Ecological Intensification for Sustainable Development

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Abstract

The extent and quantity of natural resources (NRs) are going to degrade day by day due to overexploitation, misuse, unscientific management and some other anthropogenic deleterious activity in addition to climate change. NRs are nature's properties that not only sustain life but also maintain ecosystem structure and its services to humankinds. Resources like agriculture, forest, animals, soils and water are global treasure and their extent of utilization must be in optimum, i.e. without overlooking the environment. Agriculture, forestry, animals are integrated unit and linked with each other that deliver various multifarious tangible and intangible products which can be modified by varying level of resources like soil, water and other environmental factors that affect the performance of agriculture and forestry at global level. Today, due to huge application of fertilizers in farm, intensive agricultural practices, illicit felling, deforestation, intensive grazing are affecting the soil health, water purity and its availability that leads to depletion of other NRs which are directly and indirectly linked with food and nutrition security, human and animal health, soil and environmental security. Therefore, the terms ecological intensification (EI) and sustainable intensification (SI) have proven to be a good strategy and play a significant role in conserving and managing these resources without affecting our environment health. FAO has

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M. K. Jhariya et al. (eds.), *Ecological Intensification of Natural Resources for Sustainable Agriculture*, https://doi.org/10.1007/978-981-33-4203-3_5

defined the term EI and according to them, EI requires a knowledge intensive process that intensifies the ecosystem services (ES) of NRs by enhancing biodiversity which resulted in higher tree–crop–soil productivity through less use of synthetic inputs. This helps in maintaining food, health and climate security at global scale. However, intensification in agriculture and forestry must be promoted in lieu of maintaining food and nutritional security (FNS) of burgeoning 9.8 billion population along with minimizing global hunger and health issues of people. Therefore, EI in agricultural and forestry not only make sustainable production but also promote other ES, enhance other resource use efficiency (RUE), promote efficient nutrient cycling, maintain soil fertility along with ecological sustainability. However, there is lack of farmer's knowledge regarding EI and SI in agriculture and forestry, effective policies should be framed at government level in relation to knowledge communication among peoples. Lack of scientific oriented research and development (R&D), etc. becomes constraints behind adoption, promotion and application of a better EI in these NRs without affecting our environment. In this context, this chapter gives a framework and outlines the concept and prospects of EI, its utility in various NRs (agriculture and forestry, etc.), its role in ES, RUE, climate change mitigation along with discussions on ongoing trends of hurdles and constraint behind its adoption, related R&D and future roadmap for better applicability of EI in NRs for better environment with sustainable production systems at global scale.

Keywords

Agriculture · Climate change · Ecological intensification · Ecological sustainability · Natural resources · Resource use efficiency

Abbreviations

AI	Agricultural intensification
EI	Ecological intensification
ES	Ecosystem services
FNS	Food and nutritional security
GHGs	Greenhouse gases
NRs	Natural resources
R&D	Research and development
RUE	Resource use efficiency
SI	Sustainable intensification

5.1 Introduction

Expanding agricultural land through deforestation and other anthropogenic activity and intensification of farming systems by higher synthetic inputs for maximizing production have confirmed negative impacts in terms of losing biodiversity, emission of GHGs (greenhouse gases) into the atmosphere, increasing global warming, declining tree–crops–soil productivity, affecting resource use efficiency (RUE) and also disturb other natural resources (NRs) by affecting ecosystem services (ES) for ecological sustainability (Foley et al. 2005; Phalan et al. 2011; Meena et al. 2020; Kumar et al. 2020; Raj et al. 2020; Banerjee et al. 2020). However, intensifying agriculture, i.e. heavy synthetic inputs helps in producing more foods which satisfy billions of people by reducing hunger and malnutrition but at the cost of ecosystem and environment health due to land degradation, depletion of NRs, RUE, declining biodiversity and affecting socio-economic status of peoples (Foley et al. 2011; Godfray et al. 2010).

In this context, both ecological intensification (EI) and sustainable intensification (SI) play emerging role in management and development of agriculture and forestry by minimizing negative impacts of agricultural intensification (AI), having more crop diversification resulting in higher production through intensifying ES. Minimizing nutrient loss, soil erosion, eutrophication reduces GHGs and pollution. Further it helps in building soil fertility, crop productivity and food nutritional security along with ecological sustainability. These are possible through promotion of better EI methodology, i.e. intensifying agro-ecosystem and varying farming systems (e.g. agriculture, agroforestry and other farming systems). Various processes such as changing biological interaction, modifying tree–crop interaction, minimizing pesticide and insecticide application, enhancing beneficial microbial, fungal and plant interaction (e.g. Mycorrhizae, etc.), minimizing the application of inorganic, promoting healthy livestock's population and organic based farming systems would help in building sustainability in farming systems in various agro-ecological region of the world (Fig. 5.1) (Gaba et al. 2014; Xie et al. 2019). However, many farmers and stakeholders are advocating AI and giving solutions which vary from drastic change of food system to smaller field based improvement (Clay 2011; Foley et al. 2005; Royal Society London 2009). Many terms have emerged which focuses on these issues along with solving strategies and these are EI, SI and agro-ecological intensification. There is a blurred boundary in between EI and SI and very less information are available globally (Petersen and Snapp 2015). The concept of sustainability is totally based on ecological sustainability and related intensification. This promotes the practices of SI which depends on the principle of sustainability of production without ignoring environmental health. But the biggest hurdle is that various controversies arise from significant effects of EI and SI in management and conservation of NRs. The main question is *"Whether the principle of EI is applicable for any farming system and is it viable?*" *"How these varying forms of intensification will be operational for NRs management for higher significant benefits?"* and *"Can EI improve RUE?*"

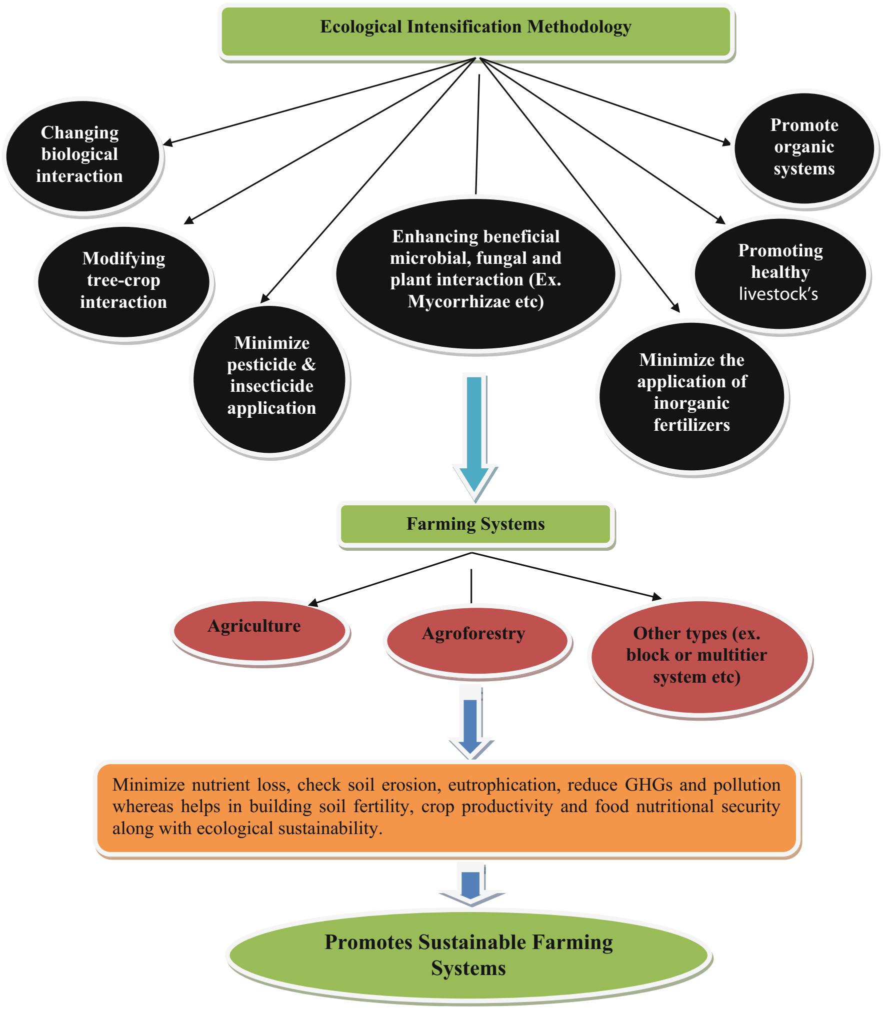

Fig. 5.1 Ecological intensification for sustainable farming systems (Gaba et al. 2014; Xie et al. 2019)

In this context, this chapter covers all relevant concepts regarding EI and SI, its role in NRs management, ES and climate change mitigation by reducing GHGs emission due to intensive farming systems. This chapter also highlights the role of EI in maintaining food and nutritional security (FNS), soil and environmental security. Effective policies, research and development (R&D) and future roadmap for adoption and operation of EI and SI are also discussed. In this chapter we also produce a conceptual framework and models for EI and SI which is quite linked with tree–crop–soil productivity by enhancing biodiversity through intensifying ES.

5.2 Ecological Intensification: Principle and Concept

The term EI itself represents intensification that is based on ecology oriented principle and applied for management and conservation of NRs such as agriculture, forestry, animals, etc. Similarly, the principle relies on the practices and management for higher tree–crop–soil productivity, better soil fertility, efficient RUE, biodiversity management and interaction among resources like plants, animals and soil inhabiting organisms (Agropolis 2013; CIRAD 2008; FAO 2009). The main aim of these intensifications is to make more deep understanding and knowledge for efficient use of NRs and related ecological processes (Doltra and Olesen 2013). As per CIRAD (2008) this intensification gives a better knowledge about tree–crop–soil interactions and linking concepts between biotic and abiotic factors through efficient bio-geochemical and water cycles and also intensifies the interactions among plants and animals.

The principle and practices of EI are based on achieving multiple goals/ dimensions such as enhancing biodiversity and its conservation, improvement of tree–crop–soil productivity, maintaining soil fertility with balance flows of nutrient (Meena et al. 2018; Meena and Lal 2018). Further, it helps in efficient cycling in the systems, reducing insect pest infestation in the whole systems through better understanding about plant–insect and insect–insect interactions. This helps in balancing numbers of predators and parasites in the ecosystems and development of climate resilient farming systems. Such types of system have diversified forms of plant breeding technologies which are adapted and operationalized for reducing environmental constraints such as climate change mitigation. Further, EI is based on the principle of simplifying relations between food systems and human factors that initiated the less use of energy which helps in reducing the emissions of GHGs by controlling unstoppable uses of fossil fuels which are non-renewable resources (Dore et al. 2011; Meena et al. 2020a, b). Reducing food wastage, its proper distribution among peoples, recycling of its derived by-products, minimizing negative health among peoples and varying environment externalities are also taken into account for further studies of EI principle and practices at global scale (Tittonell and Giller 2013). Moreover, stakeholder participatory involvement, enhancing local expertise's and understanding about new species introduction along with making of collective form of decision's are also factors on which EI relies (Caron et al. 2014; Tittonell 2014).

5.3 Ecological Intensification: Origin and Historical Perspective

The historical invention of EI is crystal clear and well known among scientists, researchers, stakeholders, policymakers and farmers. Many authors have defined and elaborated the definition of EI along with its origin and historical backgrounds. For example, Egger (1986) proposed this term firstly and he described double approaches such as all practices for enhancing soil fertility on the one hand and establishing a great link among woody perennial trees, crops and animals in same piece of land under agrisilvopastoral systems. One decade later, Cassman and Pingali (1995) have emphasized the role of intensification in farming system. Cassman (1999) has described the goal and objective of EI in agriculture and according to him further AI is needed for satisfying the food requirement of humans without affecting the environmental quality.

After one decade in 2008, the sense of EI totally relies on making a conceptual framework and model which is designed in accordance to control and manage biological invasive species through proper utilization of NRs and its use efficiency with better ES (CIRAD 2008). Similarly, FAO (2009) has emphasized the role of both EI and SI in enhancing production per unit area without compromising any productive capacity of the systems. However, the studies have increased in the form of publications from 2010 afterwards.

Different authors are having their own perceptions to define ecological sustainability for example, focusing on food production with minimizing harmful impacts on environment by some authors such as Doltra and Olesen (2013), Griffon (2013) and Hochman et al. (2013). Dore et al. (2011) and Tittonell and Giller (2013) have emphasized on minimizing synthetic inputs and in contrary enhancing RUE. Thereafter, various authors came as per historical hierarchy and gave proper explanation of EI in successional forms. For example, Dore et al. (2011) emphasized the EI in terms of providing and intensifying ES, whereas Bommarco et al. (2012) made a great link between ES and production system which is managed through EI. After one year, two scientists viz., Dore et al. (2011) and Tittonell and Giller (2013) have reported a great integration of social aspects into EI. Similarly, Tittonell (2014) proposed EI into the landscape approach which provides better ES by enhancing biodiversity of ecosystem. This concept is also supported by Gaba et al. (2014). Thus, we can see the successional evolution of concept and definition of EI which is coming into recent definitions by taking account of ES and landscapes approaches at global scale.

5.4 Sustainable Intensification: Principle and Concept

SI is gaining wide importance in both scientific and development reports (Pretty et al. 2011). The concept of SI is crystal clear which mainly emphasizes on the principle of better environment health. As per Pretty (1997), SI can enhance yield potential in degraded areas along with protecting NRs. Gibon et al. (1999) have defined this term with special reference to livestock production and according to him, subtle changes in input and output in livestock production systems are aimed to maintain health and productivity along with product quality that can meet present and future demand of humans. Similarly, Pretty (2008) used this practices concerning three capital assets viz., natural, social and humans during practices of intensification. This is to be combined with various other technologies along with certain inputs such as recommended plant genotypes and effective ecological management that helps in minimizing negative impacts on our ecosystem and environment.

A very simple concept and principle behind adoption of SI adopted by Royal Society London (2009) reveals that there must be a balance between maintaining environmental quality along with increasing yield and productivity. This should not include more land areas of other land-use type. This is further rectified by FAO (2011) and according to them, enhancing more yield from same piece of land must be followed in parallel to resource conservation. Further, efficient utilization, improving environmental health, intensifying ES along with maintaining natural materials flow in the ecosystem for ecological stability are the need of the hour. This concept is also supported by Firbank et al. (2013). However, in the last decade, SI has gained wide recognition due to its popularity among farmers, scientists, researchers, policymakers and stakeholders due to crystal clear understanding of its concepts and principles. It involves management and conservation of NRs through supports from various national and international organizations. Various organizations such as Consultative Group on International Agricultural Research by (CGIAR 2011), United States Agency for International Development (USAID 2013) and International Fertilizer Industry Association (IFA 2013) are working towards this dimension.

In nutshell, the principles of SI depend on various practices such as conservation tillage (McCune et al. 2011), soil mulching along with better crop rotation practices (FAO 2011), integration of nitrogen fixing leguminous crops along with various other cash and cover crops in the farming systems (Tilman et al. 2011), hedgerow cropping system (Pretty 1997), practices of integrated pest management and soil–water conservation practices (Pretty et al. 2011; FAO 2011; McCune et al. 2011).

5.5 Linking Concept Among Intensification, Ecointensification and Sustainable Intensification

Inter-relationship between intensification, EI and SI reveals that EI and SI have blurred boundaries due to subtle difference in between them. However, link exists in all these three terms which is based on their principles and their applicability in the field and contributions in management and conservation of the NRs. Intensification represents intensive use of all inputs to intensify final products. If this practice is according to the ecological based approach, then it represents EI, whereas SI relies on higher yield and productivity without disturbing our environmental health. Therefore, higher production, RUE, ES, environmental health and ecological sustainability are various indicators/key that makes the difference among intensification, EI and SI at global scale. However, these terms overlap with each other due to similar appearance of their use as key terms. For example, the indicator "higher production" is valid for all these three terms, whereas environmental health and its sustainability are covered by only SI. Therefore, these three terms are linked concept upon which all principle and practices depend. However, some authors have integrated and correlated social dimensions into EI (Dore et al. 2011; Bommarco et al. 2012; Tittonell and Giller 2013), whereas others have integrated into SI (Garnett et al. 2013). Similarly, Kuyper and Struik (2014) reported link and similarity between EI and SI that shared same language worldwide.

Many documents are available on the EI and SI which are based on its concept, principles and significant role in conservation and management of NRs with reference to agriculture system. Xie et al. (2019) and his team did hectic works to review literatures on SI and explore database from various authentic sources and collected around 962 papers between 1980 and 2019. However, documents of research and studies (1956 numbers) were more for SI as compared to EI having 1706 numbers till 2018 which is depicted in Table 5.1. In this table, we can see that after 2010 the number of documents is increasing steeply without any interruptions which represent the work, study efficiency and scientific concern of these two intensifications due to its positive impacts. Also, it leaves various questions and research topics on concept and principles of EI and SI due to already published documental footprint in the world which states that more research studies need to be done in this aspect to explore the inter-relationship of these intensifications with various other fields. More research and topic need to be explored for proper understanding of the characteristics, principles and practices of these two AI and other NRs despite of already existing pools of data represented in Table 5.2. This table summarizes a review on SI in agricultural and other resources based on its varying characteristics, principles and adopted practices. Also these data will be helpful while applying the SI in any farming systems comprising agriculture, forestry and other NRs on the earth.

5.6 Ecointensification in Natural Resources

Conservation and managing NRs are global concern for smoothing of various ecological processes and proper ecosystem structure and its function along with various better ES to maintain the biodiversity (Jhariya et al. 2019a, b). In this context, both EI approaches and SI approaches would be helpful in promoting NRs management and their efficient utilization in ecosystems. Natural RUE will be high along with better ES and various ecological processes in EI approaches, whereas SI approach represents a balance exchange of NRs, i.e. input–output resources along with better environmental services. However, integrated NRs management approach also helps in this context by combining both SI and EI approaches. However, a conceptual model has been developed in this context that is depicted in Fig. 5.2 (Wezel et al. 2015; Lema et al. 2016).

The NRs are important treasure on the earth due to its multifarious benefits and role in overall ecosystem structure and its function that deliver uncountable services to mankind (Khan et al. 2020a, b). Although overexploitation of these resources (forest, agriculture, agroforestry, animals, soils, etc.) are becoming global concern for today and a major challenge for researchers and policymakers. In this context, ecology oriented intensification approach plays an important role in conserving and managing these valuable resources that help in enhancing agricultural productivity

Table 5.1 Literature mining and documents available on ecological and sustainable intensification in the field of agriculture during1990–2018 (Xie et al. 2019)

Ecological intensification (EI)		Sustainable intensification (SI)	
Year	Number of papers	Year	Number of papers
1990	1	1990	1
1991	1	1991	1
1992	8	1992	4
1993	5	1993	2
1994	3	1994	4
1995	9	1995	5
1996	5	1996	6
1997	12	1997	11
1998	10	1998	13
1999	15	1999	13
2000	9	2000	7
2001	15	2001	20
2002	18	2002	17
2003	16	2003	17
2004	26	2004	16
2005	26	2005	18
2006	40	2006	33
2007	49	2007	35
2008	48	2008	36
2009	45	2009	33
2010	61	2010	48
2011	81	2011	60
2012	102	2012	66
2013	107	2013	98
2014	142	2014	163
2015	188	2015	241
2016	182	2016	254
2017	214	2017	322
2018	268	2018	412
	1706		**1956**

for long term basis, maximize forest health and productivity, improve livestock's health, soil health and quality, diversity and management of natural habitat, enhance water resource availability for long term, diversifying food and fruits availability, improve both tangible and intangible services through forestry, maintain soil fertility and population of micro- and macrofloral population and organism and improve overall agro-ecosystem health and productivity under the era of climate change which is depicted in Fig. 5.3 (Mao et al. 2015; Al-Kaisi and Lowery 2017).

Table 5.2 A review on sustainable intensification in agricultural and other resources based on its varying characteristics, principles and adopted practices

Particulars	Sustainable intensification in agriculture and other resources	References
Characteristics	Intensify production along with conservation and protection of other natural resources	Pretty (1997)
	Maintain soil fertility by nutrient availability and its proper balance that signifies the return from land and labour in farming systems	Ruerd and Lee (2000)
	Helps in enhancing tree–crop productivity from unit land without affecting environment and land expansion	Baulcombe et al. (2009), Pretty and Bharucha (2014)
	Enhancing resource use efficiency and promotes the utilization of best technologies with less synthetic inputs that minimize negative impacts on environment	Pretty (2008)
	Intensify productivity and balancing the inputs and outputs in livestock animals production system while taking account of environmental stability	Gibon et al. (1999)
Principles	Based on the principle of less uses of land and utilization of various renewable resources such as light, water and labour to signify the production at farm level	Godfray et al. (2010), Firbank et al. (2013)
	Better use of tree–crop varieties and important cattle breeds	Ruerd and Lee (2000), Pretty (2008)
	Optimization of outside inputs, better resource use efficiency, improves food production systems and reduces its impact on our environment	Pretty (1997), Matson et al. (1997)
	Minimize the wastage of food with enhancing productivity	Garnett et al. (2013)
Practices	Application of mulching to cover soil and minimize losses along with conservation tillage practices in farming systems	Wezel et al. (2015)
	Better practices of integrated pest management	Pretty (1997)
	Integrating cover crops, use cash crop, beans and proper harvesting of crops is going on in crop rotation system	Tilman et al. (2011)
	Cultivation practices of improved varieties of tree–crops–livestocks along with protection of plant genetic resources	FAO (2004)
	Practices are done in favour of soil health and promotion of soil and water conservation	FAO (2004), Wezel et al. (2015)
	Practices that take account of water management in agricultural field and focus on irrigation management and fertigation, etc.	FAO (2004)

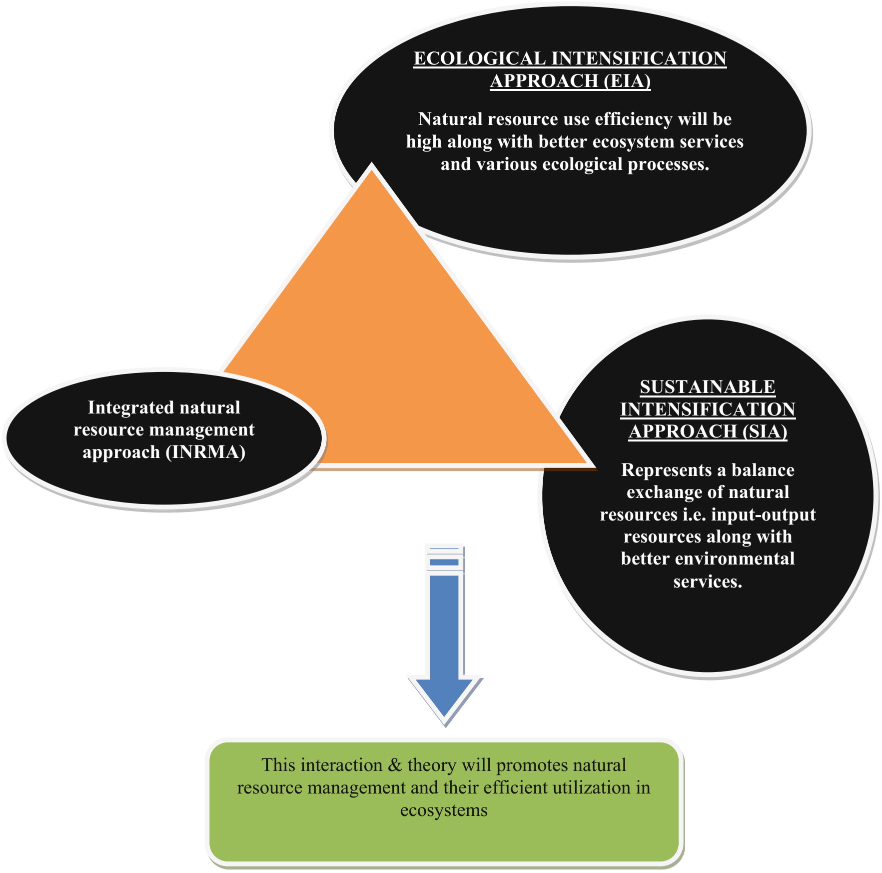

Fig. 5.2 Ecological and sustainable intensification approaches for natural resource management (Wezel et al. 2015; Lema et al. 2016)

5.6.1 Agriculture

The ongoing trends of agricultural land expansion and practices of AI are becoming major hurdles today due to various negative outcomes and deleterious impacts on our ecosystem and environment. Increasing population necessitates the food requirement that leads to expansion of agricultural lands through conversion of various existing natural forest, pastureland and other land-use that causes imbalance among various NRs. Within AI, intensifying synthetic inputs will surely help in enhancing crop productivity but at the cost of environmental health due to emission GHGs leading to global warming and climate change (Kumar et al. 2020). In this context, one question always remains in the mind of scientific community regarding the role of AI towards global warming and climate change. Agriculture itself contributes in climate change through GHGs emission through overuse of synthetic inputs into the

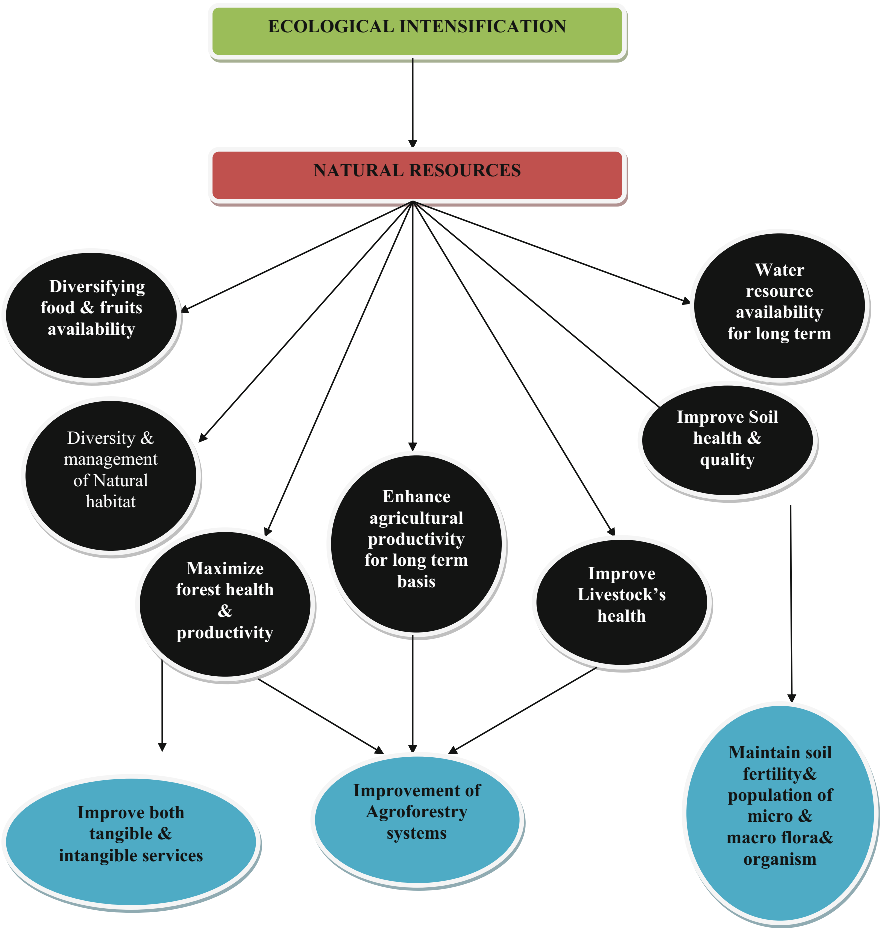

Fig. 5.3 Ecological intensification for natural resource management (Mao et al. 2015; Al-Kaisi and Lowery 2017)

land under the AI and animal intensification that also affects overall tree–crop–soil health and productivity.

In this context, both EI and SI prove themselves to intensify ES by enhancing tree–crop–soil productivity and biodiversity along with reducing GHGs by the practices of ecology based farming systems which are highly ecologically sustainable. Thus, a conceptual model was framed representing the role of EI and SI in agriculture practices for minimizing climate change impacts (Fig. 5.4, Burney et al. 2010). Therefore, various authors have proposed the significance of EI and SI into the agricultural systems, i.e. emphasizing on agro-ecological intensification (based on ecological principles) in terms of enhancing productivity and performance without disturbing environmental health that would lead to food and climate security at global scale. Further, they enhance biodiversity, improve soil fertility, maintain

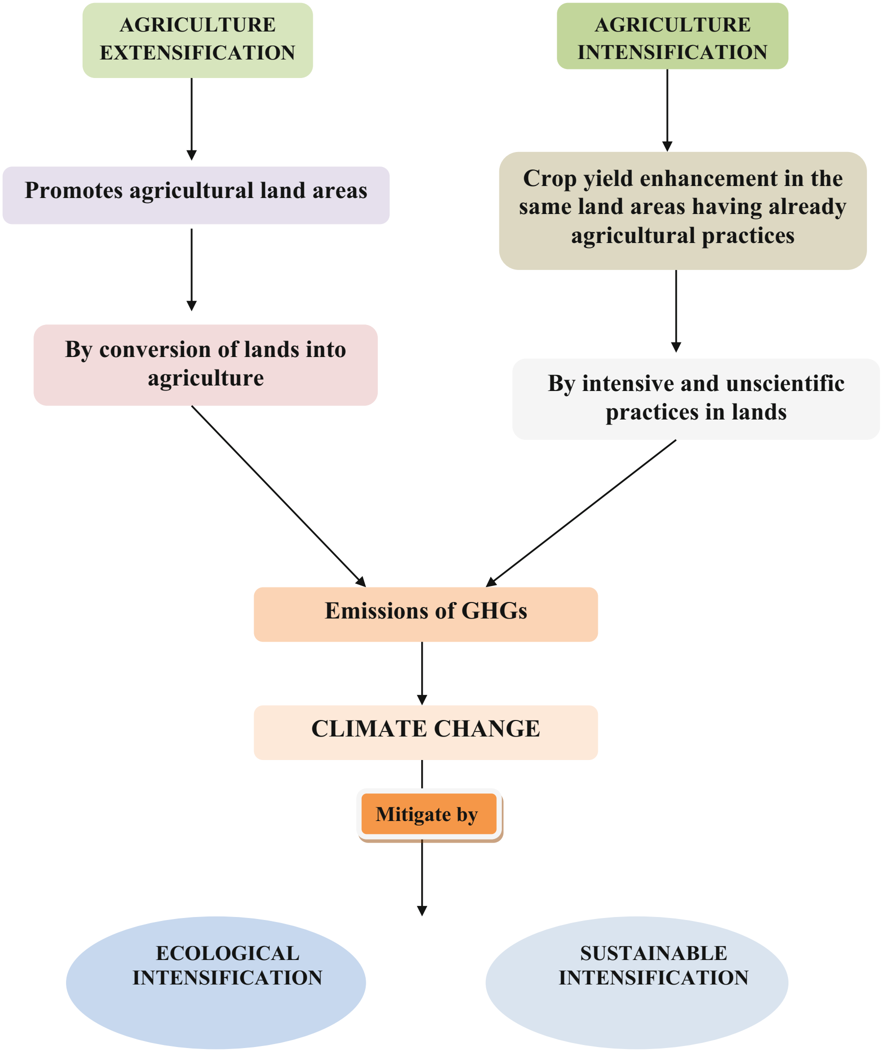

Fig. 5.4 Agriculture practices for climate change and its mitigation strategies (Burney et al. 2010)

soil heath and quality, promote material and nutrients cycling, minimize the leaching losses and soil erosion and RUE. It further increases carbon sink in vegetation and soils through carbon sequestration, optimizes water and nutrient use efficiency, improves socio-economic status of farmers, maintaining food and climate security for ecological sustainability (Milder et al. 2012; CCRP 2013; Dobermann and Nelson 2013).

Different types of practices adopted under EI and SI are described by different authors at various times. For example, the practices of crop rotations, proper soil mulching and better intercropping (Côte et al. 2010; Dobermann and Nelson 2013;

Haussmann 2011; Karamura et al. 2013; Milder et al. 2012; Ochola et al. 2013), conservation agriculture for integrated soil and nutrient management practices (Dobermann and Nelson 2013), practices for conservation of soil and water (Côte et al. 2010; Haussmann 2011; Karamura et al. 2013; Milder et al. 2012; Ochola et al. 2013), integrated pest management into the farms (Côte et al. 2010; Dobermann and Nelson 2013; Haussmann 2011; Karamura et al. 2013; Milder et al. 2012; Ochola et al. 2013), balance and control use of pesticides (Dobermann and Nelson 2013), organic based applications (Côte et al. 2010; Dobermann and Nelson 2013; Haussmann 2011; Karamura et al. 2013; Milder et al. 2012; Ochola et al. 2013) along with balance and less use of fertilizers in the farms (Dobermann and Nelson 2013), etc. are based on the principle of EI and SI.

5.6.2 Forestry

EI and SI are very good strategies which minimize the negative impact of AI by practicing EI and SI farming which helps in enhancing yield, productivity and ecosystem ES for betterment of our environment. However, many studies are available in this context of agriculture but more work needs to be done in the forestry sector in relation to EI. Forest is complex in nature in terms of structure, functions, rich biodiversity comprising of various life forms including woody perennial trees, smaller plants, understory, ground flora, lichens, fungi, animals and other beneficial soil microorganism. It is entirely complex and exchange of biological materials, its cycling indicates self-sustaining quality of forests (van der Plas et al. 2016). But due to rising populations, food requirement and other industrial development, leads to illicit felling of trees that affects whole ecosystem structure and function. In this context, the practices of EI and SI would be helpful in minimizing forest degradation by increasing biodiversity which intensifies ES. However, SI helps in promoting the concept of sustainable forest management by practices and management of ecology based multiple approaches (Jhariya et al. 2019a, b).

As per FAO (2016), exploitation of some woody and non-woody forest products contributes up to 50% of resource use. Although demand of wood and other products is increasing day by day which promotes plantation forestry around 7.3% of the forest globally (FAO 2016). In contrast, the biodiversity and delivery of ES from these plantation forests are very low due to dominancy and characterization of monoculture and sole tree plantation of some exotic species which significantly reduce the ES by less biodiversity and higher susceptibility of insect pest outbreaks (Dwyer et al. 2004; van der Plas et al. 2016). Similarly, the practices of less intensification in forest ecosystem (low-intensified forest management) have maximized biodiversity which delivers prominent ES along with economical and environmental benefits (Tscharntke et al. 2005). Therefore, intensification at certain level is of prime concern for healthy and diverse forest. Obviously, diversified forest promotes occurrence of variety of predators (small mammals, spiders, birds, etc.) and its populations which feed on harmful insect and ensure pest outbreaks prominently (Thompson et al. 2009). Similarly, diversified forest promotes the diversity of soil microbes, actinomycetes and fungal population in the soil which plays an important role in nitrogen fixation and efficient nutrient cycling. Hence, forest diversification enhances the productivity with low inputs (Hiiesalu et al. 2017). Therefore, intensification in forest must be framed and relies on the principles of ecological based approach which promotes biodiversity along with diversified products, improvement in tree–crop–soil health and productivity, reduces the chances of insect outbreaks and enhances ES for making ecological stability (Becerra et al. 2018).

5.6.3 Agroforestry

Agroforestry has various components (tree, crop and pasture/livestocks), structure and different location specific models which varies depending upon the biophysical status, topography and climates in the tropics. Agroforestry is a complex and sustainable farming system. Presently, intensive and unscientific practices and management along with improper understanding of tree–crop interaction affect the overall structure and function of different models of agroforestry which affects ES (Jhariya et al. 2015; Singh and Jhariya 2016). Therefore, EI and SI play a key role in maintaining structure and function (production and protection of tree, crop and soil) of agroforestry systems without affecting the environment and ecological sustainability. However, application of least fertilizers, incorporation of high vigour plant's variety, integration of multipurpose trees, effective soil management practices, etc. intensify the productivity and protection of model that not only enhance biodiversity (both vegetation and soil inhabiting microbes) but also promote ES, maintain FNS, reduce GHGs emission by better carbon sequestration potential for climate security. It also increases socio-economic status of poor farmers at global scale. However, a very little information was available in this context.

Studies of Egger (1986) help in understanding and exploring conservation and management of soils in pasture based agroforestry systems in the tropics. Similarly, Noponen et al. (2013) have conducted a research to evaluate and explore the trade-offs among EI, GHGs emission and profitability of agroforestry systems in the region of Costa Rica. According to them, the application of effective EI along with better management practices would help in enhancing carbon sequestration potential that mitigate the issue of changing climate. Also, it helps in bumper production of agriculture crops and reduces pressure of land conversion. However, there is a clear difference between agriculture and agroforestry intensification in which AI only helps in reducing emissions of GHGs. Intensification in agroforestry will not only mitigate climate change by GHGs emission but also build up higher crop productivity (Burney et al. 2010; Palm et al. 2010). Similarly, SI promotes both productivity and protection of agroforestry without compromising health and security of environment.

5.6.4 Soil

Soil is one of the key resources which hold and sustain various other NRs such as forest, agriculture and wildlife. Health and productivity of both plants and soils are maintained in two way direction such as tree and crops shed their leaves which decompose and add nutrients to the soils that improve soil fertility (better soil health and quality) (Raj et al. 2019a, b). In turn soils release these essential nutrients again to plants, i.e. plants absorb and fix into their body parts for metabolic activity that helps in maintaining proper growth and development of plants (better plants health and quality). These dual profits are proven to be a great link and synergy between them which is represented in Fig. 5.5 (Lal 2008; Pinho et al. 2012; Singh et al. 2017). But due to AI, unsustainable land-use systems, unscientific management of farming

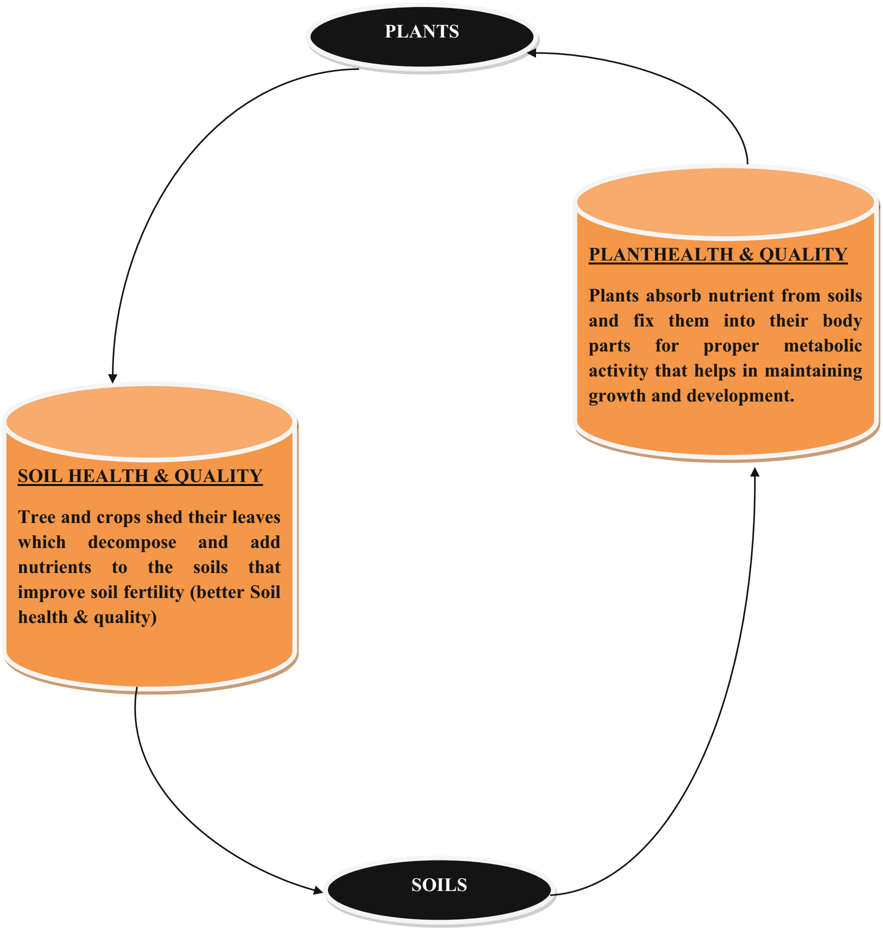

Fig. 5.5 Link between plants and soils in farming systems for better performance (Lal 2008; Pinho et al. 2012; Singh et al. 2017)

technology, use of heavy machine on farms, unstoppable use of inorganic fertilizers on farms, etc. affects health and quality of soils and disturbs related ES.

In this context, EI enhances the tree–crop and soil productivity without adding huge amount of fertilizers into the soil resulting in higher soil organic matter which improves soil microbial biomass and rhizosphere biology. Therefore, EI is used for maintaining soil organic matter which is a critical indicator of soil health (Bommarco et al. 2013). Good and effective management practices in farming systems are the basis for implanting EI. This would help in enhancing soil organic matter in the soils. Conversely decrease in organic matter would lead to loss of important microorganism in the soil that directly or indirectly affects sustainability of farming systems (Tsiafouli et al. 2015). Although enhancing soil ES is controlled by soil biodiversity that relies upon practices of effective EI which helps in controlling and maintaining decomposition and cycling of nutrients in farming ecosystems (Barrios 2007). Thus, strategies for increasing tree–crop diversification, incorporation of leguminous plants in rotation, less use of inorganic fertilizers along with minimum soil disturbance are covered under ecological intensive practices. It helps in building above and below ground biomass, enhances carbon values in both plants and soils and builds physico-chemical properties of soils without affecting overall productivity of the farming systems and degrading our environment (Kremen and Miles 2012; Brady et al. 2015; Jhariya et al. 2018a, b).

5.6.5 Livestock

Livestock maintains social, culture and economic values and plays major role in farming systems. It provides various products such as milk, meat, eggs, feather and other tangible food products. They maintain health and economics of peoples while integrating with farming systems. Integration of animals in agroforestry systems also helps in enhancing biodiversity of the systems but their management practices without affecting animal's health, crop productivity and livestock's potential to produce valuable products through the application of livestock intensification are less properly studied (Fahrig 2017). However, changing biodiversity of any farming systems relies on change in livestock's number too which overall affects the structure and services of the farming system. Therefore, biodiversity conservation is linked with occurrence of animal species and their interactive response to altered farming systems (Phalan et al. 2011; Paul and Knoke 2015). Thus, intensified livestock practices and its management are the important aspects of EI that not only enhance biodiversity but also increase productivity (tree–crop–soil) and profitability of farmers. In this context, Gomes et al. (2014) have studied the impact of EI approach in goat farming systems and made a design for sustainable livestock systems (Dumont et al. 2013) which is based on the five principles of agroecology. The principles include adoption of animal's health perspective management, less inputs for higher productions, minimizing pollution by optimizing different components of farming systems, promoting animal's diversity in the system and conservation of biodiversity in agro-ecosystems by adoption of scientific based management practices.

5.7 Constraint and Limitation in Intensification

EI and SI prove to be a good strategy in every aspects of use efficiency of NRs and intensify the ES for betterment of environment and ecological stability. But these have certain limitations and having hurdles while promoting at ground level to global scale. For example, burgeoning population demands for more foods, timber, fuelwood and other non-wood forest products that promote high input practices and illicit felling of trees for timber either directly or indirectly affects various natural ecosystems (forest, soils, water, etc.). In this context, using the principle of EI and SI would be the best option but they will affect the overall production systems. For example, we stress upon organic agriculture but "*is organic system of practices would satisfy the food requirements of people*?" This is a very conceptual question of today because high quantity of food and other products has to be intensified in agriculture and other farming systems which promote higher use of inputs in the farms. Therefore, adoption level of EI and SI by farmers in their land is questionable, although these strategies fulfil the needs at certain level. Secondly, the practices of EI having certain limitations due to carrying capacity of NRs, type of land, topography, soil types, tree–crop interaction, species natures, social, economics, farmers' attitudes for adoption and political aspects. Therefore, these measures play a major role in practices of EI and SI for NRs. Similarly, farmers and people awareness about significance of EI, farmer to farmer communications, institutional role in strengthening EI, effective policies for promotion and adoption of SI are the key points on which we have to focus while adopting and promoting EI and SI from ground level to large scale.

5.8 Ecointensification for Ecosystem Services

The EI approach in NRs is proven to be a good strategy for enhancing ES from forest, agriculture, soil and animal resources. They provide water and air regulation, soil fertility enhancement, biodiversity conservation and storage and sequestration of carbon, etc. Also, tangible (timber and non-wood products) and intangible services through forestry and agriculture food grains production are very important services that maintain FNS and environmental stability. Therefore, in this context a conceptual model has been developed which is depicted in Fig. 5.6 (Bommarco et al. 2013).

However, the practices of EI in both agriculture and forestry will promote the ES by enhancing biodiversity through mixed plantation, mixed crops and proper crop rotation. Monocropping and sole tree plantations/orchards having less diversified plants that is poor in delivery of various important ES in both direct and indirect ways and highly susceptible to insect pest attacks. For its manipulation, making more diversified form of forestry and agriculture by incorporating middle and

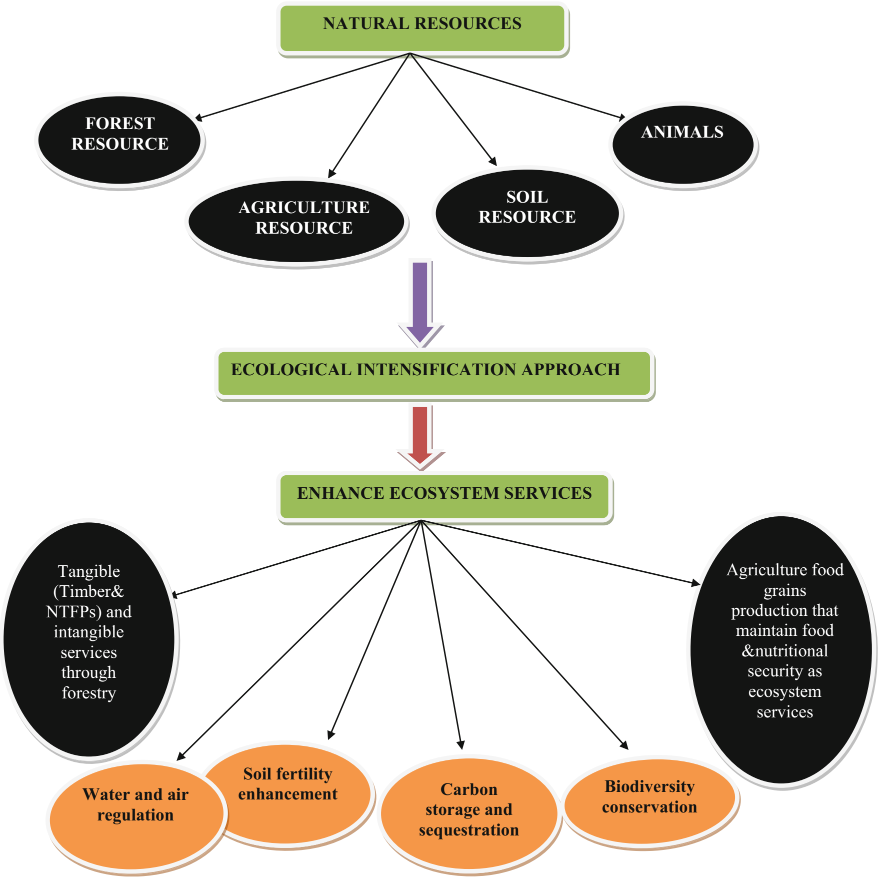

Fig. 5.6 Ecological intensification in natural resources for ecosystem services (Bommarco et al. 2013)

understory plants as mixed plantation and cropping systems would be more significant in delivery of ES. This would promote increasing biodiversity, higher productivity, soil water conservation (understory plants reduce the soil and water erosion problems), soil fertility enhancement, less catastrophic disturbance and stabilization of ecological systems and improving micro-climate of whole systems in particular areas. In this context, a model has been developed for diversified agriculture and forestry plantation and its diversified ES through application of mixed cropping and mixed plantation concepts which is depicted in Fig. 5.7 (Montesinos 2019).

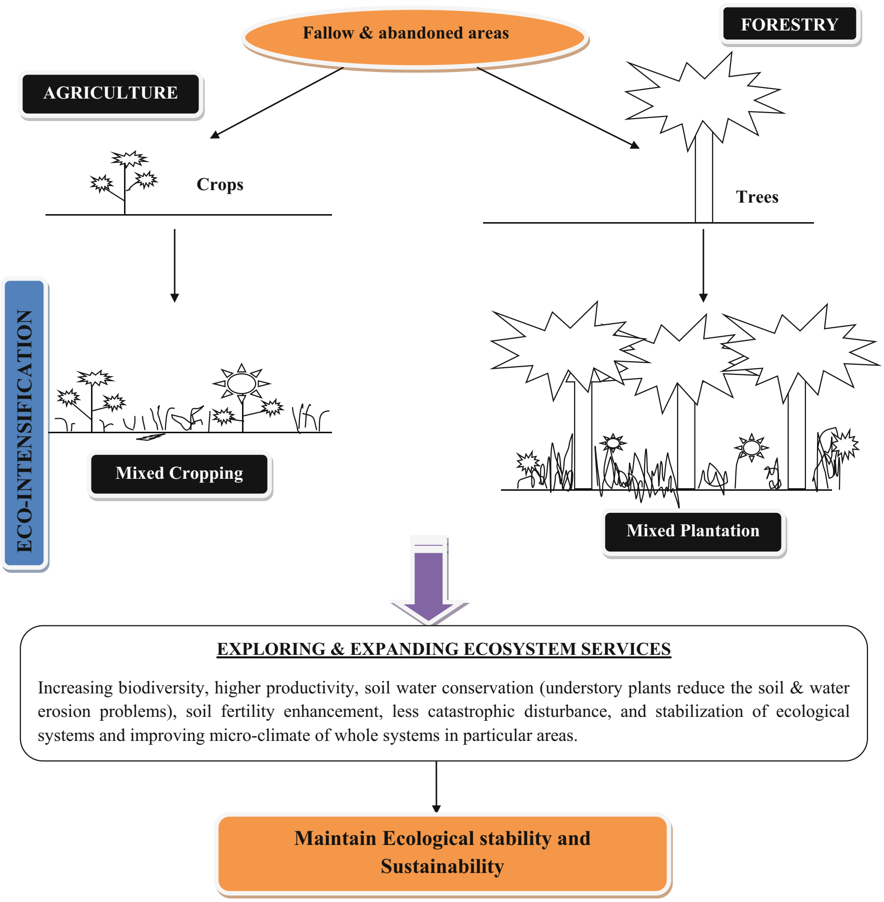

Fig. 5.7 Ecological intensification in agriculture and forestry for ecosystem services (Montesinos 2019)

5.9 Ecointensification for Food Security

Food security and its sustainability are becoming global issues in national and international scientific platforms due to speedy population growth causing hunger and malnutrition problems in these days. Hunger and malnutrition are the major challenge today and it will affect global FNS. In this context, the adoption of some ecological and social approaches is proven to be good strategies for minimizing global hunger and malnutrition problems and makes the availability of quality and nutritious food to the society. Ecological approach comprises both EI and SI. Application of better ecological approach for healthy crops and food grains is achieved by EI. Conversely SI promotes balance production with proper input–

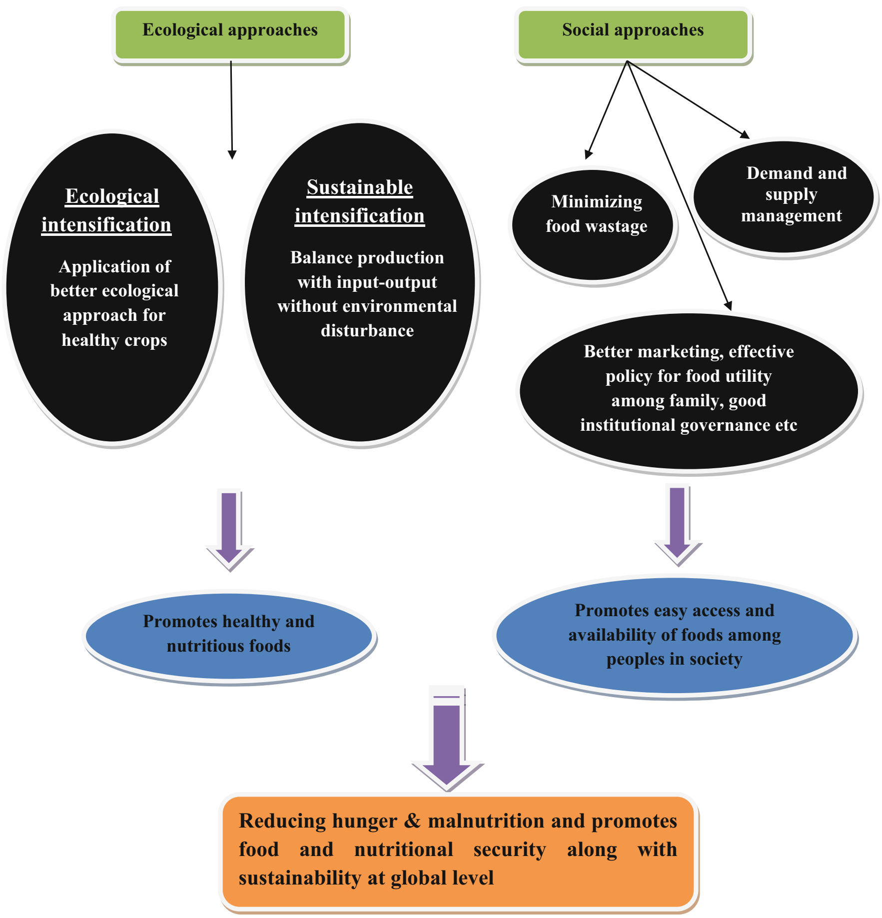

Fig. 5.8 Ecological and social approaches for food security (Garnett and Godfray 2012; Bilali et al. 2019)

output mechanism without environmental disturbance. However, better marketing, effective policy for food utility among family, good institutional governance, minimizing food wastage and demand and supply management are the other strategies that follows social approaches to promote easy access and availability of quality and nutritious foods among peoples in society. Thus, it will be helpful in reducing hunger and malnutrition and promotes FNS along with sustainability at global level. In this context, a model is developed which is depicted in Fig. 5.8 (Garnett and Godfray 2012; Bilali et al. 2019) (Table 5.3).

SI in farming systems produces sustainable production which results in sustainable diet and promotes food system transformation which maintains FNS at global scale. However, FAO (2012) has stressed upon considerable extent of intensification are required for better production that would help in meeting global food demands

Table 5.3 Indicators used for sustainable intensification in agriculture and other farming system in the world

Area of study	Primary and secondary indicators	Total number of Indicators	Source
Indicators of sustainable intensification for small land holding farming systems in the African continent	Primary indictor includes "productivity" for this secondary indicators are efficiency of external inputs and available water along with yield and livestock's health and productivity	57	Smith et al. (2017)
	"Economic balance and stability" were considered as primary indicators, whereas secondary indicators include value of tree–crops and income through agriculture/farming practices		
	Primary indictor includes "environmental stability", whereas secondary indicators consisted of existing biodiversity, carbon storage and sequestration potential, soil–water conservation, soil health and quality, nutrient dynamics, etc.		
	Primary indictor includes "social sustainability", whereas related information acquisition is considered as secondary indicator		
	Human well-being is considered as primary indicator and secondary indicator included food and nutritional security		
Indicators of sustainable intensification for agricultural systems practices in United Kingdom	"Resource unit" is represented as primary indicator for this tree–crop diversity, water table, livestock's population, soil types and biodiversity are considered as secondary indicators	110	Mahon et al. (2018)
	"Resource systems" is represented as primary indicator, whereas total farm size, land holding areas, tree–crop productivity, etc. are		

(continued)

Table 5.3 (continued)

Area of study	Primary and secondary indicators	Total number of Indicators	Source
	considered as secondary indicators		
	"Resource users" is treated as primary indicator, whereas secondary indicators included farmers housing, their age and social networks, employment status, etc.		
	Primary indicator is designated to the term "interaction" for that status of tree–crop–animal interaction, farming quantity, type of mechanization, livestock's rearing, land characteristics and level of farming technologies are considered as secondary indicators		
	"Outcomes" is a very important primary indicator for that yield potential and gaining income from tree–crop systems, GHGs emissions, pollution from agricultural practices, resource use efficiency, farmer welfare, land characteristics, etc. are treated as secondary indicators		
	"Environment" is considered as primary indicator, whereas secondary indicator included occurrence of extreme weather, price of products, competition in varying farming systems, credits, characteristics of consumers and fund amounts, etc.		
Indicators of ecological intensification for coconut based farming system in Brazil	Primary indicator is "landscape ecology", whereas ecological stability, natural locality/habitat, environmental quality, risks and production status with its diversity are considered as secondary indicators	62	Stachetti and Roberto (2018)
	"Social and cultural status" are considered as primary indicators for this gender		

(continued)

Table 5.3 (continued)

Area of study	Primary and secondary indicators	Total number of Indicators	Source
	quality, educational and employment status, public services, standard of varying consumers, natural heritage and health, etc. are considered secondary indicators		
	"Environmental quality" is considered as primary indicator, whereas secondary indicator includes soil and water quality along with level of GHGs emission, etc.		
	Primary indicator is "economic value", for this secondary indicators are land value in money, source and distribution of income, net income value, debt and housing value, etc.		

up to 2050. FAO (2017) believes on the practices of intensification that enhances diversification of agriculture productions meeting the food demands and maintains FNS at global scale. According to this organization, the practices of SI would help in improving both productivity and ecological sustainability, i.e. food and environmental security by enhancing crop diversity and ES. Although FNS is linked by a broad spectrum of soil quality, climatic situations, socio-economic and political aspects that guarantee SI at large scale (CIRAD 2016). However, food wastage reduction and its proper management are also good strategies covered by SI which enhance the availability of food to people at door steps and helps in achieving FNS by improving food chain efficiency and ecological sustainability (FAO 2011; Waste and Resources Action Programme 2011).

5.10 Ecointensification for Climate Change Mitigation

Today, intensification of agricultural for higher yield and conversion of lands into agriculture (agricultural land expansion) lead to emission of several harmful GHGs that causes global warming and climate changes. Both AI and expansion of agricultural area are the major hurdles towards environmental security and ecological stability. However, both extensification (promotes agricultural land areas) and intensification (crop yield enhancement in the same land areas having already agricultural practices) enhance agricultural productivity but at the cost of our environment due to GHGs emissions and in turn these harmful gases affect all plants, animals, soil and other NRs. In this context, EI and SI will be good strategies which not only help in reducing GHGs emission but also enhance the tree–crops–soil productivity by better ecology oriented and scientific based farming practices with better management. This would help in mitigating climate change and global warming problems at global scale (Burney et al. 2010). The practices of climate-smart agriculture, conservation agriculture, no-tillage practices, organic farming system, mulching practices and integrated farming practices, etc. would help in minimizing deleterious impacts by reducing GHGs emission without affecting the overall yield and productivity of plants.

5.11 Ecointensification for Resource Use Efficiency

Resource and its sustainable uses are having prime importance as they show significant promise towards ecological stability that maintains ecosystem structure and functions along with better delivery of ES. However, unsustainable way of production, deforestation, intensive farming and animal intensifications in farms will affect various resources and their potential of RUE. For example, AI affects the status and availability of nutrients and water in the soils which in turn influence the plant potentials of nutrient and water use efficiency. In this context, EI and SI are gaining wide recognition by making great emphasis to increase soil organic matter, promote nutrient availability, water efficacy, enhance microbial populations along with its plants capacity to utilize all these resources for their proper metabolic activity, growth and developments (Struik and Kuyper 2017). However, intensification promotes unstoppable use of resources, i.e. resource mining in depth that affects overall resource use and its efficiency which is studied at various aspects such as agronomy, socio-economic and environmental aspects. As per Foley et al. (2011), RUE will increase on decreasing NRs that would necessitate targeting more production on even similar amount of inputs. Therefore, many researchers related to this field are having a great conception on EI and according to them, EI and SI are win-a-win strategies which help in increasing tree–crop–soil productivity along with improving and promoting RUE and avoiding from expansion of farming land. Similarly, we can minimize the impact of intensive agricultural practices on our environment by reducing the overuse of inorganic nutrient fertilizers (Mueller et al. 2012).

5.12 Research and Developmental Activity

The intensification in NRs such as agriculture and forestry are not recent practices, it was taken into account from the past when population growth caused food, timbers, fuelwood and other resource depletion. This necessitated intensifying the farming systems by promoting higher synthetic inputs. In past, we have focused only on crop intensification in terms of productivity rather than focusing on other resources such as soil, animals and environment. Research was conducted only in unidirectional approach rather than multidirectional approaches. For example, intensifying crop productivity will always decline the health and fertility status of soil. Further, while approaching economic target we overlooked the ecological sustainability. Therefore, R&D must be framed to balance between economic, ecology and sustainability.

Although in recent past, various R&D were conducted in minimizing the deleterious and negative impacts on our environment and ecosystem from AI but results were not satisfactory due to population rise resulting in higher food demands which were controlled by only unscientific way of AI. Therefore, we intensify only crop productivity rather than development and management of other resources. But in this context, the practices of EI and SI make a harmony with nature by minimizing higher use of synthetic inputs, enhance biodiversity, improve tree–crop–soil productivity and overall intensify ES along with making ecological sustainability. Now a good research has been approved in this context of understanding a difference between EI and SI, exploration of multifarious significant benefits of both EI and SI in NRs management, resource utilization and related RUE.

R&D must emphasize on varying models of intensification according to farming systems prevailing in varying climate, soil types, water availability, socio-economic and political situations in any regions. Moreover, public investments, effective policies, research institute, governmental institution, non-governmental organization and public–private partnership play important role in knowing, understanding and raising awareness among people and farmers for adopting EI and SI. This would lead to betterment and development of our environment and maintenance of ecological stability (Tittonell 2014). Thus, a conceptual model must be developed through better R&D which reflects its significance and multifarious benefits in NRs management and its efficient uses in the ecosystem for maintaining ecological sustainability.

5.13 Policy Framework

Indeed, the EI and SI have proven itself as win-a-win strategy for reducing negative impacts on tree–crop–soil productivity, enhance RUE and intensify ES by enhancing biodiversity. But certain existing policies are not appropriate for promotion and awareness of EI among farmers and people. They have less knowledge and awareness about significant effects of these two types of intensifications in NRs management and related positive impacts on our environment which maintain ecological stability. In this context, many policymakers, academicians, scientists, researchers, consumers and farmers have emphasized on promotion from conventional intensification to ecological and sustainable intensification (Cui et al. 2018). However, policy must be enacted and framed for promoting various multiple indicators/dimensions which are typically used for application of EI in sustainable tree–crop–soil production systems. These various multiple indicators/dimensions are (i) biomass, carbon and microbial diversity on above and underground, (ii) long term delivery of ES, (iii) availability of water resources and use efficiency, (iv) minimizing synthetic inputs, (v) agricultural productivity for long term in sustainable basis, (vi) diversification of natural habitat, (vii) training for farmer's

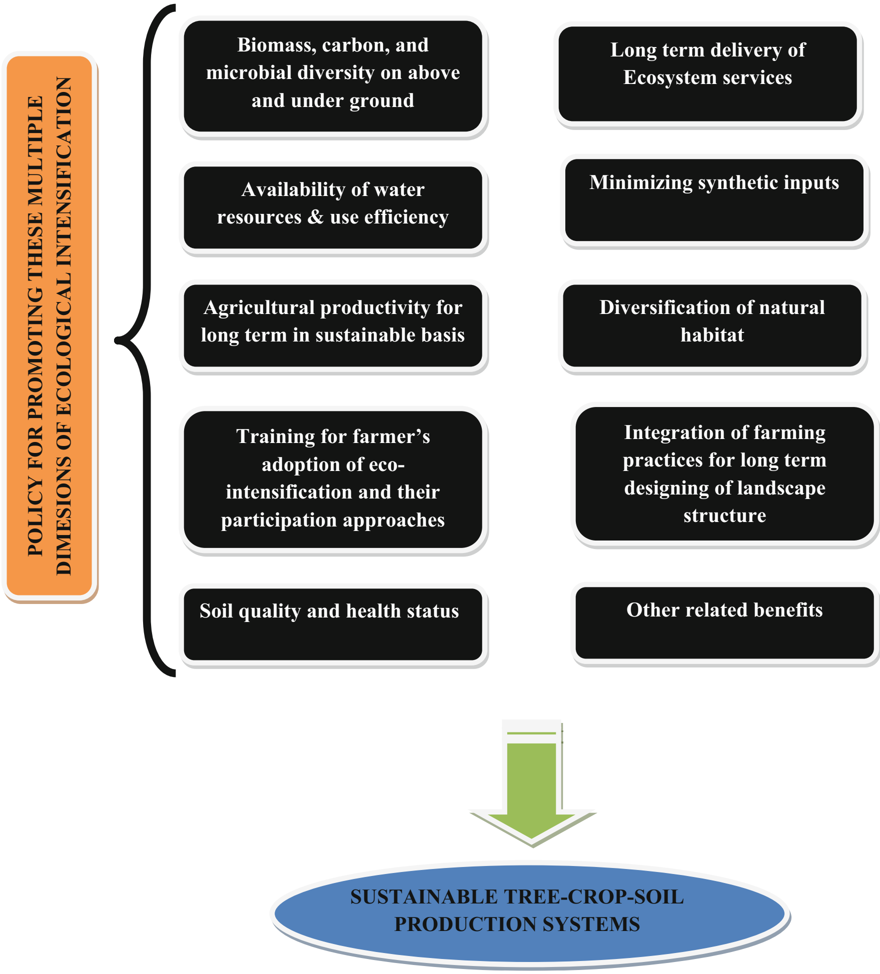

Fig. 5.9 Policy for sustainable tree–crop–soil production systems through ecointensification by considering multiple dimensions (Gemmill-Herren et al. 2019)

adoption of EI and their participation approaches, (viii) integration of farming practices for long term designing of landscape structure, (ix) soil quality and health status and (x) other related benefits. Therefore, policy for sustainable tree–crop–soil production systems through ecointensification by considering multiple dimensions is required and mentioned in Fig. 5.9 (Gemmill-Herren et al. 2019).

5.14 Conclusion

It is clearly understood about EI and its multifarious role in improvement of tree–crop–soil productivity by enhancing biodiversity and intensifying ES along with less use of synthetic inputs and farmland expansion. Although both EI and SI have blurred boundary but they are gaining popularity due to suppressing the deleterious impact of AI and having efficient output. Therefore, EI and SI are proven to be good strategies in agriculture and forestry by application of climate-smart agriculture, conservation agriculture, no-tillage practices, crop rotation, multiple cropping, mixed cropping, etc. that increase yield, improve soil fertility, maintaining people health through quality food and nutrient rich fruits, maintain food and climate security by minimizing climate change impacts. Also, policies must be in the frame of promotion of ecologically based intensification in agriculture and forestry that should buffer negative impacts on both plants and environment, also promotion of farmers for adopting these strategies in their farms which should be socially acceptable, economically viable and ecologically sustainable.

5.15 Future Roadmap

The EI and SI have a blurred boundary which indicates their significance, positive impacts and multifarious benefits in terms of plants productivity by enhancing biodiversity at various scales. No doubt, EI has intensified ES and provides various tangible and intangible products from agriculture and forestry and related other NRs (soil and animals, etc.) along with minimizing emission of GHGs and maintain climate and food security at global level. Therefore, EI and SI both are having bright future and are gaining popularity among farmers, scientists, policymakers and other stakeholders due to significant effects on maintaining food security, tree–crop–soil productivity, water security, better RUE, climate security through minimizing GHGs emissions, livestock intensification and other ES. Thus, we cannot overlook the significance of EI and for the further development a roadmap must be synthesized for adoption and prevalence of intensification at local to global scale.

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