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The Effective Use of Solid and Liquid Waste in Urban Agriculture

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Abstract: *Co-recycling of solid and liquid wastes is a common waste farming practice in urban agriculture. Long-term improper of wastes application deteriorate soil health due to nutrient enrichment and finally decline crop yield and cropping pattern. Little information is available on proper dosing of wastes in urban agriculture. The aim of this study was to determine the optimum application rate of solid and liquid wastes in a 100 years old existing waste farming area at Titagarh, India, to sustain soil health and crop productivity. The research was conducted with three pot trails on spinach, following the treatments: 1) Control, required N, P, K applied by 2) solid waste, 3) liquid waste, 4) combined solid and liquid waste, 5) Chemical fertilizers and 6) existing practice. Considering first trail results, the treatment of solid-liquid combination was found more significant in terms of the spinach yield, nutrient uptake by spinach and leaching loss. It was more confirmed after second trial and third trial, the combined application of solid-liquid waste (1:1), where 67% of required N dose for spinach was given by solid-liquid wastes, implicated highest yield and sustain soil health.*

Keywords: Solid waste , Liquid waste, Waste farming , Co-recycling.

Introduction

Population explosion is one of the most threatening concerns in the worldwide. With increasing population, municipal waste is also increasing. The production of these wastes is and will continue to be an ongoing phenomenon as long as human civilization persists. The answer to the problem of waste disposal lies partly in agriculture, as waste can be extremely nutrient-rich. Municipal solid waste not only acts as a sink and as a source of nutrients in the soil system but also serves as a soil conditioner by improving soil physical properties, as evidenced by increased water infiltration, water-holding capacity, water content[1], aeration and permeability, soil aggregation, and rooting depth and by decreased soil crusting, bulk density, runoff and erosion[2]. It also acts as a large pool for the storage of nitrogen, phosphorus and sulfur and has the capacity to supply these and other nutrients for plant growth[1]. Furthermore, urbanization and industrialization are also leading to the production of a huge volume of effluents. These industrial, agricultural and domestic effluents, such as wastewater, are either dumped on land or used for irrigation and fertilization purposes because of their nutritive value[3,4]. The advantages of reusing wastewater are that it is a convenient way to dispose waste products and that it adds valuable plant nutrients and organic matter to soil, like solid waste. Besides, nutrient-rich wastewater provides a valuable agricultural input that can be utilized as irrigation water in case of dry seasons. Therefore, the application of solid and liquid waste to agricultural soil can increase the organic matter in agricultural soil, reduce erosion and nutrient run-off, increase healthy plant production, and reduce the use of chemical fertilizers and pesticides.

Urban agriculture is defined according to The Food and Agriculture Organization of the United Nations (FAO) as an industry that produces, processes, and markets food and fuel, largely in response to the daily demand of consumers within a town, city, or metropolis, on land and water dispersed throughout the urban and peri-urban area, applying intensive production methods, using and reusing natural resources and urban wastes to yield a diversify of crops and livestock[5]. Therefore, urban agriculture has the potential to alleviate two of the most crucial problems of the developing world, namely poverty and waste management. However, there are some major methods by which waste can be utilized in agriculture such as : a) recycling— the recovery of materials from products after they have been used by consumers, b) composting—an aerobic, biological process of degradation of biodegradable organic matter, c) sewage treatment—a process of treating raw sewage to produce a non-toxic liquid effluent which is discharged into rivers or the sea, and a semi-solid sludge, which is used as a soil amendment on land, incinerated or disposed in a landfill, d) incineration—a process of combustion designed to recover energy and reduce the volume of waste going to disposal, and e) landfill—the deposition of waste in a specially designated area[6].

A number of countries already use waste by following any one of the above methods very effectively. For example, farmers in Kano in Northern Nigeria are utilizing urban waste on a large scale, principally street sweepings and household refuse, by composted fertilizing method[7]. Similarly, manure compost is utilized for organic farming in Hong Kong[8]. Canada[9], Mexico[10] and Chongqing[11] which have solid waste management systems. Taiwan is producing energy from the cogeneration system of municipal solid waste (MSW)[12].Farmers on the Jos Plateau, Nigeria, have developed a successful soil fertility management strategy based on the combination of inorganic fertilizers, manure and urban waste ash[13]. Furthermore, the reuse of wastewater for irrigation and as a fertilizer source is also a common and popular practice. Farmers of Pakistan found a substantial positive effect of the sewage water on spinach vegetable yield[14]. Treated waste waters are also preferred on agricultural field in Tunisia[15]. However, little research had been done on the co-recycling of both solid and liquid wastes in urban agriculture.

Urban agriculture can reuse city waste which is really essential for modern agriculture, but if this waste is handled improperly and indiscriminately, it may create lots of problems including contamination of crops and hazards to the people and the environment both in the immediate and in the longer term[16]. If any nutrient is in excess, for example, if nitrogen is in excess then this excess nitrogen is converted into nitrates which are highly soluble and mobile. Then, this highly soluble nitrate can easily move with percolating water out of the soil and accumulate in groundwater, and thus makes it unavailable for plant uptakes**.** On the other hand, phosphorus is very stable near the soil surface once it is mixed into the soil[17]. Besides, some organic (carbon-based) contaminants can undergo chemical changes or degrade into products that may be more or less toxic than the original compound. Improper waste disposal can also release heavy metal which cannot break down, but their characteristics may change so that they can be more or less easily taken up by plants or animals [18]. As a result, unfortunately, the amounts of soil elements and other substances may exceed the levels recommended for the health of humans, animals, or plants which result in temporary or permanent decline in the productive capacity of the land. On the other hand, improper use of waste in agricultural field may have further contribution for pollution of surface water sources. Leachable pollutants in agricultural waste include bacteria (some may be pathogenic), phenolic compounds, ammonium nitrogen, nitrate nitrogen, potassium, heavy metals and petrochemical compounds, and water containing a high biochemical oxygen demand. Nevertheless, excessive waste has reverse effect but if wastes are used in proper doses it can be the best option for urban agriculture.

The generation of solid waste in Indian cities has been estimated to grow with 1.3 percent annually. The expected generation of waste in 2025 will, therefore, be around 700 grams per capita per day. Considering that the urban population of India is expected to grow to 45 percent from the current 28 percent, the magnitude of the problem is likely to grow even larger unless immediate steps are taken[19]. And India is not far behind from managing urban waste. Already there have been a number of successful attempts taken in combining solid or liquid waste management with urban agriculture. Among them, dhapa & Titagarh within KMA, Integrated Urban Environment Improvement Project- Bangalore, Public-Private Partnership in Mumbai, Hubli-Dharwad, MSW and Jatropha curcas system are noteworthy.

This research had been conducted in an area, which is popularly known as Dangapara within Titagarh Municipality located on the east bank of the river Hooghly, 22 kms to the north of Kolkata within Kolkata Metropolitan Area abutting the Titagarh Sewage Treatment Plant (STP). In this area, co-recycling of both solid and liquid wastes has been practicing since 1929 with a view to achieving irrigation water and soil conditioning material simultaneously. Also in those places, the fertilizing potential of solid and liquid wastes has totally been ignored. The farmers are in a practice to use quite a good amount of chemical fertilizer over and above the NPK content of the wastes in order to get quick return and also to increase in production quantity. As a result, some of the vegetable crops which were grown in abundance in this field had discarded.

The present work attempts to ensure proper use of solid-liquid waste in urban agriculture to the already-existing practice of this area through the analysis of a specific environmental program. So, an attempt had been made with three different pot trials on a specific short duration crop, Spinach, to narrow down the exact dosing of nutrient through waste (solid and liquid). Therefore, the specific objectives were a) to evaluate long term existing practice, b) to choose the proper dosing of waste in agriculture at TMA, and c) to minimize the nutritional pollutants and maintain soil health.

Material and Methods

Site description: Experiments were undertaken in the Titagarh Sewage Treatment Plant (STP) which was popularly known as Dangapara, located on the east bank of the river Hooghly, 22 kms to the north of Kolkata within Kolkata Metropolitan Area. 23% of the STP land area was used for sedimentation tanks, sludge ponds and associated drainage system and the rest was left for cultivation. Here, waste farming had been practicing since 1902 by using both treated waste water and solid waste. Multiple crops like Chinese Onion, Chinese Garlic, spinach (hybrid & local), Letus, Pudina, Cauli flower etc. were mainly cultivated crops. The agro-climate was sub-tropical with monsoon regime. The soil was mostly sandy loam.

Existing practice in Titagarh municipal area (a case study)

TMA waste had collected since last 100 years in this area. They were chosen for their easy availability and soil conditioning potentiality. Liquid waste was mostly collected from a part of Titagarh Municipality's cowshed and treated in STP. The treated effluent was utilized for agricultural practice. Local pond water was also used for irrigation. Solid waste which was generated from different parts of Titagarh Municipality was being collected and dumped at the adjacent area of STP. Questionnaire survey of TMA revealed that household contribution of solid waste was 57.5%, market waste contribution was 35.3% and others mostly commercial 7.3%.

To cultivate of 5 kattah of land, about 8 tractors (8 X 900=7200 Kg) of solid waste and nearly 50,000 Lt/ha of waste water were used. Bricks, plastics, cloth pieces etc. were sorted out from the field immediately after spreading the solid waste over the land. Then, at the time of cropping, around 10 kg of 10-26-26 or 15 Kg of 15-15 fertilizers were applied in field with an expectation of good vegetative growth irrespective of nutrient requirement of different crops.

A questionnaire survey also had conducted among farmers to study in depth the existing practice of farming and to probe into the deficiencies prevailing in their practice. The survey revealed that some of vegetables which were cultivated in abundance earlier couldn't be grown in the same field, and the growth of crop was also being reduced. In many places, some crops were totally damaged. Present research project has been aimed at revealing exact status of the existing practice and improving the technology for application in all municipalities.

Experimental setup: The experiment was carried out in an earthen pot with a short duration crop (spinach) to study the effect of treatments in terms of nutrient availability, leachate content, and yield for spinach cultivations. Here, spinach was chosen because it is a regularly cultivated crop in that site and it can potentially accumulate oxalates and excessive amounts of NO_3^- . Effective dosing of waste was chosen to focus on waste utilization effect on spinach yield and finally narrowed into an exact dose for spinach cultivation Experimental pots had been prepared by filling it with stone chips and sand at bottom and then 45 kg of virgin soil had been placed above that (Table 1). About 7.5 cm at the top of the pot had been kept free for fertilizer application, irrigation and tillage purpose.

Three trials of different dosing were conducted on spinach with the following treatments: 1) without fertilization or waste (control), required N, P, K applied by 2) solid waste (SW), and 3) liquid waste (LW) and 4) solid and liquid waste combination (S-L), 5) Chemical fertilizers (CF) and 6) regular existing practice (EP) of Titagarh (Table 2).

In first trial, the response of the crops to different rates of added solid waste, liquid waste, solid-liquid waste, chemical fertilizers were separately evaluated. After getting higher yield by using SW and LW, second trial was designed. Second trial was performed with the application of SW and S-L waste in spinach cultivation. In this trial, the following two treatments (one with waste contributing 1/3th and other with waste providing 1/5th of the total nutrient requirement, the remaining being supplemented by chemical fertilizer) were studied (Table 2). And in the last trial, the exact dosing of solid-liquid waste was fixed (Table 3).

Solid waste and chemical fertilizers had been applied in the respective pot before the time of seeding but liquid waste had been applied by split application method. Here liquid waste used as source of nutrients as well as it also fulfilled the irrigation requirements. So, the dose of liquid waste was considered as per irrigational requirements for spinach and applied in periodic fashion (10 liters/week) at the time of cropping. The amount of nutrient applied per pot was studied analytically, and dosing had been done according to conventional nutrients (N, P_2O_5, K_2O) dose of West Bengal, India. Recommended doses of N-P-K for spinach was 100-60-40, so, it was decided to apply 100 kg/ha of nitrogen in each treatment to get comparable results.

Table 1: Dimensions of Earthen Pots and Thickness of Different Materials Height in the Pot

Height in cm	Diameter in cm	Materials used in different layers and free space in cm		
		Bottom layer Stone chips & Sand	Middle layer Soil	Free Space
45	30	7.5	30	7.5

Table 2: Treatment Combination for Trail-1 and Trial-2

Trial-1	Trial-2
	Control: trial-1 soil
1) control(C):	CF: required N dose by urea, SSP[1] and MP[2].
2)Liquid waste(LW): 100% of required N dose by LW	SWA: 1/3 of required N dose by SW*
3) Solid waste(SW): 100% of required N dose by SW	SWB: 1/5 of required N dose by SW *
4)Liquid-Solid waste(S-L): 100% of required N dose by SW& LW (1:1)	SWA: 1/3 of required N dose by SW &LW*
5) Chem. fertilizer (CF): 100% of required N dose by urea, SSP[1] and MP[2].	SLA: 1/3 of required N dose by SW &LW*
6) Existing Prac.(EP):	SLB: 1/5 of required N dose by SW &LW*

Note: nutrient applied in each trial based on by 100kg/ha N dosing; 109ltr of LW was applied by split application. *remaining % of required N, P was supplied by urea as N fertilizer and SSP as a P source.
SSP[1]: Single Super Phosphate, S-L: solid and liquid waste, MP[2]: Murate of Potash.

Table 3: Treatment Combination for Trail-3

Trial-3
1) Control : trial-1 soil
2) SL1: 20% of required N dose by SW &LW(1:1)*
3) SL2: 33% of required N dose by SW &LW(1:1)*
4) SL3: 50% of required N dose by SW &LW(1:1)*
5) SL4: 67% of required N dose by SW &LW(1:1)*
6) SL5: 75% of required N dose by SW &LW(1:1)*
7) SL6: 83% of required N dose by SW &LW(1:1)*

Seeds were spread over the pot after the fertilizer had been applied. After about two or three days germinated seeds were thinned to maintain equal number of plants in each pot. Total crop duration of spinach for the present run had been approximately two months.

Sampling and characterization

Soil samples were collected from virgin land in which no cropping and no nutrient had been applied before to fill each pot. About 10 kg of municipal solid waste collected from ten points both from outside and inside of solid waste heaps. Then soil and waste samples were air dried, crushed with wooden roller, passed through a sieve of 2mm size, and stored in labeled zipper mouth polythene bags. Grab samples of wastewater was collected from the outlet of the treatment plant in 2.5 liters plastic jars and leachate samples had been collected from the mouth of the tap fixed at the bottom of each pot in 1litre plastic bottles. Both samples were labeled accordingly and kept in the freezer. Plant samples were dried at 65º ± 5ºC, ground and sieved by 0.5mm sieve.

Sample analysis

All samples were collected from different stages throughout the experiments and analyzed for EC, pH, plant Available N, P and K. The following waste analyses were carried out in waste samples. Total Nitrogen determined by wet digestion and Kjeldahl Distillation Method, total N and Nitrate-N determined by usual Kjeldahl distillation procedure after digesting with H_2SO_4, $HgSO_4$ & K_2SO_4 mixture. Available P was measured using the method of Olson et al [20] and available K measured by 1 NH_4OAc using a flame photometer[21]. For analysis of organic carbon, method recommended by Walkley-Black was followed using potassium permanganate. Soil samples were also analyzed by the same methods as used for the waste samples for org C, total N, available K, P, N, EC and pH.

Application pattern: All trials were designed with three replications, and application pattern for all trials are described in Table 2 and Table 3.

Results and Discussion

The qualitative analysis for the presence of phthalates was performed on GC-MS chromatograph of the hexane extracts of sambar, tea and alcohol by comparing the retention times and the mass spectra registered for the compounds corresponding to the particular peaks with the mass spectra found in reference libraries. The tea and alcohol does not show any phthalate peaks. However, the sambar extract shows the phthalate peak with retention time of 19.95 minutes (Figure 1). The mass spectrum of DEHP (Di - Ethyl Hexyl Phthalate) is shown in Figure 2. The main ion is at m/z 149. The second most important ion is at m/z 167. The relative percentage of DEHP was found to be 20% of Total Ion Chromatogram among the other compounds. This study reveals the fact that the phthalates are highly soluble in oily food products. The Indian dish sambar is made up of various ingredients including oil. DEHP, a plasticizer can migrate from packaging into fatty foods, and exposure is restricted to keep the Total Daily Intake (TDI) below 0.3 mg/kg body weight [10, 11].

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Results and Discussion

Physico-chemical characteristics of municipal waste

It was found that soil quality was partially improved particularly with regard to the organic carbon (7.9%), available nitrogen (0.015%), available phosphorous (0.0225%) and available potassium (0.042%) (Table 4). Therefore, soil of TMA could be further recommended for crop production with utilization of wastes even for sustainable agricultural practice.

The solid waste which used in this agricultural practice was also physically separated. These wastes were contained vegetative part, bricks, cloths and plastic. The range of bricks and plastic was 2.75 to 6% which was very low in comparison to vegetative part (91%).

Table 4: Chemical Properties of Municipal Waste and Soil

Parameters	Municipal Solid Waste	Municipal Market Solid Waste	Soil
Organic Carbon %	3.63±0.52	8.53±0.92	7.9±0.09
Available N %	0.09±0.001	0.42±0.050	0.015±0.001
Available P %	0.03±0.001	0.06±0.00	0.0225±0.001
Available K mgL^{-1}	0.22±0.05	0.241±0.002	0.042±0.00
C/N ratio	9.52	19.76	

Such high value of vegetative part (91.3%) comprises a huge amount of organic carbon that provides huge amount of plant nutrients (N, P), and this fact was highly responsible for the cultivation. The results were given in Figure 1 and Table 4.

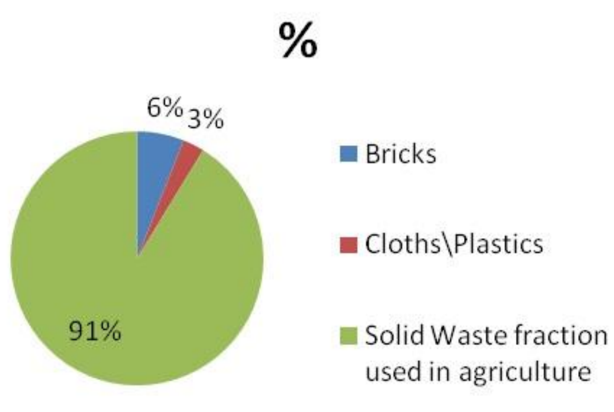

Figure 1: Physical properties of municipal waste

Chemical analysis of wastewater indicates that the constituents adequately confirm the laid down Indian Standards of tolerance limit for irrigation water (Table 5). The analytical values of the major constituents of the TMA wastewater (both raw and treated) was found to be quite satisfactory with regard to the tolerance limits for inland surface water subjected to pollution (ISB 2296 – 1982) as well as for industrial effluent discharged on land for irrigation purposes (ISB 3307 – 1977). The sodium absorption ratio (SAR) was also important because the higher SAR values (>8) might have an adverse effect on the permeability of soils with appreciable portion of clay. The SAR values even above 4 mighty cause detrimental effect when used on sensitive crops because of sodium phyto-toxicity. The SAR values of the treated effluents of Titagarh STP were found to be below 4 and this confirms their suitability for waste reuse programme even for sensitive cash crops. TDS, TSS, chloride, and nitrogen values show 'moderate' restrictions, whereas only boron and sodium values showed 'slight to none' restriction with respect to the use of WSP effluent in agriculture (Table 5). In general, WSP effluent might also be regarded as 'moderate' in relation to restriction of its use in agriculture.The bacteriological quality of the treated effluent from WSP showed values of total coliform 1.1x103 – 1.6x103 MPN per 100 ml that satisfies the recommended value for irrigation water.

Table 5: Chemical Properties of Raw Wastewater and WSP Effluent

Parameters	Raw wastewater	WSP effluent
TSS, mgL^{-1}	339	71
TDS, mgL^{-1}	696	509
TKN, mgL^{-1}	18.5	9.05
BOD_5(20ºC), mgL^{-1}	161.3	31
COD, mgL^{-1}	227.3	79
Total Alkanity, as $CaCO_3$, mgL^{-1}	329	115
Total Hardness, as $CaCO_3$, mgL^{-1}	198	117
Chloride as Cl, mgL^{-1}	202	135
Sodium as Na, mgL^{-1}	42.5	35.48
Sulphate as SO_4, mgL^{-1}	9.35	8.49
Total coliform MPN/100 ml	1.8×10^7	1.1×10^3

Effect of waste on spinach cultivation in first trial

The first pot trial was conducted by using SW, LW, S-L, EP and CF (as treatments- Table 2) considering the nutrients (N, P) content on short term spinach cultivation. From this study, the response of the plants to different treatments was compared in terms of plant uptake availability, yield and leaching loss. Results revealed that yield was significantly influenced by the combined application of S-L waste and LW, over that of C (Table 6). Increased plant yield as a result of waste application was expected as waste contained and released considerable amount of plant available N, P, K, and micro nutrients to soil [22]. On the other hand, the yields of the CF and EP treatment were low (Table 6). Similar findings had been reported by Siegenthaler[23] where long term application of large amount of organic fertilizers decreased the yields of plants probably due to nitrogen surplus and phytotoxicity[24]. The yield of the rest of treatment followed by the order: SW> CF > EP> C (Table 6). However, nutrient application due to long term irrigation with LW induced changes in the quality of soil as trace element were sustained over long periods. There were various reports[25,26] that showed when wastewater was used for the irrigation of edible plants for prolonged period; soil health was affected[27]. Accordingly, results obtained in this study suggested that total amount of nutrient provided in S-L treatments might be adequate for plant needs.

Yield of plant depends on easy availability of nutrient (N, P, and K) in the soil which depends on the nutrient sources applied for cropping. Plant available form of N, P was found in the treatments with SW (8.8 g\m2, 3.3 g\m^2) and S-L (8.4g\m2, 3.2 g\m^2) respectively (Table 6). On the other hand, higher plant uptake of K was observed only in the treatment with S-L (13.5 g\m2). However, in present research dosing of S-L was done on the basis of N requirement of spinach. So the amount of K was not taken into account. Furthermore, nitrogen uptake by plant in EP treatment showed very poor result (Table 6). Because of improper application of waste in EP caused a deficiency of available N for plant growth and might ultimately resulted decrease of plant growth. Moreover, in EP, the huge application of solid waste contained large amount of plastics, bricks, cloths which could also contaminate soil physical properties directly by affecting soil porosity and compaction.

In the present study, an effort was also made to estimate the nutrients which were dissolved out under different treatments (Table 6). The excess soluble form of nutrient in the soil (e.g. NO_3-, $NH4^+$) with high irrigational water percolated through the soil layer and caused ground water pollution. This dissolved N could contaminate groundwater through percolation or might lose as nitrogen gas as a result of denitrification[28]. Therefore, higher amount of liquid waste application in LW treatment could affect ground water quality. In contrast the S-L treatment showed no significant losses due to leaching in the first trial (Table 6). This showed that, S-L treatment was a better treatment for maximum production, maximum uptake availability, and lower nutrient loss.

Effect of specific dosing of waste on spinach cultivation in second trial

The second pot trial was performed with the application of different proportion of SW and S-L on spinach cultivation (Table 2). The highest yield was observed with 1/5 doses of SWB treatment and it was 430.98 g/m2. The rest of treatment followed the order: SLA (368.38 g/m2)> SLB (361.98 g/m2) > CF (287.1 g/m2) > SWA (199.88 g/m2) > C (116.23 g/m2) (Table 7). Though in SWB, 1/5 of the total N dose for spinach (100-60-40) was applied by SW which was lower than the amount of SW application in SWA that was supposed to give higher yield. This result implies high amount of chemical fertilizer application in SWB treatment enhance plant yield followed by SWA (Table 7). However, only CF treatment gave less yields than SWB. This result implies higher efficiency of SWB than SWA for plant yield (Table 7). Besides, in SWB treatment, huge amount of GW had been used along with SW which was reducing the unnecessary withdrawal of GW and ultimately could impact hydrological, ecological and other natural resources and services[29].

In particular, excessive irrigation with GW could lead to ground water depletions, deterioration of water quality, and land subsidence also[29]. Secondly, even though SWB treatment showed higher yield among the treatments, but utilization of solid and liquid waste together (co-recycling) was the focus of this current study and existing practice for better waste management approach. However, combination of S-L was also showed high spinach yield.

So, it was conclusively accepted from these two phases of experiments that the combination of S-L would be the only viable option for effective application in agriculture.

Table 6: Effect of Solid and Liquid Waste in Spinach Cultivation in Terms of Yield, Plant Uptake in First Trial

Treatment	Yield g/m^2	Nutrients uptake by plants (gm/m^2)			Nutrients content of leachate(mg/l)		
		N	P	K	N	P	K
Control(C)	121.8± 5**	1.8±0.2	2.3±0.04	4.6± 0.02	3.27±0.12	1.32±0.09	12.46±0.5
Solid Waste(SW)	169.9±7	8.8±1.0	3.3±0.04	6.6± 0.03	3.83±0.09	2.30±0.12	7.10±0.4
Liquid Waste(LW)	203.4±2	7.4±0.5	3.3±0.05	9.3± 0.09	2.09±0.02	1.16±0.12	9.87±0.45
Solid-Liquid Waste(S-L)	200.1± 1.5	8.4±0.5	3.2±0.01	13.5± 1.0	3.01±0.13	1.08±0.31	9.06±0.23
Chemical Fertilizer(CF)	163.2±5	4.9±0.4	2.7±0.01	6.4± 0.5	4.39±0.43	2.26±0.14	11.07±0.43
Existing Practice(EP)	154.5±5	2.2±.01	2.6±0.05	6.9± 0.5	-	0.8±0.11	8.8±0.12

** ± Standard deviation value
LW: 100% of required N dose by LW; SW: 100% of required N dose by SW
S-L: 100% of required N dose by SW& LW (1:1); CF: 100% of required N dose by urea, SSP[1] and MP[2]

Table 7: Effect of Solid and Liquid Waste with Specific Dosing in Spinach Cultivation in Terms of Yield, Plant Uptake in Second Trial

Treatment	Yield g/m^2	Nutrients uptake by plants (gm/m^2)			Nutrients content of leachate(mg/l)		
		N	P	K	N	P	K
Control	116.23±5	3.47±0.11	0.7±0.01	0.56±0.01			
CF	287.1±7	3.36±0.12	0.86±0.01	1.38±0.02	3.36±0.9	1.376±0.09	3.46±002
SWA (1/3rd)	199.88±3	2.01±0.03	0.61±0.09	0.96±0.01	2.01±0.6	1.018±0.02	1.81±0.04
SWB (1/5th)	430.98±7	5.17±0.21	0.99±0.04	1.81±0.03	4.18±0.6	1.671±0.04	4.53±0.11
SLA (1/3rd)	368.38±6	3.68±0.12	0.96±0.07	0.88±0.01	3.66±0.9	1.609±0.1	2.19±0.06
SLB (1/5th)	361.98±6	5.25±0.11	0.94±0.01	1.52±0.09	4.24±0.5	1.575±0.03	4.21±0.07

**Control: trial-1 soil; CF: required N dose by urea, SSP1 and MP2.
SWA: 1/3 of required N dose by SW*; SWB: 1/5 of required N dose by SW *
SLA: 1/3 of required N dose by SW &LW*; SLB: 1/5 of required N dose by SW &LW*

The result of nutrient uptake by plant followed the order, for N: SLB>SWB>SLA>C>CF>SWA, for P: SWB>SLA>SLB>CF>C>SWA, and for K: SWB>SLB>CF>SWA>SLA>C respectively (Table 7), this also support efficient use of S-L treatment for spinach cultivation. Precisely, in the second trial, it was observed that the treatment with 1/3th S-L (SLA) provided maximum production and also showed better performances in terms of nutrient utilization.

A greater amount of Nitrogen loss through leaching was found in the SL2 (3.58 mg/l) and SL1 treatment (2.44 mg/l) but the loss was lower in the treatment of SL4 (1.79 mg/l) treatment and SL3 (1.14 mg/l) (Table 8). From the values, it is seen that yield of spinach was higher in SL4 in comparison to others. Similarly, plant uptake of N, P, K for soil and nutrient loss due to leaching in spinach showed consistently very good results in the case of SL4 treatment (Table 8). This also signified that SL4 showed standard results in terms of N uptake by plants as well as plant yield. So, it could be concluded that, the positive attribution of solid-liquid application (SL4) implicated maximum yield of spinach, high nutrient uptake, low nutrient loss and finally sustained soil health.

Table 8: Effect of Solid and Liquid Waste with Exact Dosing in Spinach Cultivation in Terms of Yield, Plant Uptake in Third Trial

Treatment	Yield g/m^2	Nutrients uptake by plants (gm/m^2)			Nutrients content of leachate(mg/l)		
		N	P	K	N	P	K
Control	138.99±5**	2.39±5	0.53±0.03	4.25± 0.9	1.54±0.08	2.23±0.04	3.464±0.02
SL1	171.08±5	3.56± 0.05	1.77± 0.05	4.16± 1.0	2.44±0.08	2.7±0.03	3.419±0.03
SL2	217.99±7	4.73± 0.05	1.95± 0.02	6.21± 1.0	3.58±0.11	2.095±0.02	1.694±0.01
SL3	239.11± 10	3.2± 0.05	2.65± 0.02	6.98± 0.9	1.14±0.12	4.622±0.04	1.358±0.01
SL4	246.42± 10	4.14± 0.1	2.77± 0.07	6.16± 0.8	1.79±0.09	3.229±0.04	2.78±0.08
SL5	182.94±5	2.39± 0.05	0.89± 0.09	5.47± 0.8	2.17±0.04	4.7010.03	2.792±0.05
SL6	191.24±7	1.89±0.05	1.82± 0.09	5.99± 0.9	1.96±0.03	4.18±0.02	3.487±0.05

** ± Standard deviation value
Control: trial-1 soil
SL1: [20% of required N dose by SW &LW(1:1)]* ; SL2: [33% of required N dose by SW &LW(1:1)]*
SL3: [50% of required N dose by SW &LW(1:1)]* ; SL4: [67% of required N dose by SW &LW(1:1)]*
SL5: [75% of required N dose by SW &LW(1:1)]* ; SL6: [83% of required N dose by SW &LW(1:1)]*

Conclusion

The overall results of this experiment indicate that combination of solid and liquid waste significantly affected spinach yield and plant available nutrients. So, the interaction of 67% solid-liquid waste with 33% of chemical fertilizers was the best solution from the point of view of waste disposal and sources of organic fertilizer through wastes replacing substantially chemical fertilizer, which had adverse effects on soil and plant.

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