Chapter

Factors Affecting Yield of Crops

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Abstract

A good understanding of dynamics involved in food production is critical for the improvement of food security. It has been demonstrated that an increase in crop yields significantly reduces poverty. Yield, the mass of harvest crop product in a specific area, is influenced by several factors. These factors are grouped in three basic categories known as technological (agricultural practices, managerial decision, etc.), biological (diseases, insects, pests, weeds) and environmental (climatic condition, soil fertility, topography, water quality, etc.). These factors account for yield differences from one region to another worldwide. The current chapter will discuss each of these three basic factors as well as providing some recommendations for overcoming them. In addition, it will provide the importance of climate-smart agriculture in the increase of crop yields while facilitating the achievement of crop production in safe environment. This goes in line with the second goal of 2030 Agenda for Sustainable Development of United Nations in transforming our world formulated as end hunger, achieve food security, improve nutrition and promote sustainable agriculture.

Keywords: crop, yield, production, food, agriculture, environment

1. Introduction

Agriculture is a key activity of human being since it provides basic needs such as food, clothing and shelter. It has been demonstrated that every 1% increase in agricultural yield translates into a 0.6–1.2% decrease in the numbers of absolute poor households in the world [1]. Meanwhile, population growth was predicted to be 9.7 billion by 2050 and this will require an increase of about 70% in food production to meet the demand [2]. Rainfed agriculture is projected to produce one-third or more of the food increase in global food output for the coming decades. Unfortunately, agricultural productivity depends on increasingly extreme weather phenomena. Thus, water availability, air pollution, and temperature have a large impact in agriculture [3].

Several factors pose significant risk to farms leading to yield reduction when they are not correctly monitored and well managed. These factors can be grouped into three categories which are technological, biological and environmental [4]. The pressure to increase crop production in many countries, has resulted in the expansion of land area dedicated to agriculture and the intensification of cropland management through practices such as irrigation, use of large quantities of inputs like inorganic fertilizers and synthetic chemicals for pest and weed control [5]. These practices have resulted in degradation of soil properties and water quality, acceleration of soil erosion, contamination of groundwater and decline of food quality. This has prompted sustainable intensification initiatives to increase yields on existing farmland while decreasing the environmental impact of agriculture [6–10].

Organic crop production is one of the alternative agricultural practices promoted for the reduction of environmental pollution. As a result, several countries have introduced organic farming practices to replace the chemical-dependent ones [11]. To conserve and regenerate soil properties, the maintenance of soil organic matter (SOM) has received considerable attention. Although SOM is considered key to soil health, its relationship with yield is contested because of local-scale differences in soils, climate, and farming systems. The relationship between these factors should be quantified and proper soil management strategies set up to ensure sustainable crop production [5].

The impact of climate change in our agricultural systems is undoubtable. For example, drought followed by intense rain can increase the flooding potential, thereby creating conditions that favor fungal infestations of leaves, roots and tuber crops. In addition, reduction of bees' density due to global climate change has led to local extinction of several plant species [12]. The production of enough food to match population growth while preserving the environment is a key challenge, especially in the face of climate change. This chapter will review factors affecting yields of crops and provide some strategies to overcome yield loss while preserving the environment.

2. Environmental factors affecting crop yields

The environmental factors affecting crop yields can be classified into abiotic and biotic constraints. Actually, these factors are more intensified with global warming which leads to climate change. Abiotic stresses adversely affect growth, productivity and trigger a series of morphological, physiological, biochemical and molecular changes in plants. The abiotic constraints include soil properties (soil components, pH, physicochemical and biological properties), and climatic stresses (drought, cold, flood, heat stress, etc.). On the other hand, biotic factors include beneficial organisms (pollinators, decomposers and natural enemies), pests (arthropods, pathogens, weeds, vertebrate pests) and anthropogenic evolution.

2.1 Abiotic constraints

2.1.1 Effects of climatic conditions on crops

Variations in annual rainfall, average temperature, global increase of atmospheric CO2, and fluctuations in sea levels are some of the major manifestations of climate change, which negatively impact crop yields [13]. Temperature and rainfall changes are expected to significantly have negative impact on wide range of agricultural activities for the next few decades. With the changing of climate, agriculture faces increasing problems with extreme weather events leading to considerable yield losses of crops. Most often, crop plants are sensitive to stresses since they were mostly selected for high yield, and not for stress tolerance. Climate change is the result of global warming. It has devastating effects on plant growth and crop yield which can affects directly, indirectly, and socio-economically reduce crop yields by up to 70% [14] (**Figure 1a**). Weather variations present positive and negative effects in the environment with very high expression of negative effects (**Figure 1b**).

The regression analysis model between historical climatic data and yield data for food crops over the last 30 years in Nepal showed an increase in temperature of approximately 0.02–0.07°C per year in different seasons and a mixed trend in precipitation [15]. Additionally, no significant impact of climate variables on yields of all crops was observed and the regression analysis revealed negative relationships

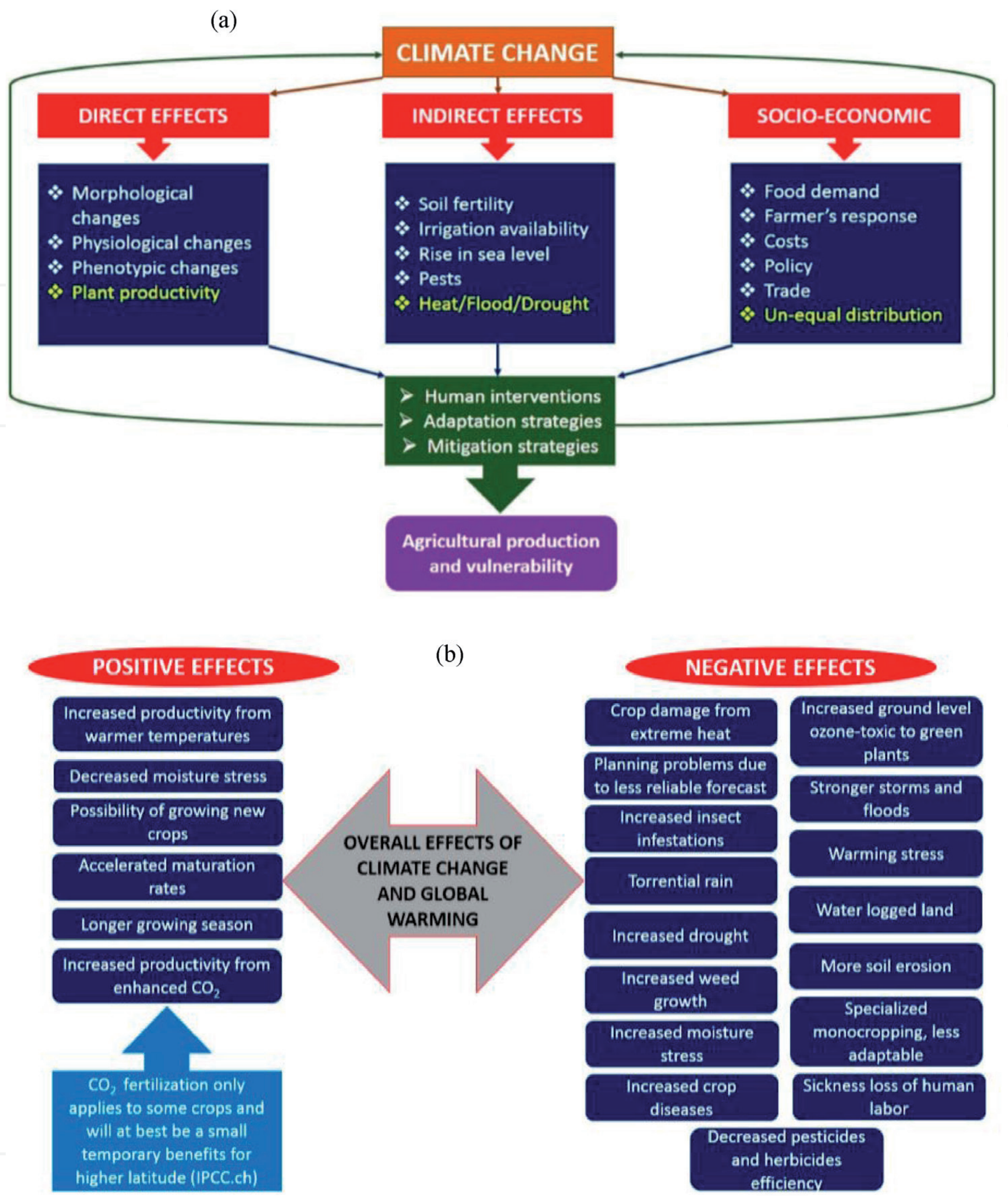

Figure 1.
General effects of climate change in agricultural production (a), the positive and negative impacts in the environment (b) [13].

between maize yield and summer precipitation, between wheat yield and winter minimum temperature, and finally positive relationship was observed between millet yield and summer maximum temperature.

2.1.1.1 Drought

Drought refers to a situation in which the amount of available water through rainfall and/or irrigation is insufficient to meet the evapotranspiration needs of the crop [16]. Climate change is driven by changes in water availability (volumes and seasonal distribution), and in water demand for agriculture and other competing sectors. The impending climate change adversities are known to alter the abiotic stresses like variable temperature regimes and their associated impacts on water availability leading to drought, increased diseases and pest's incidence and extreme weather events at local to regional scale [16]. Moisture or drought stress accounts for about 30–70% loss of productivity of field crops during crop growth period [16]. Drought stress can induce abscisic acid (ABA) accumulation in guard cells to trigger stomatal closure [17]. Drought also results in abnormal metabolism that may reduce plant growth, and/or cause the death of entire plant. Drought has different effects at different stages of plant growth with the most sensitive growth stage being flowering period.

2.1.1.2 Heat stress

Heat stress is the rise in temperature beyond a threshold level for a period sufficient to cause permanent damage to plant growth and development [18]. The Intergovernmental Panel on Climate Change (IPCC) projected rise of the temperature by 3–4° by 2050 [19, 20]. High temperature regimes due to climate change affect the percentage of seed germination, photosynthetic efficiency, crop phenology, reproductive biology, flowering times, pollen viability and pollinator populations [16, 21]. Under heat stress at reproductive growth stage, the increase of temperature prevents the swelling of pollen grains, which results in poor release of pollen from the anther at dehiscence. Heat stress is deleterious to plant developmental stages, including generation and function of reproductive organs. Furthermore, variable temperature regimes may result in unpredictable disease epidemics across geographic regions in the world. Heat stress contributed about 40% to overall yield loss of wheat [22], 1.0–1.7% yield loss per day in maize for every raise in temperature above 30°C [23].

2.1.1.3 Cold stress

Cold or chilling stress experiences by plants from 0 to 15°C [24], leads to major crop losses. Various types of crops in tropical or subtropical origin are injured or killed by non-freezing low temperatures, and exhibit different symptoms such as poor germination, stunted seedlings, chlorosis, or growth retardation, reduced leaf expansion and wilting and necrosis. In general, plants respond with changes in their pattern of gene expression and protein synthesis when exposed to low temperatures [25]. In general, plants from temperate climatic regions are considered to be chilling tolerant with variable degree compare to tropical and sub-tropical crops, and can increase their freezing tolerance by cold acclimation [26].

2.1.1.4 Soil properties

Soils are the uppermost part of the earth's crust, formed mainly by the weathering of rocks, formation of humus and material transfer. They vary in terms of origin, appearance, characteristics and production capacity. Soil fertility is the ability of a soil to deliver nutrients needed for the optimum growth of a specified crop. Soil fertility is one of the most important factors in crop production [10]. It has the ability to support crop production determined by the entire spectrum of its physical, chemical and biological attributes. Soil fertility is one important aspect of soil productivity since it is a major source of micronutrients (Fe, B, Cl, Mn, Zn, Cu, Mo, Ni) and macronutrients (N, P, K, Ca, S, Mg, C, O, H) that are needed for plant growth. The lack of these nutrients in the soil causes deficiencies in plants, and their excess leads to toxicities, which have negative impacts on crop yields.

Several parameters can be used to determine the fertility status of a soil. Among them, the soil fertility index was found to be the most useful indicator that helps to improve sustainable land use management and achieve economical yield in crop production [27]. In several regions in the world, some croplands have undergone human-induced soil degradation resulting in poor yield production per unit area of crop harvest. Around 40% of agricultural lands are affected by human induced land degradation. Intensive agricultural production characterized by overuse of fertilizers and chemicals without adherence to agricultural sustainability leads to a decline of soil health, land degradation and severe environmental problems [28]. It is important to note that the deterioration of soil fertility normally takes pace over several years.

2.1.1.5 Soil salinity and acidity stress

Salinity stress affects crop production in over 30% of irrigated crops and 7% of dry land agriculture worldwide [29]. It is one of the major problems affecting crop production all over the world since around 20% of cultivated land and 33% of irrigated land are salt-affected in the world [30]. Salt causes osmotic stress and ionic toxicity in crop plants. Under normal conditions, the higher osmotic pressure in plant cells permits the absorption of water and essential nutrients from a soil solution into the root cells. However, under salt stress conditions, the high concentration of salts in the soil solution prevents absorption of water and essential minerals but will facilitate the entry of Na^+ and Cl^- ions into the cells, which will have direct toxic effects on cell membranes as well as on metabolic activities in the cytosol [31].

Low soil pH increases as a result of release of acidifying aluminum, iron and manganese ions, leaching of base ions such as calcium, magnesium, potassium and sodium, decomposition of soil organic matter and regeneration of organic acids, nitrification of ammonia-based fertilizers [32, 33] as well as land management practices. Low soil pH significantly affects crop growth and therefore decreases yield. In maize for instance, soil acidity causes yield loss of up to 69% [34].

2.1.1.6 Floods

Floods entail different stressful conditions to plants, mainly depending on water depth and its duration. Soil waterlogging damages most crops, with the exception of rice, which like other wetland species thrives when plants are not completely submerged. In view of the changing climate, flooding has become frequent in many lowlands and cultivated areas every year and causes a lot of damage to human beings including losses in crop yields and food stuffs.

Flooding usually occurs with heavy rainfall, poor soil drainage and poor irrigation practices. Soil waterlogging has negative impacts on crop production especially for dryland species (such as most cereals, legumes, tubers, etc.) which include several crops. The excess water results in complex changes in plant physiology for non-adapted crops. This leads to restriction of gas diffusion between the plant and its surroundings (accumulation of high CO_2 and ethylene in the root zone with very low O_2), hypoxia (oxygen levels limit mitochondrial respiration) and anoxia (respiration is completely inhibited), often accompanied by increased of mobilization of ‘phytotoxins’ in reduced soils, leading to poor root metabolism (inability to absorb nutrients), lack of energy within plant cells, restriction of photosynthetic activities and therefore poor growth or death of plant roots and shoots.

The first constraint for plant growth under flooding conditions is the immediate lack of oxygen necessary to sustain aerobic respiration of submerged tissues [35–37].

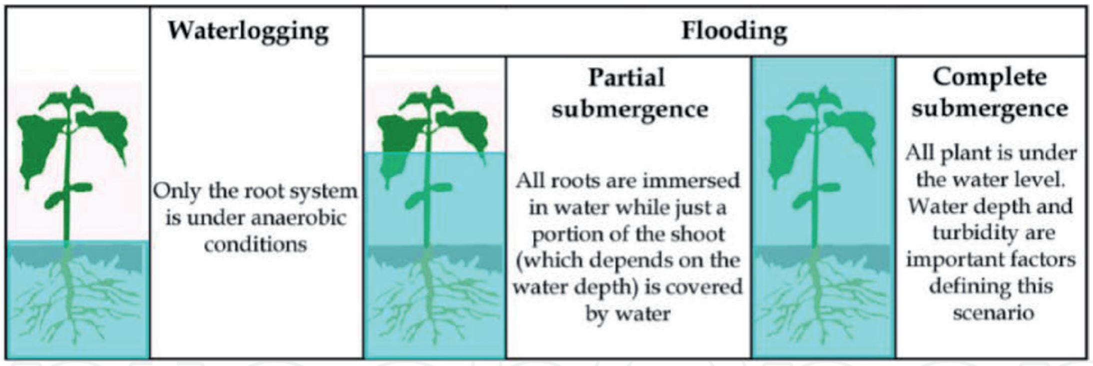

Figure 2.
Different levels of excess of water in crop environment [38].

As the duration of flooding increases, there is progressive decrease in soil reduction-oxidation potential (redox potential) [38] (**Figure 2**). Flooding events can be classified by two categories: waterlogging where only the root system inside the soil is affected [39]; and submergence, where also parts or the whole shoot are under water [40]. In tree species with different flooding sensitivity, the importance of root-to-shoot transport of metabolites to 'use rather than lose' is a relevant criterion used to identify the tolerant species [41]. Only non-wetland plants can survive flooding for a short period of time. The two survival strategies to flooding are plant avoidance of oxygen deficiency in tissues and the adaptation to oxygen deficiency [42].

3. Biotic factors affecting crop yields

3.1 Diseases and pests

Plant diseases are caused by different micro-organisms such as viruses, bacteria and fungi. In addition, various soil-borne and above ground insect pests also affect crop production. Variation in climatic conditions often favors the multiplication of pathogens while negatively affecting plant productivity and soil fertility. It causes the reduction of available resources for plants, which fail to produce enough biomass, seeds, and thus yield. Climate-driven migration allows the movement of pathogens and pests from one region to another. Thus, the locally adapted crop genotypes confront new biotic stress factors. The interaction of plants with microbes or microbe-associated molecular patterns can induce resistance to secondary infections by pathogens. This involves the production and systemic signal of a complex of low-molecular-weight plant metabolites, which are well described for dicotyledonous plants, but poorly understood for monocotyledonous plants such as cereal crops [43]. Because of climate variability and change, it is anticipated that new diseases and pests might appear, or that the virulence of the current types may increase.

The changing of the climate is bringing new types of diseases and pests that do not have any control methods yet. For example, maize lethal necrosis (MLN) is one of the most devastating diseases found in maize in Eastern and Central African countries. It is caused by the synergistic interaction between *Sugarcane Mosaic Virus* (SCMV) and *Maize Chlorotic Mottle Virus* (MCMV). It causes yield reduction ranging from 30 to 100% in farmers' fields depending on the time of infestation [44]. MLN is transmitted by beetles, rootworms, thrips, stem borers, several species of aphids in non-persistent manner, infected soil, infected seeds and any tools or materials used in the infected field [45]. Moreover, Russian Wheat Aphid (RWA) is one of the world's invasive pests of wheat, barley and other cereal grains. It is widespread in cereal growing regions of Africa, Asia, Europe, Middle East, North and South America, recently in Australasia [46]. The visual symptoms of infestation in plants are chlorosis, necrosis, wilting, stunting, leaf streaking with whitish, yellow and purple longitudinal leaf markings, trapped awns, rolled leaves and heads that fail to flower [46]. These pests have high resistance to extreme weathers events. RWA caused yield losses up to 80% in wheat and 100% in barley. The main challenge associated with the RWA is that new biotopes that are tolerant to available insecticides continue to appear. Some of the biotopes also overcome resistance of some crop varieties. Elevated atmospheric carbon dioxide has also been found to alter the efficacy of some biotopes. They are therefore constant threat to crop production.

4. Technological factors affecting crop yield

A wide range of technological innovations in agriculture like genetic improvement of varieties, fertilizer technology, adaptive microbial technology, pesticides, farm machinery, agronomic and management practices (integrated management of nutrients and pests) have been achieved through research programs to understand their implications in enhancing crop productivity [16]. It has been reported that 1 kg of nutrient fertilizer produces 8 kg of grain [47]. In addition, fertilizers are commonly believed to be very important in crop production since they contribute up to 50% of the crop harvest product [48]. The doubled increase of food production worldwide was partially attributed to a 6.9-fold increase in nitrogen fertilization and a 3.5-fold increase in phosphorous fertilization in the 1990s [49].

Different factors have negative influence in agricultural practices. In Bangladesh, farmers were given chemical fertilizers and pesticides at a subsidized price and therefore increased fertilizer application to enhance crop yield. In the Philippines, because of the huge amount of lime and urea used by farmers over years, the sugarcane farms developed lime layer in the subsoil, which caused phosphorous deficiency while banana farms have excessive potash, which created an imbalanced ratio of potassium and magnesium. The average yield production of sesame in Jigawa State was reported to be 0.6 t/ha instead of 1.25 t/ha under well-managed farms [50]. In general, the application of inappropriate agronomic practices such as untimely planting, incorrect plant spacing, wrong method of planting, poor sowing depth, delayed weeding, ineffective pest and disease control, inappropriate use of fertilizers, untimely harvesting and use of low yielding varieties, will always significantly reduce crop yields.

5. Strategies to overcome crop yield reduction

Climate smart agriculture (CSA) is now widely accepted as the best approach for addressing the effects of climate change in agriculture. It is defined as agriculture that sustainably increases productivity, resilience (adaptation), reduces/removes greenhouse gases (mitigation), and enhances the achievement of national food security and development goals. CSA promotes the transformation of agricultural systems and requires the transformation of agricultural policies to increase food production, to enhance food security, to ensure that food is affordable (low input-cost) while ensuring sustainable natural resource management and resilience to a changing climate.

5.1 Management of the environment

Climate influences all components of crop production including crop area and crop intensity. Weather forecasting and crop yield prediction or simulations are relevant tools that provide a warning to farmers in preparation of the upcoming season. From the simulation results, farmers can change the crop planting date, use appropriate genotypes, adjust the fertilization and the irrigation cycles to obtain reasonable yields, thus reducing the risk of unexpected events [51]. Several studies have been successfully conducted in crop yield simulation models and were reviewed by Tandzi and Mutengwa [51]. In a general view, the reduction of chemicals' usage such as fertilizers and pesticides, associated with the improvement of crop input use efficiency will minimize greenhouse gases emissions while protecting the environment. It has been reported that any programs that are working to minimize the adverse impact of climate change on food crops production should first consider the type of crop grown, the production area as well as the geographical and climatic conditions [15]. The knowledge of appropriate planting methods is important because climate events influence the selection of planting method and thus yield even though the total planted area remains unchanged [52]. There is a possibility of producing more yields in sustainable agriculture while generating less environmental pressure (**Figure 3**).

5.2 Management of agricultural inputs

Improvement of irrigation performance and water management are critical to ensure the availability of water both for food production and for competing human and environmental needs. To improve crop productivity and sustainability, it is very important to evaluate the effects of human activities in soil fertility through the use of appropriate agricultural systems such as tillage, use of recommended rates and types of fertilizer, incorporation of farmyard manure and/or crop residues into the soil (increase supply of N, P, K and other nutrients) and avoid sewage sludge irrigation. The application of these inputs improves physical properties of soil or soil organic matter in the long term and ensures sustainable agriculture. Shang et al. [28] found that high crop yields and low production variability can be achieved by increasing integrated soil fertility quality index in intensive cropping systems.

Climate-smart agriculture is the best way to lower the negative impact of climatic variations on crop adaptation. The type of inputs utilized during production combined with adapted high-yielding genotypes will determine the quality and quantity of harvest products to obtain (**Figure 4**). In addition, cover crops provide weed and pathogen control, decreased soil erosion, reduced loss of soil nitrogen, phosphorus and carbon. On the other hand, plant-beneficial microbes provided disease control and phosphorus availability [53]. The application of integrated pests and diseases management in farmers' fields will consistently reduce yield loss. Alternative agricultural practices such as organic production is promoted as being environmentally friendly with reduce agricultural impacts on water quality. Several countries have introduced organic farming practices to produce good quality food. The application of compost with chemical fertilizers not only results in high yields but also improves soil organic matter accumulation and soil fertility. In addition, the application of chicken manure compost enhanced soil quality and increased the accumulation of soil organic matter, available phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) content in Botswana [54]. Microbial fertilizers are distinctly environment-friendly, non-bulky, cost-effective and play a significant role in plant nutrition [55]. Policymakers in different countries should formulate policy on sustainable fertilizer and pesticide management in crop production with

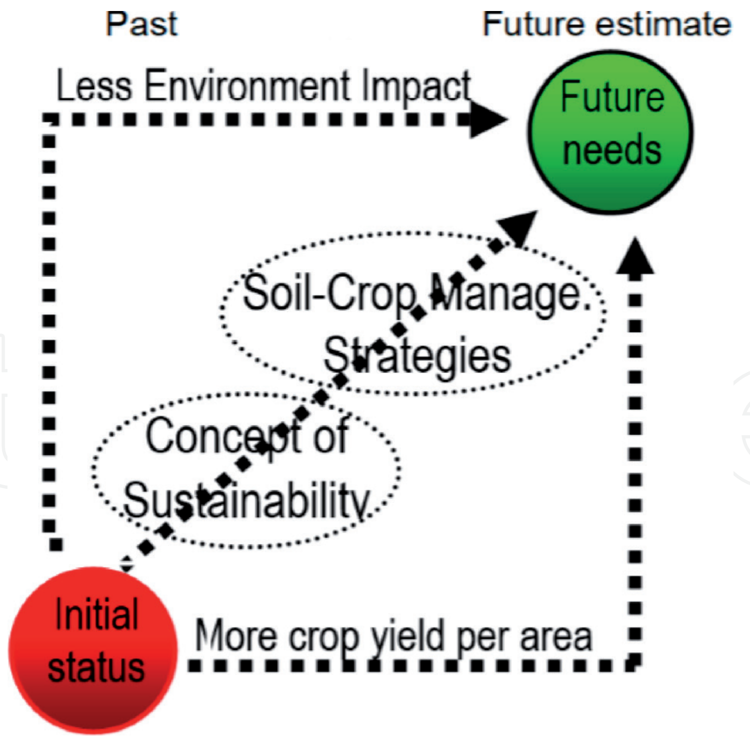

Figure 3.
Strategy of moving towards higher crop productivity and less environmental impacts [28].

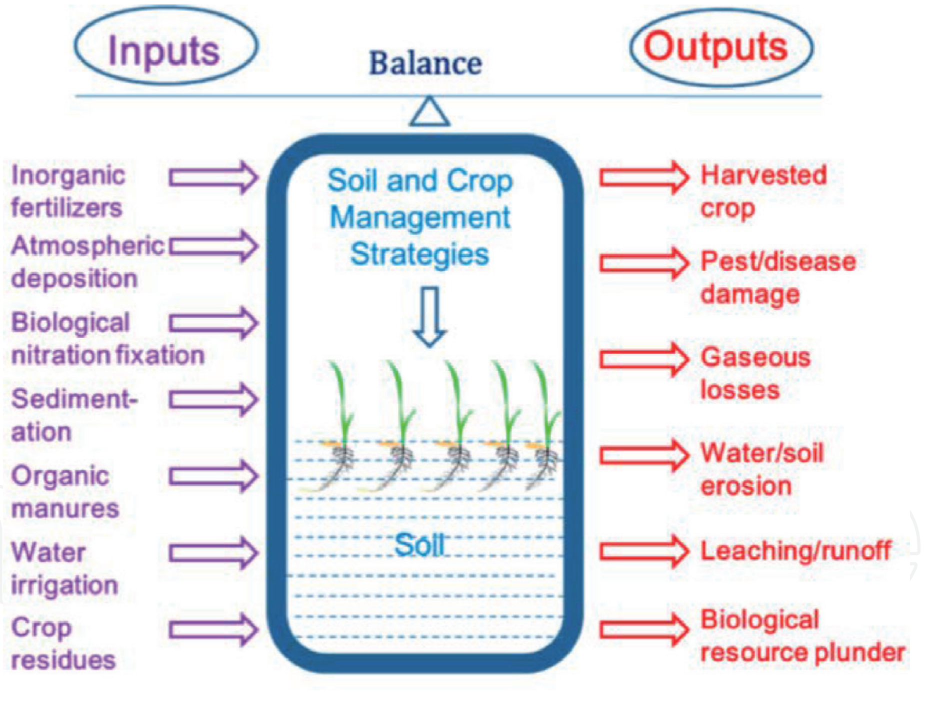

Figure 4.
Nutrient budgets between inputs and outputs [28, 56, 57].

different placement methods to reduce the overuse of those chemicals while preserving the environment. Guan et al. [58] identified RCF3, a KH domain-containing RNA-binding protein localized in the nucleus, as an upstream negative regulator of thermo-tolerance by modulating the expression of genes encoding heat-shock proteins (HSPs) in Arabidopsis. In South Africa, the maintenance of yield quality and quantity under actual prevailing environmental conditions have been largely achieved through the change in water and fertilizer management as well as new crop management practices (such as appropriate use of rotation system, lower seeding and fertilizer application).

5.3 Development of new adapted crop genotypes

Breeding is routinely conducted to increase levels of durable resistance to specific pests, diseases and different abiotic stresses using conventional crop improvement methods. However, there is now an increased use of modern biotechnology techniques such as marker-assisted selection, and transgenic approaches that involve genetic modification and high-throughput sequencing of both plant and pathogenic micro- organisms. Attempts have also been made to utilize transgenic technologies to build intrinsic tolerance mechanisms by the plants through alteration of functional genes [16]. Sustainable technologies like classical breeding approaches and integrated farming principles are also being considered to develop crops adaptation and/or enhance the adaptive mechanisms.

Under stress conditions, crop plants have evolved a set of perception and signal mechanisms to respond or adapt to adverse environmental conditions via regulation, transcription, gene expression, protein translation, modification, degradation, and metabolic regulation [17]. For example, strong associations were observed between the Na^+ content and some metabolites, including several sugars, suggesting that metabolic regulation is important for plant responses to salinity stress [59]. It has been demonstrated that manipulation of auxin biosynthesis pathway may improve crop plants tolerance to drought [60]. Physiological plant responses of crops to drought and heat stresses involve mechanisms to prevent membrane, regulate photosynthesis, respiration, and transpiration. For instance, developing crop genotypes with improved water used efficiency is one of the solutions to overcome drought stress. The most promising traits that might enhance crop flooding tolerance and facilitate longitudinal oxygen transport to sustain root aeration and water absorption in anaerobic soils, are anatomical adaptations such as formation of aerenchyma, a barrier against radial oxygen loss, and the growth of adventitious roots [39, 42]. The CBF/DREB1 genes are thought to be activators that integrate several components of the cold acclimation response by which plants increase their tolerance to low temperatures after exposure to non-freezing conditions. The DREB1/CBF genes have been successfully used to improve abiotic stress tolerance in a number of different crop plants [25].

The combination of genomics approaches such as marker-assisted selection (MAS) and genome wide associated studies (GWAS) can be efficiently used to develop biotic and abiotic stress tolerant cultivars (**Figure 5**). Future bio-computational integration of multiple omics and meta-omics with innovative research tools (reference genomes, proteomes, metabolomes with comprehensive annotations and structure–function relationships) will improve the understanding of the complexity of plant stress physiology [43] which will gather the development of the high-yielding and most adapted crop cultivars.

In definitive, there is a need to improve research activities into water quality and water use efficiency, nutrient and soil conservation technologies and techniques, climate-resistant crops and livestock, as well as agricultural productivity in line with the national development policy of each country, to promote the development of climate-smart agriculture which lower agricultural emissions and boosts agricultural production.

5.4 Climate: smart agriculture and food security

One of the most difficult and important tasks is to ensure the protection of the planet from the degradation through sustainable consumption and production, sustainable management of natural resources and urgent action to take towards climate change at national, regional and global level. Climate change is one of the leading

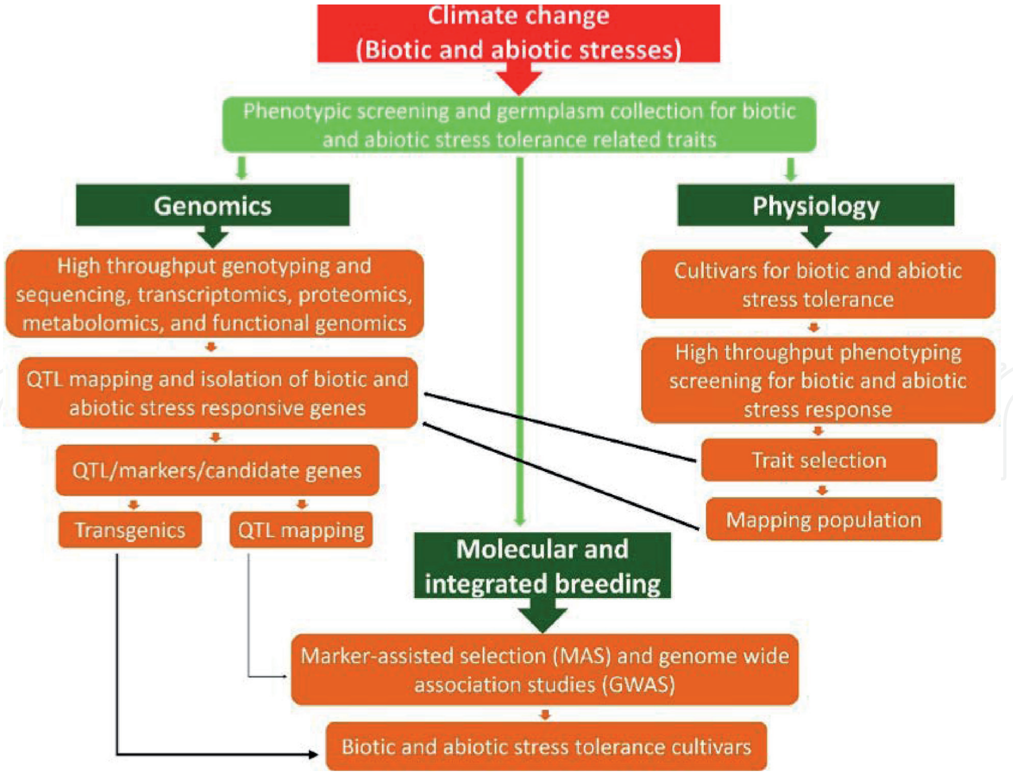

Figure 5.
Different steps of applying combined biotechnological tools in the breeding for biotic and abiotic stress tolerant crop genotype [13].

risks affecting the four dimensions of food security which are food availability, food accessibility, food utilization and food system stability [61]. Climate-smart agriculture (CSM) is an approach for transforming and reorienting agricultural systems to support food security under the new realities of climate change [62]. It promotes multidisciplinary actions to be taken by farmers, researchers, private sectors, civil society and policymakers towards climate-resilient pathways. In addition, CSM is based on three principles which are production (sustainable increase of the level of agricultural production and income), adaptation (development of resilient production systems adapted to climate change) and mitigation (reduction or elimination of greenhouse gas emission where possible) [63]. It is therefore a response to the challenges faced to satisfy the food needs of an increasing population in a changing climate.

6. Conclusion and recommendations

Climate smart agriculture sustainably increased crop yields while facilitating achievement of adaptation and mitigation goals in crop production. The development of new climate resilient crop tolerant and adapted to biotic and abiotic stresses will require the propagation of novel cultural methods, the implementation of various cropping schemes, and the combination of different conventional and non-conventional approaches. The development of integrated soil-crop system management and integrated diseases and pests' management with existing crop varieties and the increase of new improved and adapted high-yielding varieties under water and nutrient limited environment should be the new target for the coming generations. The application of genetically engineered crop plants by the introduction and/or overexpression of selected genes seem to be a viable option to hasten the breeding of improved adapted and high-yielding crop genotypes. Trans and interdisciplinary researches are needed to find relevant solutions for all the environmental challenges reducing crop yields while ensuring food security.

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