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GLOBAL AGRICULTURAL LOSSES AND THEIR CAUSES

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Abstract *Various biotic, abiotic, and anthropogenic factors are causing enormous food losses. The burgeoning human population demands more food. However, scarcity and unavailability of natural resources occur globally. Major factors causing these losses include pests, diseases, pathogens, climatic changes, salinity, drought, loss of arable lands, and weeds. Post-harvest losses also playing a devastating negative role in global food losses. Inadequate use of resources leads to the exploitation and loss of arable land. Currently, 38% of losses to agriculture are solely caused by insect pests, while 34% are due to weeds. Abiotic factors account for more than 50% of agricultural losses. Arable land is decreasing day by day due to increased urbanization and industrialization. Climate change also potentially decreases 10-25% of agricultural productivity and is forecasted to cause more within the next 50 years. All these problems are worse in underdeveloped countries due to uncontrolled measures and lack of awareness among the community. It has been reported that the human population will increase to 11 billion within the next 80 years; it is crucial now to minimize these losses to ensure food security and sustainable development. Food losses need to be minimized by considering the current scenario and need to devise appropriate strategies to enhance food production by exploiting minimum natural resources. The focus of this review article is to convey reasons for food losses worldwide and the depletion of natural resources to the research and the farming community so that appropriate methods for food security and sustainability be devised and implemented.*

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Introduction

Agricultural losses have threatened the food security and well-being of the farmer's and trader's economy (Avelino et al., 2015). Agricultural losses reduce food availability for global use, cause damage to the economy, and environment, and waste natural resources used in their production (Vermeulen et al., 2012). According to Food and Agriculture Organization (FAO), approximately 1.3 billion tons of food is wasted yearly (Gustavasson, et al. 2011). Food wastage can be quantitative or qualitative and occur due to attacks of pests, mites, rodents, chemical or composition changes, and mycotoxins. It is estimated that 1.2 billion people worldwide are food insecure, and food losses limit the income of small-hold farmers by a minimum 15% (Brown and Halweii 1998). These food losses exploit 1/4th of the entire world's fresh water and 1/5th of the total arable land; if this scenario goes on, it will cost 83$ billion/year to meet the food demand (Hodges et al., 2011). Various factors are contributing to crop losses i.e. biotic factors (animal-pests, diseases, pathogens, and weeds), abiotic factors (lack of water, salinity, temperature fluctuations, radiations, and nutrients), and anthropogenic factors (Fig 1). More than 50% of global yield losses of economically important crops are caused due to abiotic factors (Oerke, 2006). Due to global warming and climate change, an increased amalgam of biotic and abiotic adversities, causing acute crop effects and yield losses (Pandey et al., 2017). Contingency and escalation of weeds, pathogenic organisms, and insects are impacted of abiotic stress factors like drought and temperature fluctuations (Peters et al., 2014). These factors also influence minor insect pests, making them more harmful (Duveiller et al., 2007). Attack of pests and insects can occur on agricultural land (pre-harvest), or after the harvest (post-harvest). Crop quality tends to decrease, and production is hindered due to these factors (Savary et al., 2006). Financial outcomes are also adversely affected by these losses, while buyers also look forward to better quality, and low-quality or affected products lose their worth in the market (Nutter et al., 1993). Furthermore, all the societies, including rural communities, local and international markets, traders, and exporters, are affected by the losses caused by the factors mentioned above. Above all, food security for the world's population is affected. Data assessment of overall losses is still scant, and efforts to evaluate losses and their causes are not up to the mark (Avelino et al., 2015).

Weeds and invasive plants are also potential threats to agriculture (Clark et al., 1998). Weeds are more harmful than pests, and all weed species have different competitive abilities (Milberg and Hallgren, 2004). Weeds cause 34% of the global agricultural potential loss compared to animal pests and pathogens (18% and 16% losses) worldwide (Oerke, 2006). Pathogens also play a detrimental role in decreasing global crop productivity. Losses caused by pathogens can be direct or indirect and have variations in their consequences. Pathogens collaborating with animals and weeds are responsible for 20- 40% of total agricultural productivity losses (Savary et al., 2012). Abiotic factors like salinity, drought, and heat are important factors that hinder agricultural production. Dry periods are increasing daily, and salinization affects about 50% of the world's irrigated land, which can be one-third of the world's food (Hu et al., 2005). Drought affects the transpiration rates and uptake of nutrients by the plant through its roots and shoots (Alam, 1999). Climate change influences agricultural production through increased temperatures, altered precipitation, changes in atmospheric CO_2, extreme events, and rising sea levels (Wheeler et al., 2013). Rising temperatures, fluctuations in the global climate, and changing weather patterns greatly impact crop production as plant growth and development are influenced (Barnabas et al., 2008). The agricultural productivity of poor, underdeveloped regions is likely to fall 10-25% by 2080 (Mahato and Anupama, 2014). Inappropriate human interventions also threaten Agricultural sustainability. It is important to increase food production, but more importantly, scientists suggest that reducing food waste would be a better strategy for the global food security and sustainability of the planet (Papargyropoulou., 2014). Globally, food losses relate to the modes of harvesting, storage, and packing; due to less technology and educational awareness, food loss starts from the farm in developing countries, whereas in developed countries, food loss occurs at the edge of consumer's end (Beretta et al., 2013). Farmer education, awareness, better infrastructure for storage, and the development of better market mechanisms are the best strategies for reducing food losses in developing countries (Hodges et al., 2011). Reducing food wastage, particularly in developing countries, will promote sustainable development (Thi et al., 2015). About 30% of the total production could not reach consumers due to wastage at different stages of production and supply (Kc et al., 2016). In this paper, the main causes of global food losses and their impact on agriculture have been briefly summarized. Short overviews of all the main issues plaguing agriculture are outlined, and some are explained in detail. Primary focus of this review article is to convey reasons for food losses and the wastage of natural resources to the research community so that appropriate food security and sustainability methods can be devised and implemented.

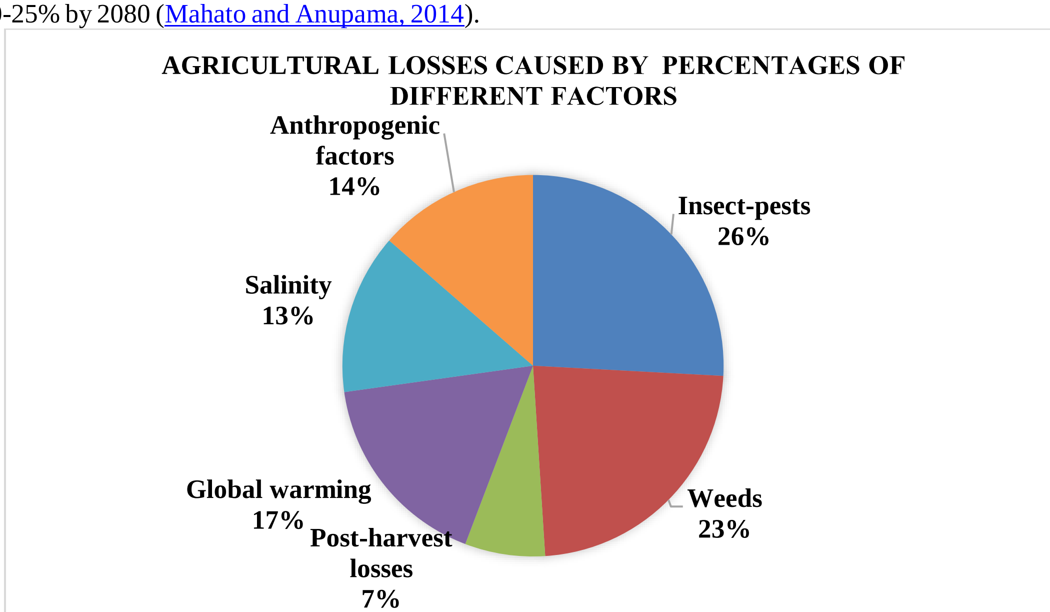

Fig 1. Agricultural losses along-with their causing factors are shown.

1. Biotic factors

We grouped the main biotic factors (Fig 2) that are responsible for global agricultural losses into the following categories:

a) Insect-Pests and Pathogens

Pest-induced losses are emerging as a major component in the global decline in crop yields, and the agricultural industry is battling slow but steady economic setbacks linked to diseases and pests (Mahato and Anupama, 2014). It is difficult to assess the total damage caused by insect pests globally

(Culliney, 2014). According to current estimations, insect pests account for 38% of all agricultural losses (Cerda et al., 2017). Furthermore, 270,000 km2 of land is lost to desertification or deforestation because of crop growing, and the use of pesticides and fertilizers accounts for around one-third of greenhouse gas emissions worldwide (Vos et al., 2014). Agricultural losses caused by insect pests are directly associated with the farming systems adopted by the farmers, their economic condition, and their adaptability to advanced technology. Developed countries have a strong system of checks and balances for insect pests and can estimate their losses (Yudelman et al., 1998). Damages caused by pests are much lower in naturally occurring ecosystems, as most pests require host plants for feeding and lifecycle, so their outbreak is serious and frequent in our ecosystem. Over the past few years, population increase has caused intense agriculture, and as a result, the losses linked to pests have greatly increased (Arora and Dhaliwal., 1996). Minimizing the losses caused during the pre-harvest phase is associated with pests, and it will cause improvement in agricultural production and sustainable development (Anonymous, 2016). World is facing serious scarcity issues in this area, and it is quite surprising that one-third of the world's agricultural production is wasted due to the harmful effects of animal pests and different diseases. An estimated 18–20% of the world's yearly crop production, worth over US $470 billion, is destroyed by arthropod pests (Sharma et al., 2017). In addition to being expensive, the precautions taken to stop them from attacking also pollute the environment, which increases the financial burden (Mahato and Anupama, 2014). Pests are responsible for 7.7% of crop output losses in Brazil, according to Oliveira et al. (2014).

Crop losses threaten rural households' well-being, wealth, and food security. They also strain governments' and traders' overall economies (Savary and Willocquet, 2014; Avelino et al., 2015). At the national and regional levels across several continents, significant crop losses attributed to pests and diseases were estimated to range between 20–40%. These losses affected important food and cash crops, including rice, wheat, barley, maize, potatoes, soybeans, cotton, and coffee (Oerke, 2006). Attacks by pests and diseases can happen either in the post-harvest storage phase or throughout the production cycle (pre-harvest). There may be a decline in the crop product's yield and quality during the pre-harvest and post-harvest phases (Savary et al., 2006). Lower financial returns, less productive work, and decreased quality for consumers are the outcomes of this decline (Nutter et al., 1993). Furthermore, agricultural losses have far-reaching effects that go beyond specific farms. Reduced output can potentially affect whole rural communities and regions, impact exports and national markets, and, on a larger scale, threaten the world's food supply.

b) Weeds

Weeds are deemed undesirable, unsuitable, hazardous, and unwelcome plants. They are usually identified by their fast growth, particularly when they are C_4 fast-growing plants. As they compete for vital resources like space, air, CO_2, water, light, and moisture, their rapid growth presents a serious threat to the economic success of a variety of crops, including vegetables, cereals, sugar crops, fiber crops, and floricultural crops (Leghari et al., 2015). Weeds are more harmful to agricultural output than pests and diseases in various situations because of how quickly they develop. Weeds have a significant potential to result in crop losses in addition to abiotic causes (Oerke, 2006). Weeds compete with economic crop production for essential resources like water and fertilizers, significantly impacting agro-biodiversity, yield, and quality while raising the overall cost of production (Zimdahl, 2018). Bhan et al. (1999) reported that approximately 31.5% of agricultural production losses can be attributed to weeds. Given the diverse weed species in natural ecosystems, each possessing varying competitive abilities, estimating crop losses specifically attributable to a single weed type is challenging. Hence, losses are often measured as the cumulative impact of all weeds. Globally, weeds are responsible for about 34% of agricultural losses, surpassing the 18-16% losses caused by pathogens and pests (Gharde et al., 2018). Milberg and Hallgren (2004) highlighted a 31% reduction in cereal production due to the competition between main crops and weeds. In rice cultivation, weed-related losses are more severe than those caused by pests, accounting for 60-70% of yield reductions. Additionally, oilseed crops suffer substantial yield losses ranging from 27-77% due to weed infestations (Leghari et al., 2015).

Food losses from weeds have been reported in Northern and Central America for various crops; one such instance is the loss of 148 tons of corn, or 50% of the grain produced in the United States. This crop loss caused a direct economic loss of 26.7 billion USD due to weeds (Soltani et al., 2016). Weeds significantly reduce the amount of food plants can access, which lowers crop yields because plants find it more difficult to absorb nutrients and meet their energy needs. Weeds have an especially negative effect on plants during important growth times by competing with plants and taking resources from the soil (such as moisture and minerals) and environment (such as light and air). This negatively impacts plant growth and lowers output/yield (Leghari et al., 2015). Weeds are difficult to control as they multiply tremendously, and thousands of seeds are produced from a single plant (Anderson 1983).

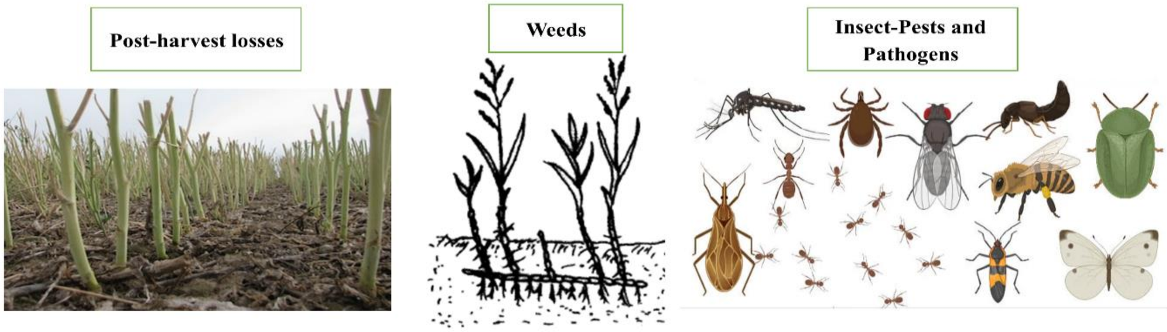

Fig 2. Major biotic factors contributing in agricultural losses

c) Post-harvest losses

We can define post-harvest losses as the measurable quantitative and qualitative losses happening from the time of harvest till its end uses (Hodges et al., 2011). Several causes participate in post-harvest losses i.e. micro-organisms, rodents, birds, bio-deterioration, and improper handling. Internal factors causing decay include stresses, changes in composition, physiological disruption, rooting, and sprouting (Bartz and Brecht, 2002). Main factors that cause food losses include handling, processing, weather, management and production practices, transportation, food grading, consumer's thinking, and availability (Aulakh et al., 2013). Quality deterioration especially occurs due to inadequacy in handling i.e. changes in protein, fats, mycotoxins, parts of insects, or their excrement also contribute to damage. Hence, when quality decreases, food becomes unhealthy for consumption and is ultimately rejected (Aulakh et al., 2013). Due to inappropriate traditional storage practices, about 20-30% of losses occur to staple crops in developing countries due to insect pests and grain pathogens during storage (Tefera et al., 2011). Post-harvest losses are significantly influenced by season and commodities. Many vegetables and fresh fruits that are more perishable are discarded or not used, causing 20% of food-service losses. In developing countries, up to 50% of losses occur after crop harvest. Roughly one-third of the global vegetable and fruit products are not consumed by humans (Kader, 2004). In developing countries, approximately 90% of the losses occur within the food supply chain; it directly affects poor consumers by increasing prices, reducing nutrition, and causing unavailability. Crop losses to biotic and biotic factors reduce food production and availability. Developed countries are less prone to agricultural losses than underdeveloped countries (Hodges et al., 2011). This is due to the lack of techniques and services in handling, packing, and storing perishable materials, as well as on-farm practices of storage and movement of products from the field to the market, which are inadequate. The lack of proper storage and transportation facilities is a major cause of deterioration in developing countries. Various studies have found that about 30-40% of fruits and vegetables are wasted during transportation till the end customers. These losses occur at different stages i.e. harvesting, consumer packaging of products, markets, and delay in appropriate handling (Kitinoja et al., 2011).

2. Abiotic factors

Main abiotic factors (Fig 3) that are considered for the decline in agricultural production are explained below:

a) Global warming

Climate change is a sustained alteration in the statistical distribution of weather patterns over an extended period, ranging from decades to millions of years. It impacts agro-ecosystems by inducing long-term changes in crucial variables that influence plant growth, such as rising temperatures (Lorenzoni et al., 2006). The ongoing process of global warming contributes to increased atmospheric CO2 levels, leading to reduced available land and diminished quality (Peters et al., 2012). Projections indicate that agricultural yields and productivity will decline by 3-16% by 2080. Underdeveloped, economically challenged countries, which already experience higher average crop temperatures, are expected to face a more substantial decrease in agricultural productivity, ranging from 10 to 25% by 2080. In contrast, well-developed countries with lower average temperatures are projected to experience a more modest decline in yields, varying from an 8% expansion of productivity to a 6% decline by 2080 (Mahato and Anupama, 2014).

Various effects are caused by climate changes i.e. changes in CO_2 levels, variability in sea levels, fluctuation in precipitations, and continuous higher temperatures (Wheeler et al., 2013). Changes in precipitation patterns increase the likelihood of short-run crop failures and long-run production declines. Although there will be gains in some crops in some regions of the world, the overall impacts of climate change on agriculture are expected to be negative, threatening global food security. The agriculture sector is widely contributing to the changing climate patterns and is most affected by these changes, as only the livestock industry is responsible for 5-10% of global warming (IPCC 1996). Increasing depletion of the underground aquifers, continuing loss of farmland due to urbanization, and increased drought and flooding are due to climate change (Schuster and

Torero 2016). The impact of global warming on crop yields will decrease productivity immediately, as weather changes in most of geographic regions will increase their average temperature, reducing the proper sowing and maturing timings of crops.

b) Salinity

All soils include naturally occurring salts, many of which serve important functions as necessary and advantageous nutrients that raise agricultural output. But, when salt concentration in the soil rises above a certain point, it can affect crop quality and yield. The effect of excessive salts on soil efficiency depends on the kind and amount of salt found in a given soil and environmental variables. Saline soils have an overabundance of salts, which might reduce their efficacy (Qadir et al., 2000). A serious and increasing danger in most parts of the world is salinizing arable lands (Al-Karaki, 2006). Several crops worldwide are delicate towards salt stresses and show low productivity. Globally, water used for agricultural production is mainly saline. About 7% of the total land is subjugated by salinity, and expansion of salinity-affected lands will contribute to a 50% loss to arable land until the middle of the 21st century (Evelin et al., 2009). About 96% of sea-water and ground-water is saline, so there is only a small fraction of fresh water; one-third is only fluid fresh available water. Salinity-related agricultural losses are predicted to cost the world economy $12 billion annually (Pitman and Lauchli 2002). A significant problem is the salinization of irrigated land; globally, 17% of cropland receives irrigation, accounting for up to 30% of total agricultural output (Hillel, 2000). Soil salinity is of high importance for agricultural production. It has been reported that 77 million hectares of land is affected by the salinity problem (Sheng et al., 2008). Excessive use of fertilizers, chemicals, over-exploitation of available water, and use of irrigation water with soluble salts resulted in elevated soil salinity levels (Al-karaki, 2006). Salinity affects growth and crop establishment, causing productivity losses (Mathur et al., 2007). Salts cause physiological drought by reducing osmotic potential, resulting in the plant's unavailability of water (Jahromi et al., 2008). Extravagant amounts of Na and Cl in the cell cause toxic effects i.e. interruption of macromolecules and enzyme activities, causing damage to the plasma membrane, cell organelles, and respiration process (Evelin et al., 2009). Plants are also affected by ionic deficiencies and nutrient imbalances due to saline soils (Adiku et al., 2001).

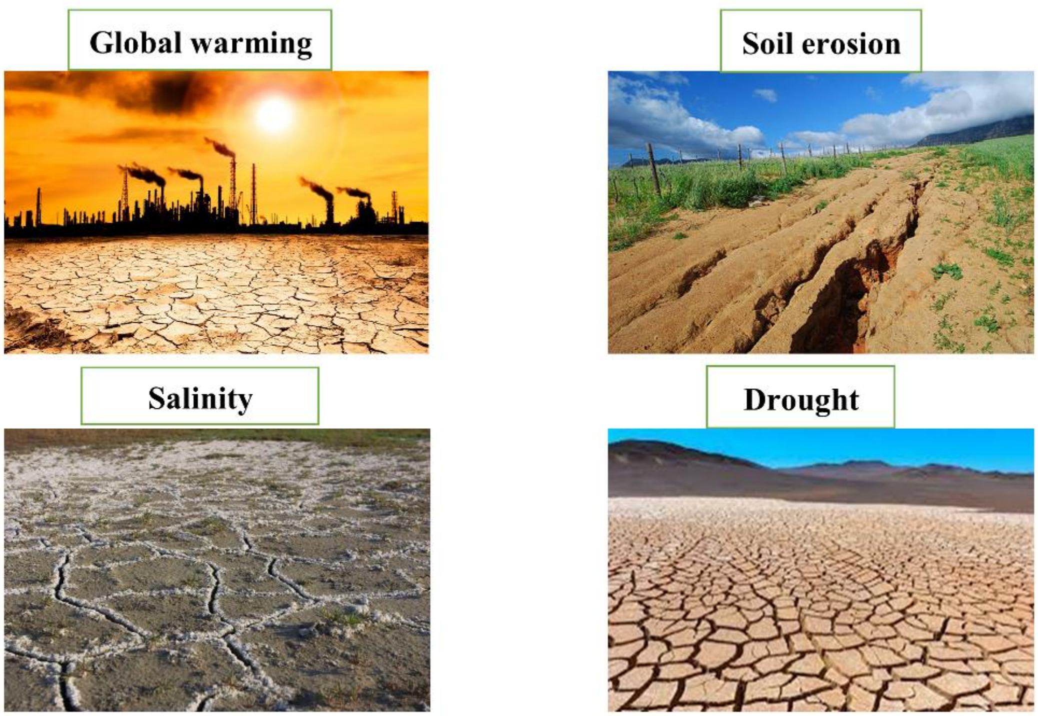

Fig 3. Major abiotic factors causing agricultural losses

c) Soil erosion

According to Ellison (1944), erosion is the process by which erosive agents separate and move soil particles. Sustainable agriculture is seriously threatened by land loss due to erosion since 99.7% of the world's food comes from land, and only 0.3% comes from aquatic systems or the ocean. According to World Health Organization (WHO) 3.7 billion people are undernourished worldwide (Pimentel, 2006). For sustainable agricultural production, healthy fertile soil is the key factor, but during the last 40 years, 10 million hectares of land have been lost due to soil erosion, and each year 0.25 million population is increased in this world; now it is a constant threat to the environment and agriculture (Pimentel et al., 2018). Approximately 75 billion metric tons of soil particles are detached and moved from the land annually via wind and precipitation (Myers et al., 1993).

As a result, arable land is degraded daily, and production is declining. Inappropriate practices used by farmers are also a big reason for soil erosion; efficient land and proper management practices play key roles (Lal et al., 1990). About one-third of global land under cultivation is used for producing crops, and two-third of land is used for pastures (Pimentel et al., 1995). In most regions, food supply is inadequate and lacks efficient agricultural practices; presently, 0.5 hectares of land is needed per capita to feed every person (Pimentel et al., 2018). Many factors contribute to soil erosion, excessive and unneeded application of chemical sprays and fertilizers, and unnecessary irrigations, damaging our soils and affecting the environment. As a result of soil erosion, arable land is declining, and we need the required land for farming; for this purpose, deforestation rates have increased, causing damage to the natural habitats of organisms and the overall environment.

d) Drought

According to Trenberth et al. (2014), drought is a persistent lack of precipitation or an inadequate amount of it, resulting in dry spells and hydrological imbalances. The increasing scarcity of water resources is a cause for concern, as the losses resulting from these shortages are greater than those resulting from other factors because they occur widely and develop gradually. Droughts are the most common natural disaster in terms of the overall number of persons affected worldwide (Hewitt, 1997). Drought's main effect is to upset the balance between water and plants, which makes them utilize less water. Almost every element of a plant's system is impacted by water shortage, including phenology, growth rates, photosynthesis, respiration rates, and reductions in the diameters of leaves and stems (Farooq et al., 2009). Drought is a pervasive issue affecting virtually all geographic regions worldwide (Wilhite, 2000). According to Kogan (1997), one-half of the earth is becoming vulnerable to water scarcity every year. Intensity and extremity of drought cannot be predicted properly because of its dependency on many factors i.e. precipitations and distribution, the capacity of soils to absorb moisture, and their evaporative abilities (Wery et al., 1994).

Drought causes impaired growth and inability to crop stand and heavily affects the plant at the seedling and germination stage (Kaya et al., 2006). Water deficit is responsible for low production and poor crop quality; growth of the cell is also dependent on water availability (Taiz and Zeiger, 2006). Drought stress reduces stomatal efficiency to conserve water. As a result, photosynthesis is affected, and CO_2 fixation is hindered, causing lower yields (Mafakheri et al., 2010). Under extreme drought, the stomata close down, reducing photosynthetic process (Flexas et al., 2004). Acute drought conditions minimize chlorophyll content in the leaves (Ommen et al., 1999). Active oxygen species cause damage to chloroplasts under drought stress, lowering chlorophyll content (Smirnoff 1995).

3. Anthropogenic factors

Global population is increasing at an alarming rate, and at the moment, the population increase rate is higher than ever. According to the United Nations Organization (UNO), there will be 11 billion human beings on this planet by 2100 (Gerland., 2014), and by 2050, there will be 9.5 billion people. The growth of the human population has witnessed a remarkable acceleration over the centuries. The human population took over a million years to reach the first billion milestone in 1804. However, this number surged to 7 billion within another 207 years, reaching this level by 2011. In the last 50 years alone, the human population has more than doubled, jumping from 3.5 billion to over 7.4 billion. Despite significant advances in agricultural productivity and economic well-being across the world during this period, food insecurity remains a substantial and persistent challenge for large segments of the human population. This recent surge in human population over the past 50 years has outpaced the entire period of more than a million years that humans have inhabited the Earth (Sharma et al., 2017). According to various estimates, around 1 billion people globally are undernourished and/or without adequate access to energy. Furthermore, the human population is expected to continue growing quickly, reaching 9.1 billion by the year 2050. This emphasizes the continued difficulties in providing enough energy and food security for the world's population. The increasing population and the need for shelter for human beings have decreased cultivable land, and the loss of arable land is happening. The issue is especially worrisome since future population growth is predicted to be focused mostly in Asia and Africa's developing nations. Severe food shortages are already an issue in many of these areas. By 2050, estimates indicate that the world's food needs will be met by double the amount produced in developing nations and a 70% rise in global food production (Anonymous, 2015a). This emphasizes how urgently comprehensive policies are needed to solve the problems with food security in these at-risk areas.

Human activities have highly impacted the groundwater and surface water. Since high population increase rate, water use within the past 60 years. The use of intensive fertilizers and chemicals also degraded the quality of underground water. It impacts not only human beings but also wildlife, aquatic life, and birds. According to Aydinalp and Cresser (2008) human activities have increased greenhouse emissions by up-to 20%. In the past as populations increased, governments developed infrastructure. They invested to supply water as per demand, but now it is urgently needed to use water in efficient ways for agriculture and for human use. Conservation of water is the need of the hour.

Table 1. Summarized table reviewed from past studies elucidating various factors and their damages to agriculture

Factors	Damages	Reference
Insect pests and Pathogens	7.7% (Brazil) 38% (Global) 20-40%(Global) 50% (In American Corn)	Oliveira et al., 2014 Cerda et al., 2017 Oerke et al., 2006 Soltani et al., 2016
Weeds	34% (Global)	Oerke et al., 2006
Soil erosion	80% (Global Agricultural land)	Pimentel et al., 1995
Salinity	20% (Global Agricultural land)	Pitman and Lauchli, 2002
Post-harvest losses	10-30% (Global)	Hodges et al., 2011
Anthropogenic	20% (Greenhouse gas emissions)	Aydinalp and Cresser, 2008

Conclusion

It is necessary for sustainable agricultural production to reduce losses and adapt proper agricultural management techniques. Exact numbers cannot be determined because much less work is done on estimating food losses. Abiotic and biotic factors collectively cause huge losses, and a wide-ranged focus should be needed to reduce their occurrence. This review has highlighted different factors causing agricultural losses at different stages. Food security is not possible by just increasing the production. We should devise advanced mechanisms to minimize food losses from farm to consumer. Agricultural production using our available natural resources is important. Abiotic, biotic, and anthropogenic factors have caused huge losses to crop production. Intensive use of land and water and the application of chemicals and fertilizers have caused huge losses to our natural resources. Commercial farming has disturbed diversity in ecosystems, causing vulnerability to more pests. Climate change has changed the levels of precipitation in different regions, causing random floods and droughts. Crop growing patterns and soil erosion is also affected by climate change. Especially in developing countries, agricultural losses are acute and need urgent attention. These food losses use $1/4^{th}$ of the entire world's fresh water and $1/5^{th}$ of the total arable land; if the situation worsens, it is estimated that 83$ billion/year would be wasted. Approximately 90% of the losses occur within the food supply chain; it directly affects poor consumers by increasing prices, reducing nutrition, and unavailability of food. Crop protection highly depends upon the pests and methods deployed by farmers for their control. Human beings are damaging sustainability more than the other factors. Tons of food have been lost daily in restaurants, and farmers are using inappropriate techniques for fertilization, inadequate watering, and sprays due to a lack of information and extension facilities. Food availability could be improved by enhancing agricultural production, reducing food wastage, and disseminating knowledge about the proper population's diet into the least resource-intensive foods; concurrently, it could also lead to the protection of the natural environment. In this review article, we tried to compile information from available literature regarding global agricultural losses to identify the major factors causing them and their severity. Natural resources are depleting, and the human population is increasing at an exponential rate, so it is necessary to control these losses to minimize future food scarcity, and appropriate mechanisms should be devised. The Main causes encountered in this review are divided into three categories: biotic, abiotic, and anthropogenic. These destructive factors cannot be eradicated, but they can be minimized with appropriate measures.

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