produce more biomass than non-treated plants for the same consumption of the nutrient solution. Furthermore, the use of HLS induced a flowering precocity and modified root development suggesting a possible interaction of HLS with developmental processes. Ayuso et al. [14] showed that HLS derived from sewage sludge and other chemical formulations were equally effective. N uptake was better at lower concentration of HLS and P and other micronutrients were enhanced at higher concentration.

The anaerobic decomposition is convened as pre treatment of heavily loaded waste material of sludge or refuge from extensive waste producing industries, a mandatory requirement in many countries, for disposal of industry waste water in to municipal waste water disposal systems. The principle of anaerobic decomposition is utilized in dung gas plants, where methane is produced and recovered for heat energy and digested dung slurry discharged for further uses such as composting and vermin composting. However, due to limitations of burning efficiency of the methane and unpleasant scenes and need of extensive repairs of dung digester plant make the dung gas plants less attractive after some years of use. The municipal waste water disposal systems carry out waste water treatment largely up to secondary treatment. The organic solid wastes are stabilized and water biological treatment completed by trickling filter or prolonged retention in facultative and maturation ponds' technology. Raising of algae or rearing fish in the facultative pond has also been found beneficial. Waste water containing nitrogen and phosphorus are released in the natural water streams that promote eutrophication of the lakes and other stagnant water bodies. The anaerobic (pre) treatment of concentrated wastes of N, P, and K are extracted and applied directly to the field crops [15]. Land disposal is one of simple disposal methods of waste water treated up to secondary stage [1].

Thus, the anticipated beneficial effects of recovered material/mass from the waste streams when converted in the form of anaerobic compost do not bring desired beneficial effects. The situation gets worsened for irrigation with sewage water or salty water or in saline alkali soil, which bring the bad effect of sewage sickness. The sewage sickness restricts air circulation that produces hydrogen sulphide, known for many harmful effects [6]. Sulphur accumulation by anaerobic decomposition of organic wastes left by weeds that grow in wet lands ecosystems may cause acidity in future [16].

Substantiation of application of the scientific fact

Experimentally proven data published in research journals are used to show unbiased data based facts. The published results of experimental studies of Seth et al, [17] was utilized to show the benefit of NADEP composting over the other forms of composting for converting recovered material in to useful manure for agriculture. Further, another study by Acharya et al. [18] was taken to demonstrate the applicability of sulphur cycle and validating the innovative applications drawn on the basis of the scientific fact based on sulphur cycle, focused in this

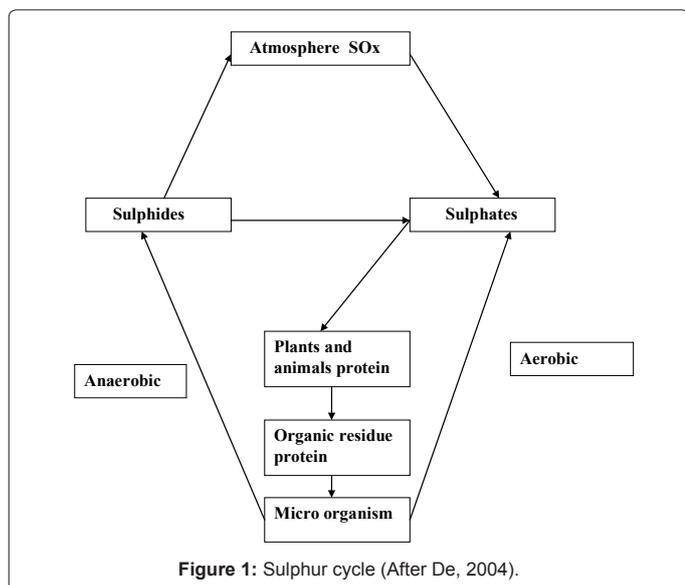


Figure 1: Sulphur cycle (After De, 2004).

study. In addition to these, literature supports have also been taken to form stake to establish whether the scientific knowledge has been taken in consideration in the studies pertaining to aerobic and anaerobic decomposition process relevant to agriculture and environment.

It is substantiated that how the aerobic decomposition supplements the S in sulphate form. The sulphate is taken up by the plants for increasing plant function, growth and yield. The review clearly indicated that benefits of sulphur cycle are realized, but working of scientific fact was not perceived by the researchers [18,17].

The benefits from the cellulose decomposition are realized by aerobically decomposed compost (NADEP) in India. In Europe, particularly in France, researchers conduct intensive research to find benefits of humic like substances (HLS). The implications of working of sulphur cycle were realized in terms of increase of water productivity and nutrient uptake by the crops. Researches on aerobic rice cultivation, particularly in China realized benefits of aeration of root zone soil by alternate wetting and drying (AWD) in aerobic rice cultivation practice. In aerobic rice cultivation the rice productivity has decreased to almost 50-65% of yield of flooded rice. Water pollution by buildup of H_2S , which is produced under anaerobic decomposition of cellulose, was indicated by Jingshuang and Xinhua [16] and Yadav et al. [6].

Scenario of application of scientific fact of sulphur cycle

After substantiation of the sulphur cycle, various overviews of implications are further elaborated. There too benefits of the process are realized, but lack of visualization of the scientific fact produced contradicting and controversial results. Thus, no universal application could be found to exist in the scientific sphere on application and working of sulphur cycle. Research efforts have gone in India on NADEP composting of sludge/slurry drawn from waste water streams, which is technically feasible in most developing countries. Extraction of phosphate from sludge and nutrient concentrated streams to convert it in to struvite was successfully done in Oregon, USA [19] and China [20]. Use of the struvite for food crop is not in practice, whereas, that of NADEP is free from such risks of use for food crop. Use of extracts of N, P, and K from anaerobic pretreatment is practiced in Netherlands [15]. Lot of research efforts and emphases are found in literature on green manuring of plant

Dhaincha (Sisbania rostrata) in rice cultivation worldwide. The green manuring gives high yield of paddy but also produces methane (CH_4), that leads to creating harm to the environment. New formation of NGM (NADEPED green manuring) developed in the present study overcomes problem of release of methane to the environment. The beneficial effect on paddy yield increase is already established. In the paddy wheat -cropping system, inversion of paddy residue in field and its aerobic decomposition is found as the best practice. In this situation utility of direct seeding of wheat in paddy fields by zero tillage drills will be questionable.

Application of sulphur cycle for aerobic decomposition by raised bed cultivation of wheat produces high yield and saves irrigation water. For the problem of arsenic (As) in green water (underground irrigation water) the raised bed cultivation seems to show some way to alleviate arsenic uptake by rice. The problem of arsenic is severe in Afganistan, Bangladesh, China, India, Indonesia, Malaysia, Nepal, Phillipines and Vietnam, [21]. Chemistry of S and As follows the same path of formation of sulphate and arsenate ($As V$) under aerobic decomposition and that of hydrogen sulphide (H_2S) and arsenite ($As III$) under anaerobic decomposition. However, no research efforts have gone in this direction. Thus, the review revealed that innovative

application of sulphur cycle will open several avenues and serve as an engine in driving recovery of nutrient from the waste water streams.

Implications of scientific facts on existing knowledge

The study describes situation wise aerobic decomposition of dry residues and slurry those recovered from the sewage or waste water streams by application of sulphur cycle. Creation of aeration in the agricultural fields by ploughing and/or interculture is the simple ways that will convert cellulose in to sulphate. The sulphur required for protein synthesis, plant function and structure [12], is taken in sulphate form, thus, large deficiency of sulphur in soils can be supplemented by convening the innovative aerobic decomposition of residues. Studies (<http://www.deepdyve.com/lp/elsevier>) showed that the treatment on effect of transformed and enhanced lignocelluloses in liquid humic like substance (HLS) under hydroponic condition had no effect on germination percentage of corn, but it enhanced root elongation, lateral root numbers, root and shoot biomass, The results rightly supported enumeration of Cimirin et al. [12] that effect of sulphate will promote plant tissues and plant functions. However, the researchers did not foresee functioning of sulphur cycle for justifying the positive results of HLS. Study by Ayuso et al., [14] on growth stimulation of barley by the HLS showed that absorption of macronutrients (nitrogen, phosphorus and potassium) was significantly affected by the addition of humic substances, but differed for each nutrient. Nitrogen absorption, for example, was stimulated by the lower doses, such stimulation decreased as the dose increased, while the opposite was true for phosphorus. The absorption of micronutrients was favoured by the lowest doses while doses above 10 mgCl^{-1} inhibited it, which was probably one of the causes of the depressed growth observed with the highest dose. Experiments under aerobic and anaerobic condition produced supportive results. A study on characteristics of humic acids (HAs) showed that the carbon content © in HAs from organic wastes (41.1–63.2%) fluctuated around the C value in soil HA with the exception of composted bark and tobacco dust [22]. Compared with soil HA, the N contents of HAs from sewage sludge and brewery sludge were found much higher than the other sources. In Oregon, United State of America and China technology was developed for recovering N, P, K, and Mg and forming struvite ($MgNH_4PO_4 \cdot 6H_2O$) Magnesium Ammonium Phosphate (MAP) [19,20]. Their work uses well known process of anaerobic decomposition of waste materials in water based disposal systems. The struvite is being utilized for greening of Golf course grasses, where application is on the surface i.e. aerobic condition prevails for all the times. The efficacy of the products is yet to be evaluated when it is applied for anaerobic condition of rice and basal dose of crops such as wheat.

The innovative application of the scientific fact is for creating condition for aerobic sulphur cycle to develop to promote nutrient uptake and produce high yield and crop productivity, is presented in the following

The practice of composting: Organic materials including agricultural wastes are decomposed in compost pit by anaerobic decomposition and known as compost. Aerobic decomposition by the NADEP composting is found to produce better nutrient levels than the conventional composting (Table 2). This fact supports that aerobic decomposition (NADEP) is better than anaerobic decomposition (ordinary compost). There can be possibility that aerobic composting practice is free from the environmental variations and under all the situations it produces the same nutrient content. If this aspect is found true to happen, it offers an opportunity for developing a new reformed practice of preparation of compost manure. It may be noted that no

S. No.	Source	Nutrient composition due to NADEP Composting %		
		N	P	K
1	Diversified agriculture, Lucknow, U.P.	0.5-1.5	0.5-1.0	1.0-2.0
2	Organic Farming, Department of Agriculture, Lucknow, U.P.	0.5-1.5	0.5-0.9	1.2-1.4
3	Utthan, An NGO, Allahabad, U.P.	1.5	1.0	1.4
4	Aranya Varta, Karauli, Rajasthan, An NGO	1.5	1.0	1.4
	Acceptable adopted unified values	1.5	1.0	1.4

Table 2: Nutrient compositions in NADEPED compost reported from different NGOS in India.

efforts have been made to analyze the sulphate content of NADEP composting. This is clear cut indication that there existed no vision to look at the implication of sulphur cycle in the NADEP Composting in the past.

Utility of NADEP composting: Results of an experimental study (Table 3) [17] illustrate the usefulness of NADEP composting in agriculture. In the experiment sulphinated press mud (SPM) and its compost were prepared by heap, pit, NADEP and vermin composting methods. These SPM and composts were applied @ 15 tonnes/ha in the sodic soil placed in pots and rice crop (*Oriza sativa*) was grown. The NADEP composting was in general found superior to other forms of composts in increasing growth, yield and nutrient uptake. The residual nutrient status after the paddy crop was also superior in NADEPED compost to other form of composts. The enrichment of S has earlier not been considered while comparing nutrient supplementation ability of composts.

As evident from the values of nutrients in table 3, the NADEP composting is the best of all composts and had maximum content of S. Because of aeration, the aerobic decomposition converts S in to sulphate, which is readily taken up by the plants. It is further evident that although in treatment SPM NADEP+Straw contained more Sulphur in the form of cellulose than the SPM NADEPED, their decomposition under the water logged condition i.e. lack of aeration, produced hydrogen sulphide and not the Sulphate. Hydrogen sulphide brings harmful effect to the plants that is, why the yield was reduced in that treatment. The researchers could not justify this fact scientifically due to no visualization of working of sulphur cycle in the soil-water-plant and air in the root zone of the experimental crop. Study by Masciandro et al. [23] established a positive correlation ($p < 0.05$) between chemical and biochemical parameters meaning that soil productivity was affected by mineral nutrients derived from organic matter mineralisation. The researchers had not thought over such scientific fact in their study, thereby meaning that the knowledge of sulphur cycle was not applied in sulphur management in agriculture as yet. The results further implicated that in paddy fields under submerged conditions straw/organic mulches will not bring anticipated beneficial effects, rather they suppress the yield. Farmers in India are very well aware of bad effect of decomposition of grasses and weeds etc in the submerged paddy fields, hence after weeding the weeded material is removed from the paddy field, which largely remain submerged in water. Further, puddling has been known to be beneficial to paddy where it is known to promote aeration in soil. The aeration results partially, for some time, functioning of aerobic decomposition and giving relief to the plants from the harmful effect of development of hydrogen sulphide under anaerobic condition in the submerged fields of paddy.

Sulphur requirement of cropping systems that can be supplemented by NADEP composting

Acharya et al. [18] reported results of a Ph.D level study (Table 4) culminating in conclusion that system productivity i.e. highest production rate (126.53 kg rice equivalent yield, kg/ha/day) could be obtained in rice-onion-cow pea cropping system. The quantum of variation in the yields was explained by the researchers as a speculative reason that biological and environmental complexities and their interactions in the cropping systems could have modified the plant capability to express itself in the system. The implication of the sulphur cycle was not perceived in the research even leading to Ph.D dissertation where exhaustive literature surveys are conducted. The inadequacy of the knowledge reveals that still better yields can be produced in the cropping systems by application of activities that promotes operation of sulphur cycle under aerobic condition. Why the system of cropping sequence of rice-onion-cow pea proved to be the best can be explained by the application of sulphur cycle again. The rice crop leaves lot of residues by way of roots and un-harvested rice straw which decomposes under aerobic condition of ploughed land and no submergence under onion. Further, the onion crop is given frequent secondary cultivation in the form of inter-culture and weeding. The sulphur in residues is converted in to sulphate. The onion, being a sulphur loving crop, extracts sulphate from the field and stores in the leaf tissues. Therefore, the yield of onion is increased. This fact of sulphate buildup is further supported by the findings of several studies. The paddy residue management practices at Ludhiana, India i.e. north western part of *Indo Gangetic* belt [24] and in China [25] indicated that total incorporation of paddy residue in field and its decomposition under aerobic condition produced maximum wheat yield. The paddy residue under aerobic decomposition cycle produced sulphate that was used by the wheat crop. Any sulphur loving crop would have made still better use of that sulphate in the field.

Further, during the summer month's cultivation of the short duration leguminous crop of cow pea fixed atmospheric nitrogen as established by the nitrogen cycle. In the atmosphere the nitrogen gas content is maximum (Table 5). The legume crops under aerobic condition fix atmospheric nitrogen in soil. Therefore, the yield of subsequent crop of paddy is high and sustainable. Addition of FYM or NADEP compost for that matter will build nitrogen, phosphorus, potash and sulphur. Further, the pods of cow pea were sold as vegetable that produced high return. Thus, although knowledge of selectivity has lead to identification of productive cropping system, application of knowledge of sulphur cycle and nitrogen cycle will further improve the productivity of best identified cropping system in any given region.

Sulphur cycle versus puddling in submerged paddy fields

Puddling in submerged fields of paddy crop has been known

S.No.	Type of nutrient	Ranges, % over the control
Residual nutrient content in soil after harvest of paddy crop		
1	Available C	33.33-69.00
2	Available N	41.4-74.8
3	Available P	47.0-97.8
4	Available K	11.8-59.2
5	Available S	10.3-90.7
Grain yield over SPM %		
6	NADEP of SPM	34.8
7	NADEP of SPM+straw	27.8

Table 3: Residual nutrient content in soil after the harvest of paddy crop (Seth et al, 2005) in case of NADEP compost applied pot.

Treatments	Yield of rice, Tones/ha	Rice equivalent yield, Tones/ha		System productivity, Tones/ha	Production efficiency, kg REY/ha/day
		Winter	Summer		
Cropping Sequence					
C1 (Rice-Potato-sesame)	4.2	21.5	2.7	28.4	97.5
C2(Rice-rapeseed-groundnut)	4.3	4.9	7.6	16.8	52.8
C3 (Rice-Cabbage-Green gram)	4.4	22.8	3.2	30.4	105.6
C4 ((Rice-Onion. Cowpea)	4.4	26.7	9.3	40.4	126.5
CD (P=0.05)	0.069	4.132	3.342	7.608	20.82

Table 4: Rice based cropping system attributes and productivity that supports functioning of sulphur cycle (Acharya et al, 2008).

Type of gases	composition, ppm
Nitrogen	78.08
Oxygen	20.94
Argon	0.93
Carbon Dioxide	0.033
Neon, Helium, Methane, Crypton, Xenon, Hydrogen, Nitrous oxide, Ozone, Water vapour, smoke and Dust etc.	Traces

Table 5: Composition of gases in the biosphere.

effective since long time back, but implication of sulphur cycle was not visualized. This situation culminated in that the experimental field studies have been in wilderness and giving vivid results. Studies in 1970s, [26] showed that both submergence and puddling are required for paddy crop culture. The study also did not visualize implication of sulphur cycle that works in the submerged field of paddy and what really the puddling does in the process. Although, the researchers measured uptake of iron, zinc and magnesium, but failed to visualize the buildup of sulphate in the soil and crop. In their experiment addition of wheat residue in paddy crop would have resulted in the hydrogen sulphide under anaerobic condition, but as puddling was carried out, the harmful effect got reduced and the treatment produced highest yield. Thus, the implication of sulphur cycle was not visualized and experimental design did not favour creating good condition to bring beneficial effect of wheat straw as organic matter for paddy crop.

A rice knowledge management portal released by the Directorate of Rice Research Hyderabad, India [27] still does not visualize the implication of sulphur cycle that goes aerobic and anaerobic under submerged field condition of paddy. The knowledge portal gives lot of emphasis on puddling and cites its benefits viz. reduction of percolation, incorporation of green manuring, soil made soft for easy transplanting, helps better control of weeds, and increases nutrient up take. The knowledge management portal is putting lot of emphasis on puddling which is carried in preparing field before transplanting. Because of repeated churning of soil during field preparation and transplanting lot of oxygen gets dissolved in water and there is occurrence of aerobic decomposition instead of anaerobic that brings beneficial effect. The continuous submergence after planting does cause anaerobic condition under which cellulose gets decomposed to hydrogen sulphide, which is injurious to crop. Under that situation puddling brings aerobic decomposition resulting cellulose to decompose in to sulphate. Furthermore, no visualization of the sulphur cycle has lead to a flat recommendation of application of green manuring in paddy field. Green

manuring crop contains lot of fibers and its anaerobic decomposition will produce hydrogen sulphide which will cause more harm than good.

In China puddling was considered beneficial in sealing soil to reduce leaching i.e. save irrigation water, nevertheless, study by Zhong and Zhao, [28] suggested that drainage of soil should only be the way to accelerate aeration of soil under the condition. Intermittent drainage of rice field is practiced to provide aerobic condition and to reduce harmful effect of anaerobic decomposition. The intermittent draining of submerged land brings situation comparable to direct seeded paddy crop and it will lead to reduction of release of methane gas from the paddy fields to the atmosphere. Thus, lack of visualization of working of sulphur cycle under submerged paddy fields lead to making controversial inferences from that of Singh et al. [26] and no uniform and rational research result interpretations existed.

However, *Dhaincha (Sisbania rostrata)* which is succulent and grows fast under both flooded and dry condition is proving as a very suitable crop for green manuring in paddy wheat cropping system [29,26]. The *sisbania* fixes nodulation on roots and its stem and under both dry and flooded condition, it gets ready for inversion as green manure in 50-55 days and decomposes fast, in about 20 days. It releases all nutrient particularly nitrogen very fast and with application of average doze of chemical fertilizer it produces significantly higher yield than control. It was found to supplement 25-50% nitrogen and produce remarkable yield of hybrid varieties of paddy in the cropping season (2011-2012) in Bihar, India. But, its effect on increasing yield of subsequent crop of wheat is insignificant. This type of green manuring is being popularized in India extensively. Because this green manuring is supplemented with puddling and in most of South East Asian countries paddy fields are drained intermittently and about 20 days prior to harvesting, it gets aerobic condition to convert residues in sulphate. Nevertheless, studies have shown that the green manuring of *sisbania* too releases methane from the paddy fields. Its effect on release of methane goes on cumulative i.e. in first year the methane release is low but in 15 subsequent years of application methane release increases by 8-10 folds. Lauren et al. [30] measured methane flux released by wheat straw mixed with different kind of legumes used for green manuring under flooded rice in California. While straw decomposes to release high flux of methane in 45 day or so, with green manuring mixture, the methane flux release got advanced to 25 days or so. The quantum of fluxes was about similar. Therefore, the green manuring by *Sisbania* or any other legumes are giving sustainability in paddy yield, but its effect is not serving the interest of protection of environment. The green manuring is being justified for the sake of controlling price of food grain by way of promoting high yield of paddy crop. If the green manuring is performed under no flooded condition and its decomposition occurs aerobically, the problem of release of methane is also eliminated. In India, green manuring of sunhemp/*sisbania*+green gram+pearl millet, followed by cultivation of potato crop in ridge and furrow system of planting, inter cultured frequently is known to produce remarkably high yields of potato.

Puddling and conservation of water resources

Chapagain and Hoestra [31] estimated global foot print of water for rice production to be 784 billion m³/y. The study further indicated that for production of rice in India, Indonesia, Vietnam, Thailand, Myanmar and Phillipines, the fraction of green water (irrigation water) was substantially larger than fraction of blue water (rain water). USA had the blue water fraction 3.70 times the green water fraction and in Pakistan 5.6 times. Blue water fraction in average water use

of rice export is bit higher than average rice export produced using green water. Thus, it is evident that lot of water is consumed in rice production. If innovative application of the scientific fact of application of sulphur cycle is made, substantial conservation of water and increase in rice yield can be achieved. Agricultural engineering organizations have devised various types of paddy field puddlers. These puddlers are used in field preparation before planting. These or suitably devised puddlers should be used in standing crop to promote aerobic decomposition by conducting puddling that makes oxygen mixing i.e. to bring similar effect of intermittently draining the crop field. In this domain, promotion of scientific fact and its suitable application will lead achieving water conservation or increasing water use efficiency and reducing release of methane from the paddy fields. The countries using green water will save lot of energy in application of irrigation water for water lifting and pumping etc. Reclaimed wastewater quantities are matched against specific irrigation needs. Exploitation of such waste water resource are planned to relieve water stress in Crete islands [32].

In Punjab India, under wheat and rice cropping lot of ground water was withdrawn for irrigation that lead to drastic lowering of ground water table. Now farmers have resorted to direct seeding of paddy crop, where water required for submergence and puddling is relatively less than for extensive puddling. As indicated by study of Singh et al [26] and Lana et.al [10], when submergence and puddling is not available to rice crop, average productivity of rice will go down. Therefore, in order to avoid reduction in crop yield a proactive practice of submergence and puddling with awareness of scientific fact of sulphur cycle will be a rational and unified practice for rice culture for both using blue or green water and reducing release of methane and global warming. Further, recent application of green manuring of *Sisbania* under upland condition is showing way to maintain paddy yield under intermittently flooding condition, this will also lead to reduction in release of methane gas to environment. But, wheat yield is likely to be not benefited by this green manuring by *Sisbania* crop.

Sulphur cycle and arsenic problem in the paddy growing regions

Arsenic (As) exists in the environment in various organic and inorganic forms (species); the most important inorganic species in the soil are arsenate (As V) and arsenite (As III), and the organic species monomethyl arsenic acid (MMA) and dimethyl arsenic acid (DMA), with their natural presences lower than that of inorganic As [21]. Speciation of inorganic As in the soil is largely controlled by reduction and oxidation processes (redox). Under aerobic (oxidizing) conditions, As V predominates, whereas under anaerobic (reducing) conditions As III predominates. Under more reducing conditions, As III becomes by far the predominant species and the solubility of As increased sharply. Microbial activity can influence Arsenic in irrigation water, soil and crops speciation via various mechanisms such as redox reactions with Fe and As and via (de) methylation of As species [21].

Conditions in the rhizosphere may deviate substantially from the bulk soil. Plants will influence the pore water composition by uptake and excretion of substances. Micro-organisms in the rhizosphere will also influence its composition. Because Fe and As behaviours in the soil are closely related to each other, it can be expected that plant processes related to Fe uptake may also influence As bioavailability and uptake. The same is true for PO_4 , when a paddy field is flooded, the rhizosphere can still be aerobic. The main reason is that rice plants can transport oxygen from the leaves to the roots, resulting in the transfer of O_2 to the rhizosphere. A number of micro-organisms are also capable of

oxidizing the rhizosphere. The oxidized conditions can result in the precipitation of FeOOH around the roots, also known as Fe-plaque. The Fe-plaque has been reported frequently on roots of wetland plants including rice. It may influence As speciation, bioavailability and uptake and Fe reducing and oxidizing bacteria are likely to play a major role. The importance of Fe-plaque on As uptake by wet land plants including rice remains to be resolved [21].

Addition of PO_4 to As-contaminated soils to minimize As uptake is controversial under non-flooded conditions. As III is actively taken up by so called water channels (aqua porins) in the roots. Laboratory experiments have shown that Boro (dry season) rice cultivars take up less As III and As V than Aman (rainy season) rice cultivars. This may be related to physiological or morphological differences between the root systems [21]. However, this does not imply that Boro rice will accumulate less As than Aman rice under field conditions, because Boro rice is irrigated with As-rich groundwater, whereas Aman rice is rain fed.

The uptake mechanism of organic As is largely unclear [33]. It seems that monomethyl arsenic acid (MMA) and dimethyl arsenic acid (DMA) are taken up by rice plants, but that the rate of uptake is much lower than inorganic As [34]. To date, it has not been possible to predict As uptake by plants from the soil.

There is similarity of decomposing environment for formation of hydrogen sulphide and arsenite, both of them increase under anaerobic condition. Likewise, sulphate and arsenate are formed under aerobic condition. However, the study [21] did not recognize role of sulphur cycle. The document did not reveal any study on nutrient uptake except iron and PO_4 . However, aerobic condition is less favourable for As uptake and more for Sulphate. Application of scientific fact of sulphur cycle will show some way to manage arsenic in agriculture, which requires concerted thinking and experimental studies with precise measurements. An example of this fact is the raised bed planting system that maintains better aerobic condition during the crop cycle. It also reduces number of irrigation that saves water which in turn will reduce As V and As III accumulation in soil, The raised bed planting system for wheat is being popularized with justification of deriving advantage of saving of irrigation water and harnessing benefit of crop growth due to border effect, but not the more recovery of sulphate as induced in the sulphur cycle under aerobic condition. Extension of raised bed cultivation of rice with As containing water will be an innovative application of scientific fact of sulphur cycle. In north China studies on deficit irrigation [35] showed that furrow planting resulted in an increase in WUE of wheat under deficit irrigation and raised bed planting had the potential to increase wheat yield, but WUE was not consistent.

As V and Sulphate chemistry needs to be manipulated for alleviation / solution of As problem in the agriculture of the arsenic prone paddy regions.

The nutrient enrichment in NADEP composting practice

By now it is clear that addition of organic matter or green manuring under submerged condition is going to bring some harmful adverse effects in standing water in paddy crop. It will also convert cellulose under aerobic condition in to sulphate which is readily taken by the plants. Thus, nutrient supplementation should be through NADEPED compost. It is pertinent that the natural resources management (NRM) strategy must be applicable under the highly heterogeneous and diverse circumstance in which small holders live. It must be environmentally sustainable and based on the locally available resources and indigenous

knowledge. The emphasis should be the transformation of whole farming system or fields at a farm, village or country level rather than the yield of specific commodity. The technology generation should be demand driven process to fulfill economic needs and environmental circumstances of resource poor farmers. The attributes presented in table 6 reveal that NADEPED composting fulfils all ideal required conditions for a practice that will bring sustainable agriculture and protect environment.

The supplementation of nutrient has to be done for sustainable agriculture. If anaerobic decomposition is involving green manuring is not going to be effective, aerobically decomposed NADEP decomposed compost has to be produced to be applied when wet and aerobic condition exist during paddy cultivation. Table 7 contains the nutrient content of some crops which are suitable for NADEP composting, and a new formation, named as NGM i.e. NADEPED green manure. The crops can be grown prior to transplanting of paddy and harvested for NADEP composting. By the harvesting time the crop must have fixed some nitrogen by nodulation in paddy field to be transplanted that will benefit the paddy crop. The *Sisbania* crop fixes most of nitrogen by 45 days after seeding. The NADEPED compost made by using the harvested vegetative green biomass, it will get ready for dry season cropping after the harvest of paddy crop. Thus, NADEPED compost made earlier February to May during the winter season cropping after harvest of paddy, which will be ready available prior to transplanting of paddy can be applied to paddy field 20 days before and ploughed down. Formation of NGM composting of selected crop will have

Innovation characteristics important to poor farmers	Criteria for developing technology for poor farmer	NADEP composting
Input saving and cost reducing	Based on indigenous knowledge or rationale	It is an improvement in the existing practice that will reduce input cost
Risk reducing	Economically viable and tolerant to change in weather and insect pest damage etc.	All kinds of risks get reduced in NGM.
Expanding towards marginal fragile lands	Environmentally sound, socially and culturally acceptable and resilient towards land capability	Ideally suited for degraded land condition
Congruent with peasant farming system	Risk averse updated to farmers circumstances	It is an improvement in the peasant farming system and free from any risk.
Nutrition, health and environment improving	Enhance total farm productivity and stability	It improves soil health base for agriculture, improves environment

Table 6: Technological requirement fulfillment by the NADEP composting.

Highest % of nutrient contents in the crops		
Subabul (<i>Sisbania</i>)	Green gram (<i>Phasiolus mungo</i>)	Pearl millet
N (3%)	P(.18%)	
	K (1.0%)	
Anaerobic Compost		
N(.5%)	P(.8)	K(1.1%)
Nadeped Compost		
N(1.5%)	P(1.0)	K(1.4%)
Green manuring		
Nadeped Green Manure (New formation, NGM)		
N(4.5%)*	P(1.0%)	K(1.4%)

*Crop N X Nadeping factor

Table7: Nutrient composition of the green manuring crops, compost and NADEPED green manure as well as used as cattle feed.

enhanced nutrient composition. This will also provide scope for use of slurry extracted from waste water streams for year round and under all weather condition i.e. dry or wet. In NADEP preparation some artificial source of nitrogen must be added to bring C/N ratio in desired balance [5]. The cheapest source and most readily available material is the sewage sludge.

Advantages of NADEPED Green Manure (NGM):

- (i) NGM permits application of green manure *exsitu*, which otherwise has not been in practice.
- ii. The reformation enables cultivating rainy season crops also with the green manuring crop.
- iii. Application of NGM manure can be deferred to avoid loss due to runoff washing off or getting burnt due to high temperature.
- iv. NGM can be practiced in the arid region where exists lack of rainfall for decomposition in the field. Due to non decomposition termite attack becomes a limiting problem.
- v. NGM can be season free to some extent; hence it can be applicable to all areas with different agro-climatic features and green material can be obtained from alley cropping maintained or in agro forestry system.
- vi. The NGM provides some opportunity for fortification of enrichment of status of selected nutrients such as phosphate solubilising bacteria and weedicides etc.
- vii. Only a part of the already limited land in the country can be utilized by raising green manure crop in alley cropping or if as sole crop is cultivated, only for a very short period without losing any crop during a cropping season.
- viii. For *Susbania rostrata* inoculation will boost nitrogen fixation so upper part can be harvested for applying NGM in the field after paddy for bringing increase in yield of wheat after paddy. It can also lead to grow green manure crop in a fixed field for some years and carry the top producer of green manure crop to any other field to raise sustainability of farm of individual farmer.
- ix. Application of aerobic sulphur cycle in addition to improving degraded soils will enable devising simple methods for reclamation of sodic soil and bringing soil pH to the normal neutral range which is 7.0.

SRI method of paddy cultivation: In the SRI (System of rice intensification), developed in Madagascar, Africa, cultivation is carried out where no prolonged flooding is maintained so anaerobic decomposition is eliminated from the system (<http://assamagribusiness.nic.in>). The SRI method can be said on the basis of its cultivation after planting to fulfilling requirement of the sulphur cycle. Since system uses compost in nursery preparation, which is prone to release methane, due to its anaerobic decomposition, it can be said that the method was not designed as per scientific basis for complete fulfillment of requirement of convening sulphur cycle for aerobic decomposition. Therefore, application of NADEP composting will make it a true scientific fact based method of universal application for rice cultivation for bringing sustainable agriculture and protection of environment. Nevertheless, yield potential is to be contrasted with that of flooded rice cultivation in low land condition.

Raised Bed Cultivation (RBC): Among various manifestations of innovative application of sulphur cycle to create occurrence of aerobic

decomposition of organic and cellulose, the raised bed cultivation is the most popular practice. In the raised bed cultivation practice larger amount of water is held up in the increased soil depth than that in the flat bed cultivation. The review revealed that only at Project Directorate of Cropping Systems Research, Modipuram, District Meerut Uttar Pradesh, India under Indian Council of Agricultural Research, there was visualization of building up of sulphur, that too in context of burning of residues [36]. Otherwise, in India people praise the raised bed cultivation for saving in irrigation water and crop getting border effect for profuse growth and unexpected high yield [37], but no realization of continuous functioning of the sulphur cycle that produces sulphate. Ibidem, potato yield of 31.25 tones/ha was harvested against the general yield of 20 tones/ha. In the main rice growing areas of Thailand [38], northern China [39], Mexico [40] Bangladesh and Nepal [41] raised bed is praised as it enabled crop diversification in the low land rice fields, saving of irrigation water and increased yield. However, researches did not visualise working of sulphur cycle and could not find scientific reason for adverse performance of the RBC in Nepal ie in one of three sites. As the use of water is low and the chemical process for arsenic As V [21] and sulphate (Figure 1) go aerobic, the RBC should be able to reduce uptake of AsV. So far no research had come to notice in the present review study. The RBC and many other innovative application of sulphur cycle need to be studied to bring some breakthrough in reducing problem of As.

This study has established that application of scientific fact results in devising rational experimental studies. Thus, it indicated the shortcoming in approaches in the experimental studies in the past that resulted in variable and contradicting findings. The study has successfully demonstrated the scientific and experimental requirement of generation I (1G) studies for development of sustainable agriculture and protection of environment. It opens door and warrants studies on optimizations of findings in support of the scientific facts of experimentations under generation I (1G). The studies on optimization should now form experiments of generation II (2G).

Up Scaling Production of NADEP Composting Activity

In addition to the technology, as one arm of the productivity (Figure 2) requires group job performance that constitutes three factors viz. ability, motivation and physical condition. A snag in either of the factors will hinder the productivity. Table 6 describes the desirable quality character of NADEP practice. Earlier efforts on technical innovations resulted in techniques and practices for natural resources conservation and utilization. But, the factors of the productivity are becoming matter of concern in the global scenario. The *modus operandi* of any production process requires capacity building, creation of various informal groups of homogenous activities, actuation, controlling and motivation, monitoring and evaluation. The capacity building can improve the ability and motivation to people to acquire ability. The physical condition (Figure 2), largely remain beyond ones control, particularly, those governed by the nature. For these reasons agriculture is characterized as the risky and arduous job. As the agriculture is time sensitive, farmers have to carry out the required work by changing their schedule of working to a limited extends. In each of the sub groups there are factors that have bearing on the group job performance.

The Nutrient recovery from the sewage and other waste water streams requires filling of NADEP chambers at one time, therefore, many people will be required to carry out the jobs. It requires collection of materials for entire operations and filling at one time and work force. For filling one NADEP compost chamber it requires arrangement of press-mud i.e. extracts from the waste water streams etc, cow dung, cutting, chaffing and placing of materials in the NADEP Chambers. The varieties of jobs are to be carried out in cooperative group actions in a give and take participatory mode. It requires capacity building for placement and handling of the materials related to NADEP composting.

Like other two aspects of essential factors of production, finance is equally a strong factor. Accessibility to credits, economic returns of investments and organized marketing for making profits from such

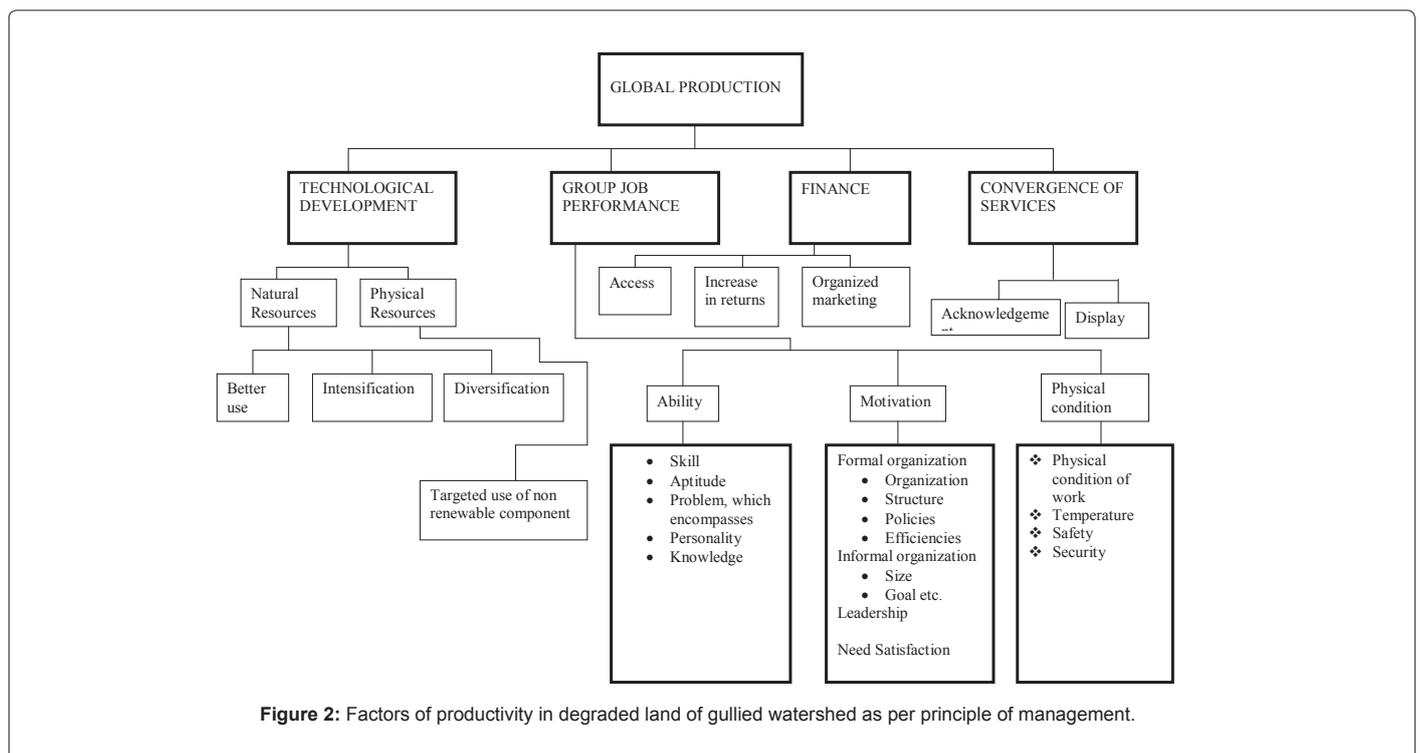


Figure 2: Factors of productivity in degraded land of gullied watershed as per principle of management.

investments are equal fulcrums. New financial banking facilities of agro-ecological initiatives should operate at farmers' level. Nevertheless, the utilization of bank credit facility has yet to pickup as still there exists some inhibitions. The mass production of NADEP compost will require small amount of finance at the farmers' level. The farmers can carryout labour cost component by themselves by people's participation.

Convergence of services is an overall important aspect in agro ecological development in general. Lack of finance is general expression by different service providers. These services should be converged in an area where other aspects have been completed or undertaken. This will provide/include environment for any service to be more productive and successful. The basic requirement is to acknowledge record and display the contribution and or role played by the line departments/service providers. It will provide better utilization of scarce resources, opportunity to technology innovation, capacity building for group job performance and cooperative action for various initiatives. Lack of acknowledgement, display of roles of various line departments becomes hindrance for agro ecological development in rain fed agro ecosystem and watershed management projects [42].

The preparation and utilization of NADEP compost requires convergence of other specialist services of agronomist, horticulturist, environmentalists and the social motivators. The convergence of services involves people to help adopt environment improvement measures, reduces harmful gases such as methane, removal of undesirable scenic dusty/muddy and rubbish materials, incidence of flies and mosquitoes etc. Therefore, promotion of environmental programme should be integrated with the programme of NADEP composting.

Follow up action

Each village family needs to be equipped with one NADEP Composting chamber. The chamber is of size 10 feet×5 feet×3 feet (3 m×1.5 m×1 m), constructed in brick masonry above the ground. In the construction 0.33 m height is regular half brick wide wall from bottom, next 0.33 m is perforated wall and again top 0.33 m is regular wall. It will be filled with cow dung, slurry/press mud/waste derived from waste water streams and the green matter or the trashes and agricultural wastes *Leucenia lucociphala* (Popularly known in India as *subabool*) crop in sequential layers. For filling green manuring, crops can be grown and utilized for NADEP composting. When filled completely, it is covered with soil, which is kept wet by sprinkling water at the top. For sprinkling water extracted from the nutrient rich streams may be used. It takes three months to decompose in to the compost. Besides subabool, green gram and the pearl millet could be NADEPED singly or in mixed in different composition. Farmers should be provided with mini kit for raising the green manure crops in the initial years for raising the green manuring crop for NADEP composting. Farmers should be trained for filling and using the NADEP compost for meeting various crop nutrient requirements. [43]

The NGM i.e. the NADEPED green manure composting is advancement over the ongoing practices of composting and green manuring. There is scope to replace chemical fertilizer by one fourth. Thus, the total expenditure in the country on chemical fertilizers can be saved up to 25%. The organic manure will improve soil health that will promote sustainable agriculture. Farmers will get enabled to supplement the nutrient requirement for their agriculture with their own resources. NADEP composting exercise will produce green and clean environment both necessary for pollution control.

Conclusion

Innovative application of the scientific fact of sulphur cycle will pull the recovery of nutrients from the sewage and other nutrient rich waste water streams which will produce organic manure for sustainable agriculture and promote indirect conservation of clean and green environment. Deficiency of sulphur in soils can be overcome by the practice when adopted in vogue. Under situations involving decomposition of cellulose the innovative application directs the best practices of various universally applicable modules for sustainable agriculture and protection of environment. The specific conclusions that emerged from the study are as under:

- The study substantiated that although benefits from the practices were realized, real scientific fact remained in black box that lead to misconception of process and inappropriate design of experiments giving universally true as well as at times contradicting conclusions.
- The study established that wherever decomposition occurs, creation of condition to charter the aerobic decomposition is important to produce sulphate, compound absorbed by plants, for tissue buildup and plant growth. The anaerobically decomposed organic and cellulose materials should be again aerobically decomposed for further transformation in to useful products.
- Aerobic decomposition of organic and cellulose material can be best conducted by NADEP composting, getting popular in India due to its low cost and high utility. The nutrient recovery from the waste water or sewage streams will be pulled by the practice of NADEP composting.
- Application of NADEP composting and NGM with *Sisbania* green manuring in this activity will promote low input involving participatory peoples' action for creating sustainable agriculture by serving as an engine for recovery of nutrients from the sewage and other waste water streams.
- Adding a component of application of NADEPED composting or NGM in the SRI method and raised bed cultivation (RBC) will make them complete scientific fact based practice of universal application for sustainable agriculture and environment protection.
- Conducting experimental studies on optimization of factors revealed under generation I (IG) by research endeavours under generation II (2G), will save time, money and labour that are involved in conducting generation I (IG) studies.
- The study opened a frontier to carryout research on possibility of reduction of arsenic uptake by food crops by creating aerobic condition of decomposition that would produce sulphate. Under high concentration of sulphate nutrient uptake of phosphates are likely to be promoted that will suppress uptake of arsenic.

The lessons drawn from this study are applied to chalk out useful potential research areas as follows.

- Conduct more site specific studies on NADEP composting and NGM by capacity building for participatory NADEP preparation using decomposed materials from waste and sewage sludge streams. This will bring confidence, knowledge and modus operandi involved in bringing sustainable agriculture.

- Under take studies of second generation (IIG) on optimization of factors identified by the innovative application of sulphur cycle as generation I (IG).
- Undertake development of DASP (diammonium sulphophosphate) that will be useable for agricultural crops unlike the struvite having restricted use for greening of golf course grounds.
- Conduct exploratory experimental studies on possibility of reduction of arsenic uptake by creating aerobic condition of decomposition that would produce sulphate. Under high concentration of sulphate nutrient uptake of phosphates and potassium are likely to be promoted that will suppress uptake of arsenic.
- Carryout studies on efficacy of RBC, which is already found effective for variety of advantages, on reducing uptake of arsenic by the food crops in high arsenic soil and water regions.

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