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OPINION ARTICLE

Weeds can help in biodiversity and soil conservation

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ABSTRACT

The sustainable production systems aim at conservation of both soil and ecological biodiversity. This change in research perspective has changed the view point on weeds, which was focused earlier mainly on eliminating their competition and detrimental effects on crop plants. This opinion article is focused on the positive role of weeds in soil conservation and maintenance of biodiversity. Weeds being a host for rhizobacteria, also act as a source of various nutrients and organic matter which helps in rejuvenating degraded soils and preventing soil erosion. The heavy metals presence detection in the soil and its remediation with weeds helps in sustainable quality production of food. Biodiversity of weeds describes the enormous variety of weeds present in the niche. Maintenance of its biodiversity is crucial as they have enormous potential to serve as genetic source for crop yield and quality improvement and for control of insect pests and diseases in major food crops. Weeds can be utilized for fencing the fields. Allelochemicals present in weeds can be utilized as biological agent for controlling other weeds and thereby minimizing dependency on herbicides for ecofriendly products. The appreciation of the role of weeds in maintaining soil and biodiversity conservation is a key to the sustainable agriculture development.

Keywords: Weeds adaptability strategies, Climate change, Soil remediation, Soil conservation, Weeds usage

Weeds are defined as unwanted and undesirable plants growing out of place. "Are the weeds really unwanted? or man's greed for food crops makes them unwanted!" is the question that arises. Anything which is growing in nature must have its value as nothing is waste here. Weeds are thriving successfully as they are most adaptive and sustainable plants in nature (Rao and Chandrasena 2022). Why weeds are unwanted, reason being we have not yet explored the usefulness of such plants. The wider knowledge and adaptability of weeds for their beneficial aspects are unknown and need to be explored before blaming them as unwanted plants (Chandrasena 2023).

The currently cultivated crops were earlier opportunistic weeds but their cultivation as food crop after domestication expelled them out of the weed category. The cultivated crops have their weedy ancestors which were grown and domesticated due to promising evolutionary process and selection for potential food crops. *Secale cereale* was earlier a serious weed problem in North America over hundreds of years but in the early 1960s farmers cultivated rye for human consumption and now it is ranked as one of the world's top 10 cultivated grain crops (Ellstrand *et al.* 2010). *Zea mays*, the cultivated maize was domesticated from *Z. mays* spp. *parviglumis* (Matsuoka *et al.* 2002); *Manihot esculenta* being a rich source of carbohydrate was domesticated from *Manihot esculenta* spp. *flabellifolia* (Allem *et al.* 2001). Even the world's worst weed *Parthenium argentatum* acts as an alternative source of rubber for the *Hevea brasiliensis* and is known to be useful in several ways (Chandrasena and Rao 2019)

From ecological point of view, weeds are plants which modify the ecosystem of an area through changes in structure of soil while weeds are plants which reduce the productivity of land from the economic perspective; and weeds are non-native and disturb the local attributes from conservative point of view. Nature bestowed us with weed plants which have capability to overpower the natural and anthropogenic calamities. Weeds can uproot the major setbacks faced by society through their various positive aspects which can efficiently be explored for conserving soil and biodiversity.

Role of weeds in soil conservation

Soil is a fundamental component for sustaining life on earth. The soil degradation represents the loss to the natural capital assets and loss to ecosystem services of the nature (Dumanski and Peiretti 2013). Healthy ecosystem provides steady flow of environmental goods and services for steady flow of production system. The overexploitation of the resources results in considerable degradation of these

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natural assets and proving cut in production system. Traditional practices of production system involve ploughing and tilling of land which proves to be highly destructive as 24% of global agricultural land gets degraded due to regular tillage (Bai *et al.* 2008). For conserving soil, new paradigms centered on conserving and improving soil health focused on minimum tillage and conservation tillage aiming to maintenance of permanent soil cover (Cowe *et al.* 2011). Weeds can be used in better way for conserving vast variety of soils all over the world through various means which are analyzed below. This review focused on the positive role of weeds in conservation of soil and maintenance of biodiversity.

Site of rhizobacteria: The rhizosphere is a close interaction among the soil-plant-microorganisms continuum. The microbial biomass of the rhizosphere is determined by the composition of plant efflux which are particular in different plant species (Berg and Smalla 2009).The rhizosphere is enriched with photosynthates leaked from plant roots which are energy rich carbon compounds. The large availability of exudates in the root zone generally facilitates the much higher microbial activity and their biomass in the root zone of weeds. Sturz *et al.* (2001) observed maximum species related to genera *Bacillus* (155.6%) followed by *Arthrobacter* (76.4%), *Stenotrophomonas* (46.8%), *Acinetobacter* (40.9%) and *Pseudomonas* (38.2%) in the rhizosphere. The percentage of microbes present in root zone varied according to particular weed species, for example 19.4% of *Bacillus sphaericus* were observed in roots of *Echinochloa crus-galli*, 12.9% of *Pseudomonas chlororaphis* in roots of *Spergula arvensis*, 17.5% of *Stenotrophomonas maltophilia* in roots of *Solidago canadensis*, 7.5% of *Variovax paradoxus* in roots of *Lolium multiflorum*, 6.3% of *Arthrobacter ilicis* in roots of *Chenopodium album* and 14.5% of *Bacillus sphaericus* in roots of *Elymus repens*.

Rhizobacteria in the weed roots act as plant growth promoting agent through releasing volatile compounds and antibiotics like phenazine (Ryu *et al.* 2003, Chakraborty *et al.* 2009). Rijavec and Lapanje (2016) observed that HCN increases the solubility of phosphorus by metal chelation and sequestration in the rhizosphere. Rhizobacteria also produces siderophores which helps in iron sequestering for plants and delays senescence (Buyer *et al.* 1993). Plant hormones like gibberellins inûuences germination of seed and elongation of stem. Auxins like indole acetic acid (IAA) helps in root development and differentiation of tissues. The hydrolysis of ethylene precursor by 1-amino-cyclopropane1-carboxylate deaminase to lowers the ethylene level in plants, is well-reported mechanism for growth promotion by rhizobacteria (Glick *et al.* 2007, Saleem *et al.* 2007). Plant growth promoting rhizobacteria in the root zone of weeds can be utilized for plant growth and availability of nutrients in deficit soils for sustainable production.

Source of organic matter: Conventional agriculture aims at fulfilling nutrient requirement through fertilizers. However, the long-term nutrient availability is diminishing due to regular decrease in organic matter of soils (Riccaboni *et al.* 2021). Weeds can act as a source of organic matter for soil as these extract nutrient, moisture and light for production of carbohydrate. Sharda and Lakshmi (2014) reported that fresh plants of water hyacinth contain 95.5% moisture on weight basis together with 0.04% nitrogen, 0.06% phosphorous, 0.20% potassium and 3.5% organic matter. Biradar and Patil (2001) prepared vermicompost using weeds viz., *Parthenium hysterophorus*, *Cassia sericea*, *Achyranthus aspera* and *Euphorbia geniculata* which can act as a good source of organic matter. *Solanum melongena* when treated with vermicompost of *Eichhornia* along with 50% recommended dose of fertilizers was found to be superior as compared to vermicompost made of cow-dung. *Lantana camara* can also be used for preparing compost, and when 4t/ha of it was added in soil produces higher number of tillers/hills leading to higher grain yield of rice (Singh and Angiras 2005). Weeds can be used in soils with higher sand content to improve soil organic matter which positively affect absorption of nutrients and retention of water for better root growthin soil.

Source of plant nutrients: Weeds act as a source of nutrients and the recycling of weed biomass enriches the soil. *Chromolaena odorata* is rich in nutrient status mainly through leaves, stems, roots and bulbs. The N, P and K content in leaves (1.92, 0.18, and 1.42%), stem (0.78, 0.12, and 1.98%), roots (1.42, 0.02, and 1.18%) and bulbs (0.48, 0.06, and 0.39%) of *Chromolaena odorata*, a tropical and subtropical weed found mainly in Africa make it a better source of nutrients (Mbalila 2015). *Tithonia* has lower percentage of lignin (6.5%) and polyphenol (1.6%) while considerably higher percentage of nitrogen (3.5%), phosphorus (0.37%) and potassium (4.1%) contents (Jama *et al.* 2000). Higher N fixation from weedy grasses like *Brachiaria humidicola*, *Paspalum notatum* and *Panicum maximum* was observed which derives upto 40% of their N requirement through fixation (Olivares *et al.* 1996). *Leptochloa fusca* in Pakistan has shown high nitrogen fixation activity (Malik *et al.* 1997). Aquatic weeds have gained considerable amount of attention for nutrients contribution [such as N, P and K of water hyacinth (1.86, 0.36, 3.35%), *Potamogeton* spp. (2.51, 0.33, 2.28%), *Pistia stratiotes* (2.1, 0.30, 3.5%), *Hydrilla* spp. (2.7, 0.28, 2.9%), *Ceratophyllum* spp. (3.3, 0.47, 5.9%)] (Roger and Watanable 1984). The use of weeds as a source of nutrient can lessen the dependency on the synthetic fertilizers during period of shortage and lessens the fate of fertilizers.

Indicator and phyto-remediation of heavy metals in soil: Heavy metals [viz. arsenic (As), mercury (Hg), cadmium (Cd), lead (Pb), zinc (Zn), chromium (Cr), copper (Cu) and nickel (Ni)]are naturally occurring materials in soil. Heavy metals are normally present due to either regular climatic cycles or human exercises (He *et al.* 2005, Li *et al.* 2009). In biological systems, soil formation from ultramafic rocks and ore minerals are source of heavy metals (Szyczewski *et al.* 2009). Various anthropogenic sources i.e., vehicular traffic, refining processes and mining exercises contribute to heavy metal contamination (Kabata-Pendias and Mukherjee 2007). Rising urbanization and industrialization have brought about accumulation of heavy metals in ecosystem (Charlesworth *et al.* 2011, Wang *et al.* 2014, Ahmad *et al.* 2016). Since heavy metals are not degradable, these gradually collect in soil, turning out to be possibly hazardous to terrestrial and aquatic biological systems (Tchounwou 2012, Melucci *et al.* 2018). Heavy metals affected the microbial population and plant growth directly through damaging cell structures due to oxidative stress and inhibition of cytoplasmic enzymes (Jadiaand Fulekar 2009). Reduction in root and shoot growth of wheat plant was observed at 5 mg/l concentration of cadmium (Ahmad *et al.* 2012).

Biomonitoring techniques using indicator plants are used to recognize heavy metals in soil and environment (Zereini *et al.* 2007). Mosses and lichens, for instance, are known to be the most sensitive indicator of atmospheric contaminations, consequently they are extensively utilized in metropolitan climate (Jiang *et al.* 2018). Weeds emerged as a new source for indication of heavy metals, *viz. Taraxacum officinale* L. and *Trifolium pratense* L. accumulated higher concentration of Cu which depends linearly with amount of copper present in soil. *Plantago major* L. accumulated small fraction of Mn (5-10%) in its leaves while presence of *Urtica dioica* L. and *Trifolium pratense* L. indicated Pb in the soil (Malizia *et al.* 2012, Galal and Shehata 2015). Indication of heavy metals using weeds appears to be easily accessible method to prevent transfer of heavy metals across several trophic levels of the food chain.

Phyto-remediation of heavy metals can be done through phyto-extraction, phyto-stabilization and phyto-volatilization. Phyto-extraction is the accumulation of heavy metals indifferent plant parts and it can be done by using weeds which are hyper-accumulators [high metal accumulating (10-500 times)] and/or heavy biomass accumulator (high metal mobilizing capacity) (Salt *et al.* 1998). Hyper-accumulator plantshave hyper-tolerance by compartmentalization of heavy metals ions in the cell wall or by excluding metals from plants (Garbisu and Alkorta 2003). Reeves and Baker (2003) have given examples of different weeds which act as heavy metal accumulators viz. *Minuartia verna* (Pb hyper-accumulators), *Aeollanthus subacaulis* (Cu hyper-accumulator), *Thlaspi tatrense* (Zn hyper-accumulators), *Haumania strumrobertii* (Co hyper-accumulator), *Dichapetalum gelonioides* (Ni hyper-accumulators) and *Maytenus bureaviana* (Mn hyper-accumulator).

Phyto-stabilization helps in immobilization of the heavy metals by sorption, precipitation or complexation (Jadia and Fulekar 2009) through their root system. Plants characterized with ability to tolerate soil conditions, dense rooting system, rapid growth to complete coverage can act as phyto-stabilizing agent for heavy metals. Under well manured soil conditions, *Solanum nigrum* reduced Zn percolation through soil by 80% (Marques *et al.* 2008). Phyto-volatilization involves the uptake of pollutant from the soil which get volatilized and transpired into the atmosphere. Genetically engineered plants like *Arabidopsis thaliana* and *Liriodendron tulipifera* with mercuric reductase merA and merB can detoxify organic mercury (methyl-Hg ion) to less toxic elemental Hg, and are used for phyto-volatilization of mercury from soil (Rock *et al.* 2000). In heavily infested soils with heavy metals, weeds can be used to protect the ecosystem with good efficacy being cost effective method which can aid researchers and policymakers for future eco-friendly research.

Rejuvenating saline soils: Basophile weeds like *Prosopis julifera*, *Paspalum vaginatum*, *Sesuvium portulacastrum*, *Cressa arecta*, *Salsola* spp. and *Sporobolus diander* are dominant in saline soils and alkaline soils. Halophyte plants can grow in saline soils and have a mechanism of compartmentation of ions in the vacuoles of cell (Gorham 1995). Such weeds can be allowed to grow in salt-affected soils. These will add organic matter and humus to soils which diverges the earlier barren soils to productive land which can revolutionize the concept of rejuvenating the degraded soils. *Suaeda maritima* reduces the electrical conductivity (EC) from 4.9 to 1.4 ds/m and accumulated 504 kg/ha NaCl in 120 days. Similarly, *Sesuvium portulacastrum, Clerodendron inerme, Heliotropium curassavicum* and *Ipomoea pes-caprae* reduced EC from 4.9 to 2.5, 4.7 to 3.08, 4.8 to 2.6 and 4.8 to 3.56, respectively and removed 473.93, 325.18, 359.5 and 301.46 kg/ha NaCl, respectively in 120 days (Ravindran *et al.* 2007). *Leptochloa fusca* and *Prosopis julifera* decreased soil EC from 2.20 to 0.42 (Singh *et al.* 1989). Globally, soil is salt-affected on 17 million km^2 area which can be reclaimed using weeds. Weeds are efficient extractor of salts from soil because of their small life span, many cohorts per season and germination over variable environments.

Controlling soil erosion: Soil erosion occurs due to different climatic (serious dry spell occasions) and human factors (overgrazing of rangelands) which reduces land use efficiency (Reynolds and Smith 2002). Extensive root system of weed plants prevent soil from water erosion while above-surface growth prevents soil from wind erosion. Weeds intercept raindrops which reduce the impact of water on soil surface.Weeds also maintains the infiltration of water which reduces the crusting of soil surface. Shallow rooted weeds such as *Echinochloa* spp., *Digitaria* spp., *Bromus* spp., *Cynodon dactylon*, *Glechoma hederacea, Stellaria media* prevent soil erosion (Vannoppen *et al.* 2015). Weeds act as mulch on barren soil or sloppy areas or areas with high wind velocity and thus, prevent its erosion.

Role of weeds in biodiversity conservation

Biodiversity is variability among living organisms (terrestrial and aquatic diversity) and ecological complexes (within species, between species and ecosystem) (Penuelas *et al.* 2020). Biodiversity within different species is declining over the past 60 years due to either natural or man-mademalfunctioning in the ecosystem (Tittensor *et al.* 2014, Penuelas *et al.* 2020). Weed biodiversity is an indicator of agronomic and environment sustainability and is essential to buffer the negative impact of weeds on ecosystem and resistance evolution (Storkey and Neve 2018). The presence of more diverse weed community within a niche prevent competition. The continuous suppression of weeds either biologically or chemically have posed a threat to genetic diversity of species forbidding food webs and ecosystem services like pollination (Blaix *et al.* 2018). A diverse weed flora provides wide spectrum of seeds which had positive impact on food web interactions (Harvey *et al.* 2008). Weeds may-provide support for maintenance of biodiversity and ecosystem stability.

Donor of useful genes to crops: The knowledge of genetics, organic chemistry and crop physiology is used in improving varietal traits such as resistance against herbicides and pests (Shuqin and Fang 2018). Weeds act as a plant genetic resource as they are important unit for natural selection and adaptation. Weeds can be used for crop improvement for stress tolerances (viz. salt tolerance, drought tolerance, submergence tolerance, temperature tolerance, heavy metal tolerance, herbicide tolerance, disease and insect resistance). *Diplachne fusca* is perfect example for imparting salt tolerance as these plants comprise of micro-hairs on leaves which secrete salts from the leaf surface to protect it from salts (Céccoli *et al.* 2015).Seeds of *Echinochloa crus-galli* germinate and grow under anaerobic conditions due to its resilience to ethanol and the capacity to utilize key substrates (Céccoli *et al.* 2015). *Cicer reticulatum* have enhanced thermo-tolerance (Hajjar and Hodgkin 2007). Triazine resistant weed biotype of the *Brassica campestris* was found which is used to produce herbicide resistant crops (Beversdorf and Kott 1987). Lr9 gene from *Aegilops umbellulata* and Lr19 and Lr24 from *Agropyron elongatum* were used to produce rust resistant wheat in India (Reddy *et al.* 1996). *Echinochloa crus-galli* has two novel proteins viz. Ec-AMP-D1 and Ec-AMP-D2 which were isolated and used against several fungus (Odintsov *et al.* 2008). The loss of mutation in the main shattering gene of seed such as SH1 in sorghum and its rice orthologs was considered for non-shattering phenotypes. The CRISPR-Cas9/ base editing was suggested to be potentially utilized in the weeds and implemented on rice to cause single nucleotide polymorphism in the regulatory element of qSH1 gene to emulate the shattering loss (Konishi *et al.* 2006; Li *et al.* 2019). Weeds act as reservoir of germplasm that functions as an important source of genes for tolerating biotic and abiotic stresses in crop plants aiming crop improvement in terms of fitness and lesser yield penalty.

Control of insect-pests: Weeds act as reservoirs of beneficial insects and these provide physical shelter, pollen, nectar and water to diverse insects. Wolcott (1928) removed the weeds under tropical climatic conditions and observed increase in crop damage by insect-pests. In a weed-free monocropping system, a large number of sprays were used to control cotton bollworm as compared to weedy system (Hillocks 1998). All these examples favour that weeds act as a host for natural enemies of insect-pests and keep the pest population below economic threshold level (ETL). Weeds on field margins act as conservation area for beneficial insects in Europe (Marshall 1988). In Uganda, *Cissus adenocaulis* was exploited as a trap crop for controlling cotton pest *Taylorilygusv osseleri*. Insecticidal effects of lemon grass oil constituents were observed against *Trichoplusia ni* (Tak *et al.* 2016). Additionally, combination of thymol, linalool and p-cymene were obtained from *Thymus vulgaris* and resulted mixtures have shown synergistic insecticidal activity by targeting the third instar larva of the *Spodoptera littoralis* (Pavela 2014). Weeds being a feeding ground of insect-pests have a positive impact on crop productivity. Beneficial insects may predate on weeds for maintaining their population. The biocontrol methods for sustainable control of weeds can be explored by utilizing this aspect of weeds.

Allelochemicals as biological agents: *Lantana camara* plants repels other plants due to major toxins such as Lantadene A (52%), lantadene B (50%) and salicylic acid (37%) present in it (Singh *et al.* 2012). *Lantana camara* leaf extract contains gentisic, vanillic, salicylic acid, â-resorcylic acid, coumarin, ferulic, caffeic, 6- methyl coumarin and p-hydroxybenzoic acids (Yi *et al.* 2005). Seed germination requires production of gibberellic acid which regulates the synthesis of á-amylase enzyme (starch degrading enzyme). Extract of *Lantana camara* inhibits the production of gibberellins to prevent the synthesis of á-amylase enzyme and inhibit seed germination of certain weeds. *Lantana camara* plants inhibits the germination of *Echinochloa* spp. by 95% (Anaya *et al.* 1997). *Lantana camara* aqueous extract inhibited the growth of *Eichhornia crassipes, Melilotus alba and Lolium multiflorum* (Mishra 2015). *Parthenium hysterophorus* showed inhibition of root length, shoot length, fresh weight, dry weight and leaf area due to leachates from *Lantana camara* (Mishra 2012). These allelochemical properties of weeds can be used as a source of natural weed checking agent under controlled conditions under organic farming system. In a study, the allelopathic effect of *Ficus nitida* was studied against *Corchorus olitorius* and *Echinochloa crus-galli* by mixing leaf powder to soil or by foliar spray. It was reported that with increase in concentration of *F. nitida* extract, bio-herbicidal potential was observed to be increased (El–Wakeel *et al.* 2023).

As fields Fencing: Weeds being hardy, persistent and prolific seed producer can be used for fencing. Live fencing around the agricultural field is done by planting trees or shrubs or bushes. *Lantana camara* can efficiently be used as fence weed along with its beautiful inflorescence which can serve as aesthetic purpose to the landscape. Spinous species of weeds viz. *Euphorbia antiquorum, Euphorbia neriifolia, Euphorbia nivulia, Cereus peruvianus*etc can efficiently be used as fencing (Subrahmanya and Raveendran 2010). However, utmost care should be taken that these weed plants (used as fencing) should be properly monitored and checked for dissemination of seeds/vegetative propagules. The use of weeds for fencing the crop field against biotic (fungi, bacteria, nematode and viruses) and abiotic stresses (unusual temperature, high wind, drought and salinity) can be explored for sustainable crop production.

Nematicidal properties: *Solanum nigrum* and *Datura stramonium* contains various allelochemicals *viz*. phenolic acids, terpenes, alkaloids and flavonoids *etc*. which can efficiently be used to control nematodes (Zhou *et al.* 2012, Sher *et al.* 2015). The plant extract preparation has nematicidal activity which don't have any adverse effect on non-target organism (Oplos *et al.* 2018). Compounds such as 4-quinolone waltherione and waltherione A inhibits egg hatching and have larvicidal activity against *M. incognita* (Jang *et al.* 2015). Leaf extracts of *Andropogon gayanus, Phyllanthus amarus, Euphorbia hirta, Sida acuta* and *Cassia obtusifolia* resulted in 100% control of *Meloidogyne incognita* (Olabiyi *et al.* 2008). Weed with nematocidal properties can be used as cover crop and intercrops in between the main crops.

Other uses: Vegetatively propagated weeds like *Sorghum halepense, Cynodon dactylon, Saccharum spontaneum* grown along roadsides, railway tracks, waste lands provide fodder, aesthetic and industrial purposes. *Saccharum spontaneum, Saccharum arundinaceum, Spartina alternifolia, Erianthus arundinaceus, Miscanthus sacchariflorus* and *Phragmites australis* contain high quality lingo-cellulose fiber which can be used as raw material for paper making industry (Chandrasena 2014). Large amount of cellulose is present in *Ageratum adenophora* which is used in china for making fiber board (Kim *et al.* 2007). In Asian-Pacific countries, *Eichhornia crassipes* biomass is used as raw material for pulp and paper industry. *Jatropha curcas, Arundo donax, Thlapsi arvense* are used as raw material for biodiesel as primary product while methane and ethanol as secondary product (Chandrasena 2014). *Saccharum spontaneum* act as repositories of diverse valuable genes for sugarcane (Pandey *et al.* 2015). Various plausible ways to use weeds for sustainable agriculture are depicted in **Figure 1**.

Way forward in attitude toward weeds

Weeds are undesired intruders in the agroecology as they compete for resources like moisture, nutrients, light and space which make them undesirable for the crops. Weeds are phenotypically plastic and genetically labile. Weeds have many harmful effects and conventional agriculture aims at controlling weeds rather than maintaining it. Weeds can be used as organic source, either by directly incorporating these in soil before seed setting or by

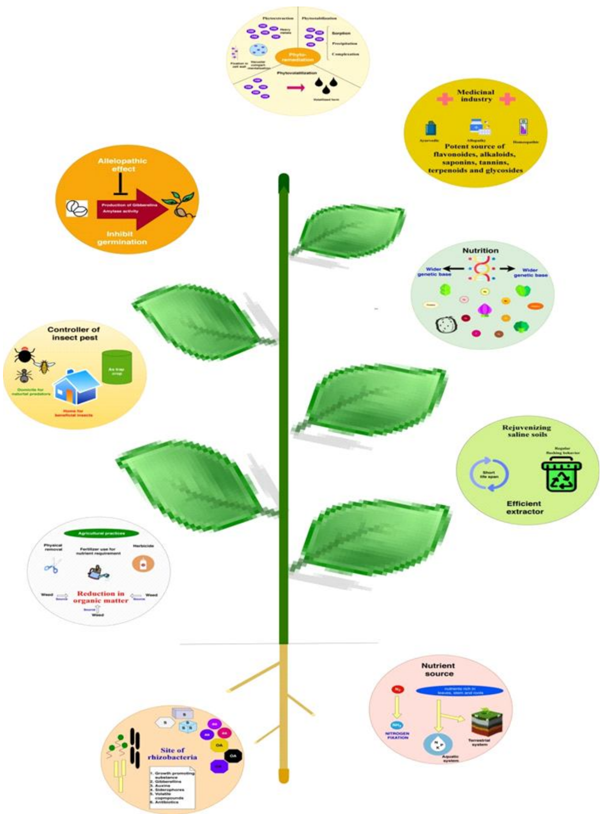

Figure 1. Possible ways of weeds utilization for sustainable agriculture development

preparing compost. However, weeds are not real offender, but are traits of other problems such as overgrazing, monoculture and clean cultivation. Most of publications address the drawback of weeds and advocate for weed control. Much extensive works was carried out in sustainable management of weeds by classical and modern approaches for weed management, whereas very little attentive work has been carried out in the field of weed importance. It is the time to change the mindset of controlling weeds and to recognize the biological aspect of weeds in a way forward. Utilization of different weeds for biodiversity, soil conservation and other positive roles of weeds will help in sustainable agriculture.

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