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ARTICLE

Attaining Sustainable Enhancement in Crop Production Practices in the Turkestan Region: A Review of the Potential of Technological Innovations

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ABSTRACT

Sustainable crop intensification (SCPI) is a system that allows for increasing the intensity of the use of land and non-agricultural resources in agricultural production without having a negative impact on the environment, as well as on those additional areas that are not suitable for agricultural purposes. SCPI is most suitable for the Turkestan region, characterized by favorable climatic and socio-economic conditions for the adaptation of the strategy. It should also be noted that many agricultural technologies have already been introduced in the region in accordance with relevant economic, cultural and traditional practices that can increase the vulnerability of agriculture to environmental changes. The purpose of this study is to coordinate the results of scientific research and the experience of farmers in maintaining production efficiency and observing environmental stability considerations in the conditions of the Turkestan region. In addition, given the fact that the rate of depletion of natural resources and the burden on ecosystems is increasing, more advanced and sustainable farming methods should be applied. Small

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farms, which currently occupy a significant part of the cultivated land in the region, should be supported by technological and policy innovations leading to the sustainable improvement of farms.

Keywords: Sustainable Crop Production; Precision Agriculture; Conservation Agriculture; Agroforestry; Mixed Cropping; Rainwater Harvesting

1. Introduction

The technology made available by the Green Revolution (GR) of the 1960s has played an important role in meeting the challenges posed by the growing population and increasing scarcity of arable land. In the Turkestan region, where traditional agricultural practices face challenges such as climate change and natural resource degradation, adapting Green Revolution technologies requires consideration of local conditions and a sustainable approach. At present, food production exceeds the amount needed to feed the global population. However, with the population growing rapidly, projections suggest that by 2050, the world will require 70–100% more food to meet the demands of the increasing population [1]. The technological advancements of the GR helped achieve remarkable crop yields per hectare in developing countries. For example, between 1960 and 2000, yields increased by 208% for wheat, 109% for rice, 157% for maize, 78% for potatoes, and 36% for cassava [2]. However, this technology has also led to many environmental and ecological problems, which are now seriously threatening the structure of the natural resource base on which food production depends.

The soil quality degradation due to the indiscriminate use of synthetic fertilizers and pesticides is already beginning to show its effect as a slowing down of yield growth worldwide [3]. In Turkestan, the overuse of chemical inputs has also contributed to soil degradation and reduced agricultural productivity. Moreover, the production of synthetic inputs, an important component of the GR technology, is heavily dependent on fossil fuels for both raw materials and energy. The gradual depletion of fossil fuel reserves and other materials such as mineral deposits used for the production of fertilizers and pesticides is beginning to raise serious concerns about the sustainability of crop production using GR technology. On the socioeconomic front, industrial agriculture has failed to reduce world hunger and malnutrition to expected levels despite surplus food. An estimated 800 million people globally experience chronic caloric insufficiency, with millions of children under the age of five suffering from malnutrition: 47 million are wasted, 14.3 million are severely wasted, and 144 million are stunted. Furthermore, around one billion people lack at least one nutrient essential for health. Undernutrition is linked to 45% of deaths in children under five, and iron deficiency is estimated to result in 591,000 perinatal deaths and 115,000 maternal deaths worldwide.

The significant increase in global food production over the past fifty years has substantially reduced the proportion of the world's population suffering from hunger, even though the total population has doubled during this period Nevertheless, malnutrition due to insufficient intake of protein, energy, and micronutrients is still prevalent. More than one in seven people in the world do not have access to sufficient energy and protein and even more suffer from micronutrient deficiency. On the other hand, the availability of cheap grains is leading to a change in dietary preference for sugar and fat-rich diets and increasing consumption of animal meat that is responsible for the rapidly increasing prevalence of heart disease, diabetes, hypertension and other lifestyle diseases [4].

The world population is predicted to grow by over 4 billion over the next 40 years, and it is projected to increase from 7.8 billion in 2020 [5] to around 12 billion in 2050. Most of the projected population growth is anticipated to take place in developing countries, with the least developed countries expected to see the largest relative increase of 120% [6]. To meet the rising food demand of the growing global population, agricultural production must increase by 70% globally and nearly 100% in developing countries. In Turkestan, achieving this increase will require sustainable intensification practices tailored to local environmental and socioeconomic conditions. This translates to an additional billion tons of cereals and 200 million tons of meat compared to production levels between 2005 and 2007 [7].

In the past, the introduction of more land for cultivation and increased exploitation of fisheries were the main responses to the rise in demand for food. However, the increasing population is exacerbating the competition for soil, water, and other natural resources. Combined with environmental degradation and climate change, these factors are now affecting our ability to boost food production [8]. In Turkestan, land availability is constrained by urbanization and environmental degradation, necessitating a focus on improving productivity on existing agricultural land. As the competition for land and the pressure to maintain sufficient natural green cover to prevent rapid climate change increases, it is becoming progressively difficult to bring more land into cultivation. In fact, though grain production has doubled in the last five decades, the land under cultivation has increased by only 9% [9]. In Turkestan, addressing land degradation and promoting sustainable land management practices are crucial for long-term agricultural productivity. The option of bringing new land into cultivation, particularly in Sub-Saharan Africa and South America, exists. However, the demand for land from other human operations renders it an extremely expensive, if not impossible, option, particularly if conservation of biodiversity and public resources supplied by the natural habitats (for example, carbon sequestration by the rainforests) are given greater significance [10]. Moreover, in the last few decades, urbanization and other human uses, desertification, salinization, and soil degradation caused by unsustainable land use have taken away the land that was formerly productive. It is imminent that there will be more losses of the natural resource base for agriculture, particularly water losses caused by climate change [11].

The agricultural sector in Turkestan faces a critical challenge: how to satisfy the need for more productivity at the same time as it can be achieved while meeting environmental concerns. The conventional practice that has steeped more of the chemical inputs and water-bearing technologies has deteriorated the existing natural resource capital and caused the decrease of soil fertility and crop yields. Climate change also adds to these problems by reducing the stability of local agricultural production systems. Solving these problems has an interrelated approach based on incorporating the indicators of traditional farming and using different innovative solutions like precise farming, protective producing methods, and reasonable utilization of the land. Therefore for the region to embrace long-term productivity, conserve resources, and feed the increasing population, it has to embrace a holistic approach.

In the past four decades, much of the rise in agricultural production is associated with better genetic capital, expanded usage of pesticides, increased input of mineral materials and greater utilization of mechanized agricultural technology powered by fossil fuel, rather than the use of additional land for crop production. However, environmental pollution and ecological disturbances caused by the widespread use of chemical inputs, burning of fossil fuels, and increased water usage for irrigation of hybrid varieties have caused serious damage to the environment. In the Turkestan region, balancing the need for productivity with environmental sustainability requires integrating traditional knowledge with modern agricultural technologies. Sustainable agriculture intensification would help to improve environmental services and minimize the factors driving climate change by reducing pollution and preserving the carbon locked in the soil. This review focuses on the various approaches currently being taken for the sustainable intensification of agriculture. The relevance of these approaches for Turkestan is highlighted, particularly in terms of enhancing resilience and productivity in the face of climate change. The relevance of traditional knowledge in increasing sustainability and productivity of farms along with the principles and methods of conservation agriculture and precision agriculture are discussed. The role of genetically engineered and gene-edited crops and the importance of integrated weed management (IWM) and integrated pest management (IPM) practices in sustainable crop production are also discussed.

2. Material and Methods

2.1. Government Policies and Agricultural Incentives in Sustainable Food Production

Sustainable crop production requires planning at both pre-production and production stages. Planning and efforts during the pre-production stage, such as developing high-yielding crop varieties, improving fertilizer quality, and advancing farm machinery production, play a crucial role in enhancing crop yields and ensuring the sustainability of agricultural production. The agricultural policies of the governments, training and knowledge transfers, and the incentives provided to the farmers also have a bearing on the type of crop planted, the nature and type of external inputs used, the yields obtained, and sustainability.

Resolution of the Government of the Republic of Kazakhstan dated December 29, 2018 No. 938 approved a comprehensive plan for the socio-economic development of the Turkestan region for 2021–2025. This plan is aimed at the comprehensive development of the region, including agriculture, industry, transport infrastructure and tourism.

In turn, in the Comprehensive Plan of socio-economic development of the Turkestan region, much attention is paid to agriculture. The main ongoing processes are further improvement of the technical level of agriculture, construction of irrigation systems, stimulation of farmers and development of the processing sector. As for the reform of the agricultural sector, modernization is characterized by the use of relatively new methods, including precision farming, drip irrigation and agricultural mechanization, among others. This is done in order to increase the efficiency of land use and, consequently, yield. Irrigation development works also include the construction of new and repair of existing irrigation systems; provision of water supply to cultivated fields and promotion of water-saving ideas. This is especially desirable for drought-prone areas. Subsidies and grants for farmers include financing for the purchase of improved tools, better seeds and fertilizers. There are also other courses and seminars aimed at improving farmers' knowledge and skills in the field of sustainable agriculture. The improvement of the processing industry leads to the creation and modernization of enterprises, which leads to an increase in the level of processing of domestic agricultural products and an increase in added value, combined with the sustainability of the agro-industrial complex of the region. At the same time, the plan provides for measures to preserve and enhance biological diversity, soil cover and agriculture, taking into account climatic conditions. On this basis, it is also expected to create new jobs and improve the quality of life of the rural population. Comprehensive Plan of socio-economic development of the Turkestan region for 2021–2025 (Resolution No. 938), available on the Adilet website (https://adilet.zan.kz/rus/docs/P1800000938).

Also, these policies determine how the environment is affected by food production. For instance, subsidies for chemical fertilizers and pesticides can lead to their increased usage and the corresponding adverse effects on the environment[12]. The agricultural policies along with other national policies, also influence environmental services such as carbon storage, biodiversity, forest cover and the population of pollinators. Aquaponics can be included in such technologies, which would be one of the good alternatives to achieve biodiversity. This includes fish farming combined with growing plants in water using hydroponic technology. This approach provides a natural balance: aquarium wastewater is used for plants, and the water purified by plants is returned to fish aquariums. What gives this system a significant advantage is the recycling of water, which makes it environmentally friendly, and is already used in hydroponic greenhouses where plants are grown using minerals dissolved in water. The aquaponics project was successfully implemented in the Tulkubassky district of the Turkestan region, where the effectiveness of this technology was proven in this region as well.

For example, industrial banana production has also been successfully launched in the Sairam district of the Turkestan region (**Figure 1**). Plants for growing bananas adapted to the climate of Kazakhstan are grown in a greenhouse of continental production with an area of 5.3 hectares. The annual banana harvest at the complex is about a thousand tons per season, which proves the great potential of the region in growing non-tropical crops using hi-tech technologies.

Figure 1. Greenhouse for banana cultivation in Sairam district of Turkestan region.

Source: https://economy.kz/?p=6184.

The policies encouraging the cultivation of a variety of crops rather than one or two major crops are more favorable to sustainability by minimizing soil degradation and ecological disturbances.

For example, multicultural systems are being actively introduced in the Turkestan region, contributing to increasing the sustainability of agriculture and preserving ecosystems (**Table 1**).

Table 1. Examples of multicultural systems in the Turkestan region (demonstration from **Figure 2**).

Name	Description
1. Integration of aquaponics in Tulkubasy district	An aquaponics system has been introduced in the Tulkubas district, combining fish farming and plant cultivation in hydroponic installations. Fish waste products are used as nutrients for plants, and the water purified by plants is returned to fish tanks. This ensures a closed production cycle, reduces water consumption and increases resource efficiency.
2. Agroforestry in the Baydibek district	Farmers of the Baidibek district are introducing agroforestry practices, combining the cultivation of crops with the planting of tree species. This helps to improve soil structure, prevent erosion and create favorable conditions for biodiversity.
3. Crop rotation with legumes in Ordabasy district	In Ordabasy district, farmers practice crop rotation, including alternating grains and legumes. Legumes enrich the soil with nitrogen, reducing the need for synthetic fertilizers and increasing land fertility.

Figure 2. *Cont.*

Figure 2. Examples of multicultural systems in the Turkestan region (names from **Table 1**).

Research and innovations in agriculture, such as the development of new high-yielding and drought- and pest-resistant varieties, preservation of germplasm of wild varieties for use in future breeding programs, and improvements in agricultural inputs such as fertilizer or crop protection products contribute towards the sustainability of crop production by preventing further land from being converted for cultivation.

2.2. Agricultural Technology

Technological advancements have been vital in increasing food production to accommodate the growing population. Over the past 50 years, global food production has risen significantly, leading to a substantial decrease in the number of hungry people worldwide, even as the total population has doubled. It is projected that the global population will reach approximately 9.6 billion by 2050 before stabilizing, necessitating a 70–100% increase in food production to meet this demand **Figure 3** shows current and predicted data on agricultural productivity in the Turkestan region for 2021–2026.

Currently, we are witnessing a new agricultural revolution, driven by technology, the first two being the industrial revolution, which introduced mechanization in agriculture, and the green revolution, which made available to farmers new high-yielding hybrid varieties with increased requirements for irrigation and fertilizer inputs. Currently, technology is being used not only to increase crop yields but also the sustainability of agriculture by helping farmers make timely and informed decisions on the use of external inputs. This helps minimize the use of these inputs and contributes to the reduction of environmental pollution and soil degradation, and translating into greater profit margins for the farmers. Modern agricultural technologies such as drip irrigation and precision farming are being actively introduced in the Turkestan region, which significantly increases the efficiency of agricultural production. For example, drip irrigation is already used on an area of more than 31,788 hectares, which has reduced water consumption and increased yields. Precision farming, including the use of GPS and sensors to optimize fertilizer and seed application, is being implemented on farms, which helps reduce costs and improve environmental sustainability.

Technology, especially information and communication technologies (ICTs), can significantly contribute to the sustainable intensification of agriculture. ICTs are already being used to reduce agricultural inputs such as fertilizers, pesticides, energy, and water. ICTs are essential in the realm of precision agriculture, a farm management approach that uses sensors to measure as many variables as possible (pH, potassium, phosphate, moisture, nitrogen, crop yield, etc.) in different locations on the farm. This location-specific data is then used for the operation of various input devices such as sprayers and seeders using Variable Rate Technology (VRT), which deposits the inputs at a precalculated optimal level at various locations on the farm, guided by GPS technology. The reduction of input application thus achieved has a positive economic and environmental impact. Precision agriculture reduces the carbon footprint of agriculture and lowers greenhouse gas emissions by saving the energy required to produce and apply these inputs [13]. Farmers in the Maktaaral district use drip irrigation on cotton crops, which allowed them to save 30–40% of water and receive an additional 20% of production. Farmers in the Baidibek district are creating an agroforestry system, which involves growing trees together with crops to improve soil structure, reduce erosion, and increase biodiversity.

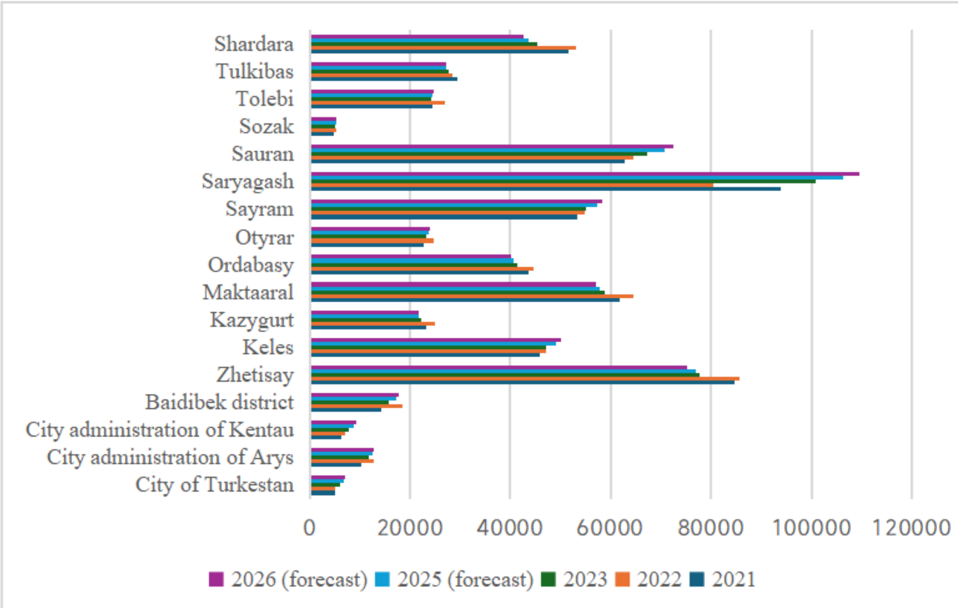


Figure 3. Gross output of agricultural, forestry, and fisheries production (services) by districts for 2021–2023, with forecasts for 2025 and 2026 byuro nacional'noj statistiki respubliki kazahstan.

Developed countries are the most promising markets for precision agriculture technology, and the adoption of this technology in developing countries remains a challenge due to the cost factor [14]. A significant impact of these technologies on the achievement of the goals of sustainable intensification of crop production can only be realized when smallholder farmers, who own about 80% of the world's farmland, have access to them through incentives and subsidies. In 2023, 80 million U.S. dollars. are planned to subsidize the agro-industrial complex of the Turkestan region, which proves that the state stimulates the development of agricultural production in the region of interest. These funds are intended to finance subsidies to cover the costs of purchasing seeds, fertilizers and pesticides and establishing greenhouses. In particular, the investment subsidy provides for the following: up to 25% of the costs of construction and reconstruction of greenhouse complexes and up to 50% of the costs of creating drip irrigation systems that reduce water consumption and increase yields are reimbursed.

In addition, another serious problem faced by farmers in the Turkestan region is desertification.

This is due to clearly unfavorable trends in the development of virgin and fallow lands in Kazakhstan (1954–59), as well as the increased intensification of the use of agricultural land in Kazakhstan over the past fifteen years to increase exports of wheat and wheat flour. Traditional extensive animal husbandry also has an impact on almost the entire territory of Kazakhstan.

For 2024, it is proposed to allocate 14 million U.S. dollars to reduce the cost of mineral fertilizers and 1.2 billion U.S. dollars for the development of seed production, which, together, should contribute to increasing the yield of priority crops such as corn and greenhouse vegetables. This strategic subsidy is aimed at improving the agroecological status and food security of the region in the future.

Similarly, the salary increase was complemented by educational activities in the field of improving the professional competence of agricultural producers in the region. The Ministry of Agriculture of Kazakhstan has authorized training on the use of EGISS for farmers and specialists of the Department of Agriculture of the Turkestan region. This training program is useful because it reduces the number of processes and steps required to apply for grants, which makes financial support more accessible and the distribution process more understandable.

3. Results

Location-Specific Traditional Knowledge

Location-specific indigenous knowledge represents a crucial resource for rural communities in regions like the Turkestan area of Kazakhstan, where access to modern agricultural technologies is limited and the economic viability of small-scale farms heavily depends on such traditional practices. Farmers in these countries have used this knowledge for thousands of years to produce food sustainably without the use of chemical inputs and farm machinery powered by fossil fuels. Approximately 90% of the world's 570 million farms are small (less than 10 ha), and most of them are located in rural regions in developing countries [15]. Many of these farmers are poor and have limited access to technology, markets, and services, increasing the importance of traditional knowledge for productivity and economic viability of these farms. In Turkestan, this traditional knowledge remains essential to overcoming challenges related to resource limitations and environmental conditions, which require further research and adaptation to align with modern productivity and sustainability goals. Some important traditional agricultural practices are discussed below

1. Agroforestry

It involves planting trees along with the crop to create a microclimate that helps mitigate extreme climatic conditions commonly experienced in the Turkestan region. The trees protect the farmland from soil erosion and the crop against extreme temperature, rain, and wind. At the same time, the farm produces a diversified range of products such as food, firewood, timber, and products of medicinal value. In Turkestan, agroforestry is recognized for its role in soil conservation and as a habitat for native flora and fauna, which aids in maintaining local biodiversity. Agroforestry is more common in low- and middle-income nations, particularly in tropical regions, but is gradually gaining ground in more temperate regions also [16]. Increased recognition of agroforestry as an effective conservation method is reflected in constantly increasing research and policy support.

2. Mixed Cropping

Mixed cropping, or intercropping, is a traditional system of agriculture in which the farmers cultivate two or more crops at one time on a farm. In the Turkestan region, mixed cropping has proven beneficial by providing greater resilience to environmental stresses and economic stability for smallholders. The main advantage of mixed cropping is the reduction in the risk associated with a single crop failure, stability of outputs, resilience, and sustainability. Mixed crop systems have also been found to reduce the losses associated with pests and diseases, suppress weed growth, and reduce the requirement for inputs such as fertilizers and pesticides. Some common mixed cropping combinations are grains and pulses, and grains and oilseeds, and the right combinations can result in a significant increase in yield. Mixed cropping systems are less dependent on external energy for stability due to the mutually beneficial and synergistic effect of different plant species and associated animal species [17]. Studies have indicated that mixed cropping can reduce the occurrence of diseases and pests [18] and suppress weed growth [19]. The main economic advantage of multiple cropping systems is that they offer economic stability as multiple products buffer the unexpected fluctuation in the price of one commodity. The disadvantage of multiple cropping systems is that they may be more challenging to manage and may not always lead to higher yields. Also, they are more suitable for farms where seeds are sown manually.

3. Crop Rotation

Crop rotation involves the practice of cultivating various crops in successive seasons on a farm which improves soil fertility by increasing soil mineral breakdown [20], and soil organic content [21, 22]. The practice also helps in achieving better control of weeds and pests [23–25] and results in increased yields [26, 27]. The Food and Agriculture Organization acknowledges crop rotation as a fundamental approach within integrated pest management strategies [28]. It is also an effective tool for the interruption of disease cycles, as the non-availability of the host plant species for a period of time interferes with the completion of the pest life cycle and results in a reduction in the inoculum present in the soil over time. Numerous studies have indicated that crop rotation can significantly impact soil microbial communities, which are shaped by the architecture of plant roots and the chemical properties of root exudates [29, 30]. Soil microorganisms facilitate 80–90% of all processes taking place within the soil [31] and a healthy microbial community favors plant growth and development. Soil microbes perform functions such as fixation of atmospheric nitrogen, release of plant growth regulators, production of antibiotics that inhibit the development of pathogenic microorganisms, and improvement of soil texture by producing polymers, improving the absorption of nutrients such as phosphorus and so on. Crop rotation is particularly important for organic farms that do not utilize chemical inputs for cultivation. For Turkestan's organic farming, crop rotation is particularly vital, enhancing soil health without chemical inputs and fostering long-term sustainability. The general principle of crop rotation is to plant a leguminous crop (e.g., pulses, alfalfa, or clover) after a cereal crop (e.g., rice, wheat, maize) and then leave the farm undisturbed for at least one season. Numerous studies have demonstrated that crop rotation can greatly enhance sustainability and long-term profitability without necessitating additional investments.

4. Water Harvesting

Rainwater harvesting is a practice of collecting and storing rainwater for productive use, instead of letting it run off and cause soil erosion, and has been practiced for millennia in most arid and semi-arid areas of the world [32]. Agriculture uses 60–90% of available water in a region, and it is estimated that to meet the food requirements of a growing population, a 53% increase in the con-sumption of water resources will be witnessed by 2050. This will be a huge burden on the already stressed water resources and the situation may worsen further due to changing climatic patterns. Rainwater harvesting has been found to be a viable alternative for supplementing conventional water supplies for various purposes including crop irrigation and minimizing the effects of droughts which may occur with increased frequency due to climate change [33]. Effective management of agricultural water resources and the adoption of water-efficient irrigation practices can enhance food productivity while also helping to mitigate the impacts of climate change on agriculture. Rainwater harvesting systems, such as farm ponds, dams, and tanks, can be an important source of water during water scarcity or irregular rainfall, and rainwater harvesting can prove to be an important factor in boosting farm productivity. Adopting water-efficient irrigation and rainwater harvesting systems, such as farm ponds, dams, and tanks, has become an essential adaptation strategy in Turkestan, enhancing crop productivity and food security during periods of low rainfall.

5. The materials that are used in organic fertilization and composting methods are manure, compost, and plant residues. These practices enhance the content of organic matter in the soil, improve the structure of the soil, and enable retention of water. In the Turkestan region, the substitution of synthetic fertilizers with organic ones leads to yield improvement on average by 10–15%, while the cost of synthetic fertilizers decreased by 20%.

6. Mulching is the act of putting organic matter like straw or leaves on the surface of the soil in order to conserve moisture, reduce weeds, and prevent soil erosion. In the semi-desert climate of the Turkestan Region mulching decreases evaporation of moisture from the soil by 25–35% and provides stable plant cover in the dry period. It is noted that the use of mulching decreases the rate of evaporation of moisture in the soil, which is crucial for regions with a lack of fresh water. Experts found that the application of mulch enhances crop yields by a range of 17 to 73%, depending on the type of crop and the environment in which the crop is grown. For instance, when scientists tested tomatoes, barley, and wheat crops, yields increased by these percentages while using sand that has superhydrophobic properties as mulch in field trials [34]. Due to the climatic conditions of the region, it is advised to use what is locally available like straw, hay or compost for mulching.

Common practice indicates that the mulch should be 5–10 cm thick in order to retain soil moisture and suppress weeds. When mulching is used together with other agro technical practices, including crop rotation and the use of organic nutrients, agricultural production in arid regions can achieve high levels of productivity.

7. Green fertilizer entails planting legume or mustard types of ground cover and then incorporating them at any time of the year to enhance the organic nutrient level as well as the structure of the soil. This method leads to an increase in organic matter in the soil to something like 15–20% and thereby improves anti-erosion measures. The application of green fertilizers is one of the ways of increasing the fertility and sustainability of agroecosystems in the Turkestan region, which experiences problems connected with the depletion of soil stock due to arid conditions. The practice of sowing legumes as siderates, for instance, alfalfa or clover, enhances the physical attributes of the soil, its water-holding capacity and minimizes the use of chemical fertilizers [35].

8. Integrated Plant Protection (IPR) is a method of pest control where separate measures are used collectively to reduce losses in crops. Biological pest control is one of the strategic models of IPR that employs the utilization of biological methods, whose principle is based on the management of pest numbers using their natural enemies. The effectiveness of the mentioned biological methods within the IPR context is supported by data pointing to a reduction in pest quantities with their usage. Consequently, the possibility to control the whitefly with parasitic wasps *Encarsia formosa* when cultivating plants in the greenhouse enables a reduction in the number of pests in that environment by 80–90%. The release of aphid predators, such as ladybugs, helps lower aphid numbers by 65–90%, depending on the climate. The bacterium *Bacillus thuringiensis* used in treatment programs results in a reduction in pest caterpillar populations by 75–85% [36]. Thus, it can be concluded that biological methods are an integral part of integrated plant protection, providing effective and environmentally safe control of insect pests.

In crop production, the process of introducing innovations is considered a sequence of four stages: the development of innovations, their verification, reproduction and implementation into activity. For Turkestan's agricultural sector, **Figure 4** illustrates a generalized algorithm for the effective implementation of innovations. This structured approach enables the integration of traditional practices with new agricultural methods, optimizing the sustainability and productivity of the crop production complex.

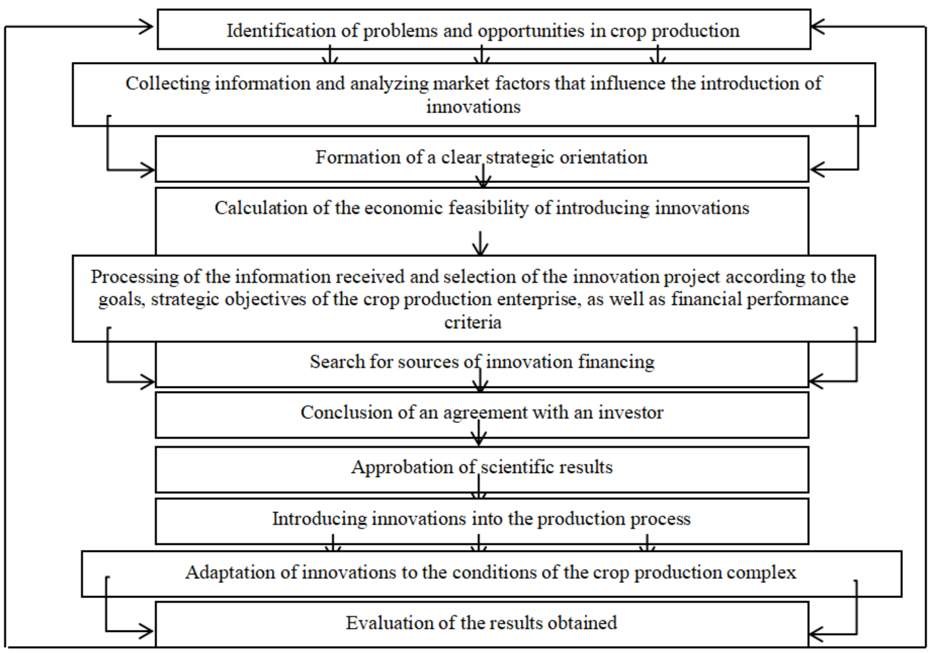


Figure 4. Generalized algorithm of technology for introducing innovations in crop production in the Turkestan region.

In the conditions of the Turkestan region, this algorithm allows us to consider the process of introducing innovations in crop production at each stage, with the possibility of identifying and consolidating positive dynamics in the development of agriculture in the region.

The formation of an effective strategy for managing innovation activities in crop production is inseparable from the problem of profitable allocation of investments and their most effective use.

The investment decision-making process is divided into the following stages: development of a system of indicators for evaluating investment projects in accordance with the objectives of the innovation project; forecasting possible environmental conditions of the investment project; development of criteria and models for making investment decisions. It is proposed to form an investment decision-making model from a set of alternative solutions, possible investment projects, and business environment factors that ultimately affect the effective implementation of accepted projects. The model is filled with parameters characterizing the state of the environment, as well as predictive constraints of variables depending on the system

It is established that the state, in the absence of sufficient resources to finance innovative development, should focus not on direct financing, but on incentive mechanisms. Methodological approaches to the application of benefits for participants in the innovation market are proposed: for the development of human capital, for crop producers, research institutions and investors (**Figure 5**).

The selection criterion for granting a tax benefit may be the compliance of innovative projects with the selection parameters according to the following criteria: the impact on rural living conditions and human life safety, the development of human capital, increasing the economic efficiency of production and resource conservation in crop production, achieving world-class and international competitiveness of crop products, changing the role of regions in the national economic system, and the development of communications and technology transfer in crop production in the Turkestan region.

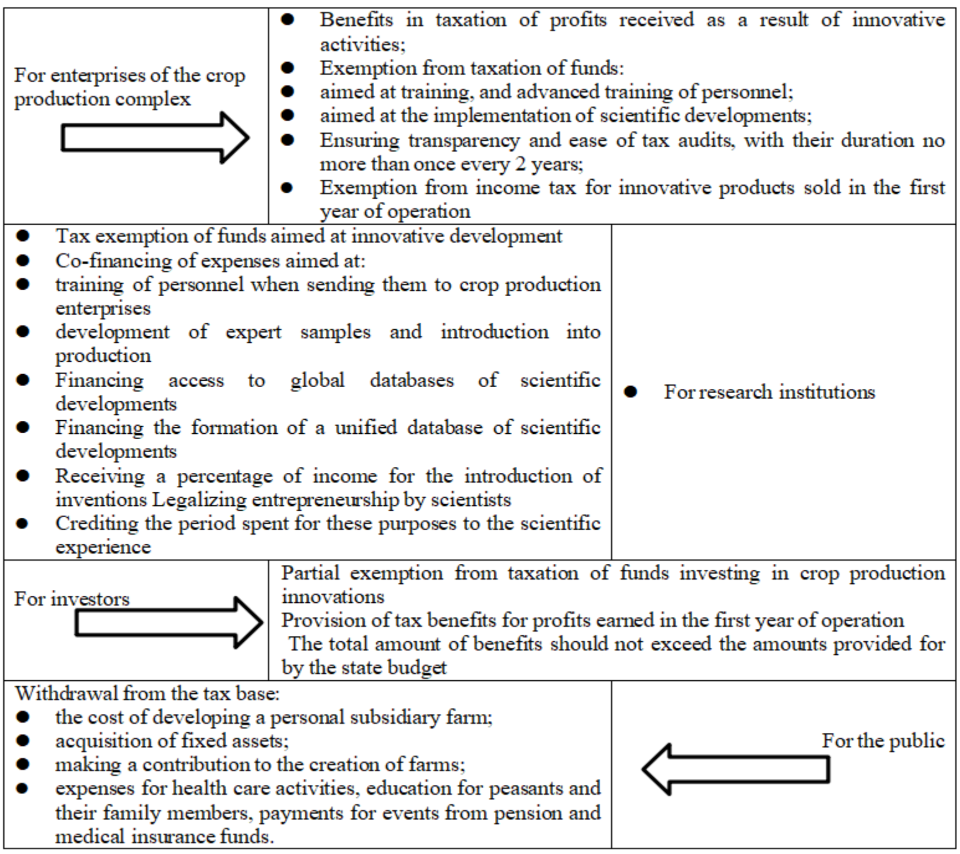


Figure 5. Scheme of the mechanism for stimulating innovative development in crop production.

Source: Developed by the author.

For the Turkestan region, this incentive mechanism offers significant benefits and supportive measures for all participants in the innovation process in crop production, from producers to research institutes and investors. Indicators for evaluating the effectiveness of innovative investments are proposed to be grouped according to the areas of quality and quantity. Having defined the concept of quality of an investment project as compliance of its parameters with the requirements of social and environmental safety, qualitative assessments include improvement of social protection, reduction of environmental damage and compliance with the interests of society and the state.

Several problems are characterized in the agricultural sector of the Turkestan region, the yields of which are quite low, and the cost of production is high; water consumption is also significant. Next we will analyze the impacts of innovative mechanisms for stimulating innovative development in crop production including precision agriculture, drip irrigation, and agroforestry, on productivity indices of agricultural activities. A scenario-based analysis was conducted to estimate the outcomes under three scenarios: pessimistic outlook, realistic outlook, and optimistic outlook.

To estimate changes in crop yields, production costs, farmers' income, and water usage, the following mathematical models were employed:

$$Y_{improved} = Y_{current} \times (1 + \Delta_{change}) \quad (1)$$

Where $Y_{current}$ represents the current yield, and Δ_{change} is the percentage improvement based on the level of technology adoption.

Water usage was modeled using:

$$W_{improved} = W_{current} \times (1 - \Delta_{economy}) \quad (2)$$

Where $W_{current}$ is the current water consumption, and $\Delta_{economy}$ is the reduction rate achievable with drip irrigation.

Farmers' income was forecasted as:

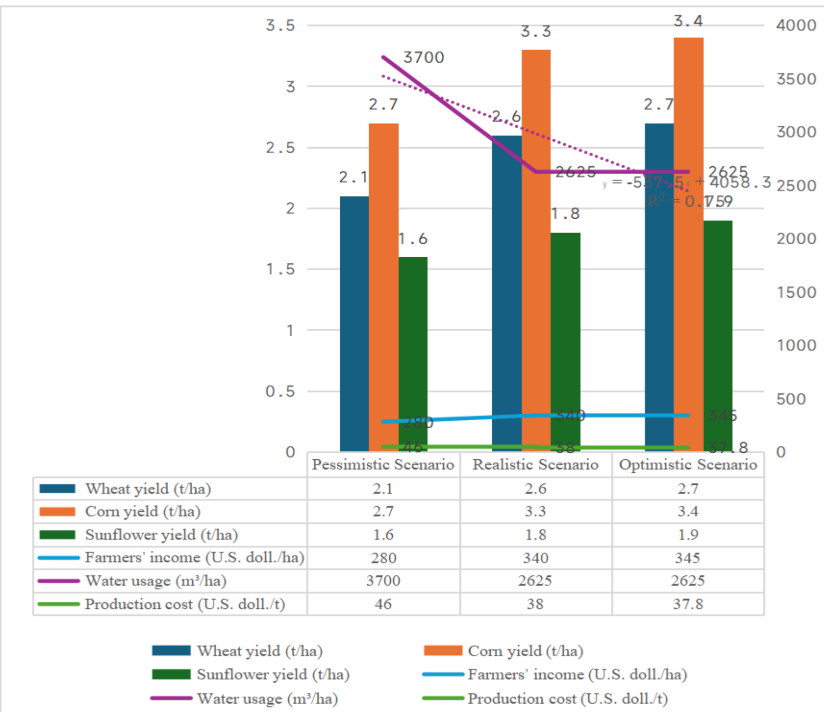
$$R_{improved} = R_{current} \times (1 + \Delta_{growth}) \quad (3)$$

and production cost was estimated as:

$$C_{improved} = C_{current} \times (1 - \Delta_{reduction}) \quad (4)$$

Where $C_{current}$ is the current production cost, and $\Delta_{reduction}$ represents the expected decrease in expenses.

The following **Figure 6** summarizes the calculated results under each scenario:



	Pessimistic Scenario	Realistic Scenario	Optimistic Scenario
Wheat yield (t/ha)	2.1	2.6	2.7
Corn yield (t/ha)	2.7	3.3	3.4
Sunflower yield (t/ha)	1.6	1.8	1.9
Farmers' income (U.S. doll./ha)	280	340	345
Water usage (m³/ha)	3700	2625	2625
Production cost (U.S. doll./t)	46	38	37.8

Figure 6. The results of the analysis of the impact of the mechanism for stimulating innovative development in crop production.

The pessimistic case considers the application of the above-mentioned mechanisms to be limited due to financial constraints and lack of farmer education. Under these conditions, yield decreases to 2.1 t ha^{-1}, water use reaches 3700 m^3 ha^{-1}, and production costs grow to \$46 t^{-1}. Farmers' income also reduces to \$280 ha^{-1}, which indicates the drawbacks of present methods.

The realistic perception with moderate levels of adoption of advanced technologies, including drip irrigation and agroforestry, exhibits marginal gains. Increases in yields stand at 2.6 t ha^{-1}, while water consumption stands at 2625 m^3 ha^{-1}, and costs are at \$38 t^{-1}. Use efficiency and productivity increase to \$340 ha^{-1} in farmer income.

The greatest gains are achieved with the optimistic case, in which the various mechanisms elaborated in the analysis are fully implemented. Integrated application of GPS and sensor technologies for effective examination of soil and crop resources enhances precision agriculture. Drip irrigation lets little water go to waste, so it cuts water usage by as much as one quarter. Other benefits associated with agroforestry include land regeneration, improvement of soil strength, and long-run sustainability. In this case, yield amounts to 2.7 t ha^{-1}, water use efficiency is 2625 m^3 ha^{-1}, and production costs amount to \$37.8 t^{-1}. The income of farmers increases to \$345 per hectare due to the increase in profitability and quality of products.

The usage of the presented mechanisms based on the results of the scenario analysis shows the opportunities for the sustainable development of agriculture in Turkestan. Substantial improvements in yield, resource use, and economic results are revealed under the optimistic scenario where comprehensive adoption is stressed. But to realize these outcomes, governments should involve farmers much earlier, invest in sophisticated technologies and launch proper education programs. To a degree, these results underscore the importance of the effects of innovations on the sustainability of agriculture and the region's economic stability.

4. Discussion

4.1. Conservation Agriculture

Conservation Agriculture (CA) is a resource-efficient and potentially sustainable farming system founded on three core principles: 1) minimal soil disturbance, which entails no-tillage or very limited tillage; 2) maintenance of permanent soil cover; and 3) promoting crop system diversity through crop rotation. In the context of the Turkestan region, where arid and semi-arid conditions prevail, these principles are particularly valuable. CA improves the natural biological processes occurring above and below the soil leading to improvement in water and nutrient uptake efficiency. The external inputs such as fertilizers, pesticides, weedicides, and mineral nutrients are introduced at the optimal level and in the manner and quantity in which biological processes are minimally disturbed [28].

Agriculture accounts for 10–12% of total anthropogenic greenhouse gas emissions, which were estimated to be between 5.1 and 6.1 Gt CO2-equivalents per year in 2005. Conservation agriculture reduces greenhouse gas emissions by sequestering more carbon in the soil. The no-tillage/minimum tillage increases the amount of carbon in the soil by reducing the oxidation of organic material present in the soil and also by locking carbon in the form of permanent soil cover. The no-tillage/minimum-tillage practice also reduces the consumption of fuel for crop production, which not only increases farm profitability but also results in lower greenhouse gas emissions. The reduced agrochemical input also reduces the greenhouse gas emissions associated with nitrogen containing fertilizers. In fact, NO_2 released from the degradation of nitrogen-containing fertilizers is potentially about 300 times more effective than CO_2 in trapping heat [34].

The economic benefit from the reduced fuel usage and the lower labor cost associated with mechanized operations such as tillage and the external input application is proven; however, the benefit also depends on the type of crop and other growing conditions. For example, in semi-arid conditions similar to those in Turkestan, conservation agriculture can reduce mechanization costs by more than 50% for maize and 75% for wheat [35]. However, the overall economic benefit obtained from the adoption of conservation agriculture is determined by the production yield, which is affected by many factors such as crop type, seed variety, soil conditions, pest management, and climate. In one study, an increase in gross margin of 6.6% was obtained by reducing production costs and maintaining the yield unchanged [36]. Since conservation agriculture helps in increasing soil water holding capacity and achieving decreased evaporation from the soil surface, the benefits are more evident in the arid and semi-arid regions [37].

Yield improvements have been noted in several studies for different crops cultivated using conservation agriculture. Despite demonstrated sustainability and economic benefits from conservation agriculture, the adoption of this system of agriculture has been slow, mainly due to inconsistent results which may be attributed to factors such as lack of experience of the farmer, slow increase in soil fertility, waterlogged soil following unexpected rains, use of fertilizers and other chemical inputs in inappropriate amounts, inefficient weed and pest management, diseases originating from the mulch and soil compaction etc. [38].

The role of conservation agriculture in improving crop production sustainability has been reported by many studies. The no-till practice of conservation agriculture significantly reduces soil erosion. One study conducted on farms in Indiana, USA, and reported in 1970 found that no-till methods reduced soil erosion by > 70% [39]. Similarly, the cultivation of tobacco with the no-till method has been found to reduce soil erosion by > 90%. Application of fertilizers in no-till agriculture was found to significantly decrease soil erosion due to water run-off [40]. Thus, the practice of conservation agriculture can play an important role in preventing soil erosion and improving soil quality.

Availability of better seed planters for no-till soil and improved herbicides in many areas of the world in the past 40 years have contributed to the wider adoption of CA. Currently, about 125 million hectares of land, or about 10% of the overall agricultural land is under conservation agriculture. The maximum adoption rate is in Australia, Canada, and the southern cone of South America (above 50% of cropland), and adoption in African, Central Asian and Chinese countries is rising [41, 42]. For greater adoption in the Turkestan region, cost-effective access to high-quality seeds, affordable mineral fertilizers, specialized equipment, and better pesticides is necessary.

However, certain limitations associated with CA are important to consider in the Turkestan region. Greater acceptability and wider adoption of CA require cost-effective sources of good quality seeds, affordable mineral fertilizers, specialized equipment, and better pesticides.

The limitations associated with Conservation Agriculture (CA) have been detailed and may encompass an increase in crop diseases and insect pests, the emergence of herbicide-resistant weeds, an over-dependence on agrochemicals, excess moisture, cooler soil temperatures, an initial rise in nutrient requirements, and the necessity for specialized nutrient management to prevent immobilization and volatilization [43]. Additionally, if livestock are integrated into CA systems, as in some farming areas of Turkestan, transitioning requires a distinct approach compared to conventional tillage agriculture.

4.2. Crops and Cultivars

The Green Revolution (GR) has provided farmers with hybrid varieties of several staple crops, including wheat, rice, and maize, which have played a crucial role in boosting food production, alleviating hunger, and preventing the conversion of additional uncultivated land for agricultural use [44]. The substantial yield improvements of many crops played an important role in increasing the availability and affordability of the food products derived from these crops to the poorer section of the population. The increased productivity of crops brought about by the hybrid cultivars developed during the GR has also played an important role in alleviating poverty.

However, the GR has also led to some environmental and ecological problems such as widespread contamination of land and water resources with agrochemicals, soil erosion, loss of biodiversity due to the cultivation of high-yielding varieties of a few crops, and overexploitation of water resources. In Turkestan, where water resources are already strained, the heavy use of water for high-yield varieties has exacerbated local water scarcity issues, especially during dry seasons. The adoption of high-yielding hybrid varieties has also resulted in a substantial increase in the carbon footprint of agriculture, primarily due to the reliance on fossil fuels for the production of agrochemicals and mechanized operations [45]. It is estimated that agriculture accounts for approximately 10–14% of global anthropogenic greenhouse gas emissions [46].

As the population continues to rise, along with increasing pressure on natural resources and environmental degradation, new agronomic practices will be essential for sustainably feeding the growing population. Development of new cultivars not only for cereals and other staples but also for fruits and vegetables will be required. Plant breeding technologies and biotechnology are expected to play a major role in the achievement of this goal.

The past few decades have seen major progress in the achievement of technological capabilities for developing new plant varieties with more control over the desired traits. Turkestan cultivates several drought-resistant crops well-suited to its arid climate. Notably, wheat varieties such as Turkestan, Yaksart, Jayhun, Asr, Gozgan, Bunyodkor, and Hisorak have been developed for rainfed areas, demonstrating high yields and quality under drought conditions. Additionally, the saxaul tree (Haloxylon ammodendron), native to Central Asia, thrives in sandy deserts and plays a crucial role in afforestation efforts to combat desertification. These new breeding technologies can potentially meet the challenge of feeding an ever-growing population sustainably by increasing yields, which will not only help in the sustainable intensification of agriculture but also help in the mitigation of the environmental and ecological problems caused by the overuse of agrochemicals. Some plant breeding technologies and their present and future role in sustainable agriculture are discussed below.

1. Transgenic crops: The genes coding for desired traits in one species can be inserted into the genome of another species by using genetic engineering, and the resulting organism is called a transgenic or genetically modified organism (GMO). The recombinant DNA technologies have allowed the precise introduction of a particular trait in plant species as opposed to the random outcomes of traditional breeding. Also, the limitation of traditional breeding of transferring traits only within the same species is bypassed using recombinant DNA technology, and the traits from any species can be transferred to any other species. This is particularly useful for vegetatively propagating plants such as banana, sweet potato, and pineapple, which are not amenable to improvement through conventional breeding. Currently, the most widely used GMOs are herbicide-tolerant and insect-resistant varieties of various crops [47]. The use of transgenic crops has increased rapidly from 1.7 million hectares in 1996 to 191.7 million hectares in 2018, a 113-fold increase. The use of transgenic crops has played an important role in increasing crop yields by 22% and farmers' profits by 68% [48].

2. Gene Editing: The technique of gene editing allows targeted modification of the DNA of an organism by deletion, duplication, replacement, and modifications of bases. Unlike genetic engineering, which causes the insertion of genetic material randomly in the genome of an organism, the gene-editing techniques allow precise modifications at predetermined sites. Several nucleases, including meganucleases, zinc finger nucleases, transcription activator-like effector nucleases (TALENs), and the CRISPR/Cas9 system, are employed for gene editing. For regions like Turkestan, where crop resilience to extreme temperatures and drought is essential, gene-edited varieties could offer solutions by introducing drought resistance, heat tolerance, and nutrient efficiency traits directly into local crops. The technology can be used for the generation of simple or complex mutations as well as for inter-specific gene transfers.

The first genetically modified organisms (GMOs) utilized in agriculture were insect-resistant crops that incorporated bacterial genes from *Bacillus thuringiensis*. Since then, a variety of other crops, including cereals, sugar beet, soybean, corn, canola, papaya, and alfalfa, have been engineered with traits for insect resistance, herbicide tolerance, virus resistance, and drought tolerance. The pest and disease-resistant crops are expected to prove important for the sustainable intensification of agriculture as their cultivation will minimize losses due to pests and diseases and result in higher yields. Currently, many groups are working on the development of genetically modified crops such as maize, rice, wheat, beans, oilseeds etc., resistant to abiotic stress of heat, cold, salinity, and flooding [49]. The crops with resistance to environmental extremes are important for mitigating the effect of climate change on agriculture. Work is also progressing in the direction of the development of nutrient-efficient crop varieties, which will reduce the amount of fertilizers required for optimal yields leading to a reduction in soil degradation and carbon footprint, an important step towards the sustainability of agriculture. The researchers are also working on increasing the photosynthetic efficiency of plants for better yields. Success in these endeavors will be an important step towards sustainable food production and reduction in the conversion of additional non-agricultural land for cultivation.

Since the introduction of genetically modified Bt cotton, genetically modified crops have found wide adoption in both developed and developing countries. The highest adoption rate is in North America, and South America followed by Asia. The acceptance of GMO crops in Europe and Asia has been poor because of unfavorable regulatory policies.

4.3. Weed and Pest Control

Weeds cause formidable losses in agricultural production and are a major constraint in increasing agricultural yield. Even with current crop protection measures about one-third of the crop produced worldwide is lost to pests. The worldwide yield losses in three major crops, rice, wheat, and maize, due to weeds are estimated to be 27.3–33.7% of losses caused by all other pests combined [50]. Weed management is a significant part of the cost of production on farms. The availability of effective herbicides and herbicide-tolerant crops has reduced the cost associated with manual labor; however, the widespread use of herbicides is now causing environmental and ecological problems [49, 51–53]. The herbicides may directly affect non-target organisms by direct exposure or indirectly by causing changes to the ecosystem and food resources. For example, it has been found that the use of the weedicide glyphosate has increased the level of pathogenic fungi in the soil by negatively affecting other microorganisms that normally keep pathogenic fungi in check. In other studies, it was found that glyphosate could reduce the population of some earthworm species which helps in the maintenance of soil quality and fertility [54]. The application of glyphosate has also been found to disturb the population of some wildlife species around the fields where it is applied. For instance, glyphosate application has been linked to declining populations of Monarch butterflies since the mid-1990s in North America. The Monarch butterfly larvae feed primarily on milkweed, and the use of glyphosate has resulted in a large reduction in the population of this plant. The Glyphosate can be washed into water reservoirs and also reach underground aquifers by washing down the soil and rocks. The groundwater is a major source of drinking water in many areas.

Sustainable intensification of agriculture requires minimal use of chemical pesticides. Some conventional weed management methods such as the implementation of preventive measures, tillage and mechanical control, soil coverage, crop competition, crop rotation, and crop diversification, etc., can be used along with biological and chemical control methods to effectively and sustainably manage weeds. The ecological concept of allelopathy can also be employed for weed control. With the increasing recognition of environmental, ecological, and human health problems caused by agrochemicals, it is important to adopt an integrated weed management (IWM) system incorporating more than one method of weed control, which maximizes crop yield while reducing the impact on the environment and human health. For instance, integrating a dual culture of fish and Azolla has been found to effectively complement the weed control methods in rice. Off-season tilling and mulching of inter-row space in combination with herbicides can effectively manage weeds in cotton.

Herbivorous insects are responsible for about 20% crop loss globally despite an annual investment of about USD 40 billion in the production and use of 3 million metric tonnes of pesticides and other non-chemical pest control methods [55]. Pests such as locusts pose a serious threat to the agriculture of the region. In 2024, the Turkestan region faced an invasion of Moroccan locusts, which required prompt measures. According to the Ministry of Agriculture, the area of pest spread in the region amounted to 271 thousand hectares, and more than

340 thousand hectares of land were treated. According to the akimat, in 2023, 70 thousand hectares of locust-covered lands were sprayed in the Turkestan region. The destruction of locusts is carried out by contracting companies, and control is entrusted to the territorial inspectorate. According to the Ministry of Agriculture, two and a half million hectares of land in Kazakhstan are covered by pests. This is one million hectares more than in 2023.16.2 million US dollars have been allocated from the budget for the fight against locusts. 2,500 people are currently fighting locusts across the country.

The pesticide residue in food and water resources poses serious health risks, and farm workers are at particularly high risk for developing health problems related to abnormally high pesticide exposures [56]. Pesticides also affect ecosystem stability by reducing insect biodiversity [57]. There is an urgent need for pest management strategies that do not affect yields but are environmentally and ecologically sustainable. Large-scale monocultures lead to increased prevalence of pests and diseases, whereas increased crop diversity achieved by crop rotation and intercropping can be beneficial in reducing pest and disease prevalence in agriculture. In one study, where cotton was interplanted with lucerne, a significant increase in predatory insects such as beetles, bugs, lacewings, and spiders was noticed in the fields [58]. In another study where castor was intercropped with cluster beans, chickpeas, black gram, or groundnuts, a natural increase in the population of natural enemies, such as *Microplitis, coccinellids*, and spiders, targeting the major pests of castor was observed. Not only was the incidence and damage due to castor pests minimized, but also the intercropped systems were more efficient in terms of equivalent yields and equivalent land ratio [59]. Intercropping of tobacco and maize was found to reduce the tobacco brown spot leaf disease and simultaneously decrease the incidence of northern maize leaf blight by 19.7% [60], while in a maize-potato intercropping system, the severity of potato late blight was reduced by 39.4% [60]. Thus, increasing crop diversity in the fields is an effective strategy to minimize the damage caused by pests and diseases. Another useful strategy for sustainable pest management is biological control, where natural enemies of the pests are used against them [61]. The application of irradiated, sterile insects to control pest population growth has been effectively employed against various pests [62]. The behavior of a pest can also be used to control its population by the use of baits, traps, and mating disruption. Microbial control (bacteria, fungi, viruses, and microsporidia) is another strategy that has also been used for sustainable pest control in many cases.

5. Conclusions

The growing population and the simultaneous degradation of natural resources and ecosystem services due to current chemical-intensive agricultural systems have necessitated the adoption of new farming practices that do not compromise on yield, but, at the same time, are more considerate of the environment. Multi-stakeholder innovation processes play a significant role in generating workable, practical solutions that farmers will be motivated to accept and adopt. The challenges facing agriculture in the Turkestan region are closely related to different problems, such as variable climatic conditions, limited water availability combined with desertification and soil erosion, as well as frequent droughts. Many of these factors significantly reduce the level of agricultural productivity and, thus, create the need to introduce sustainable and innovative methods that would help mitigate the effects of climate change on agriculture and food security in the region. Thus, the corrective and developmental measures and strategies proposed in the article can not only make direct positive changes in agricultural practices related to the production of food crops but also have a positive impact on regional policies for adaptation to new changing climatic conditions.

The algorithm for introducing innovations in crop production provides farmers of the Turkestan region with a step-by-step approach to the formation of new technologies. By breaking down the process into key stages and using problem identification, analysis of relevant market conditions, innovation and analysis of the results obtained at each stage, risks are minimized and adaptability is achieved at each stage. The stages related to the assessment of economic efficiency and verification of scientific results allow farmers to use only those innovations that are practically important and profitable in their region, which is crucial from the point of view of limited resources.

The scheme of the mechanism for stimulating innovative development in crop production allows farmers to provide significant financial incentives to eliminate obstacles to the introduction of innovative farming methods. Offered in the form of benefits or subsidies, as well as through co-financing mechanisms, these rates reduce costs even for small producers and facilitate the development of technologies such as drip irrigation and precision farming systems. It also provides farmers with information on various possible ways in which they can use government support to finance the changes that need to be implemented economically, while moving towards sustainable methods that will help improve the efficiency of the use of necessary resources and overall yields.

In addition, educational programs and scientific resources provide farmers with the opportunity to expand their knowledge and skills, which allows them to apply a non-trivial approach to mastering new technologies and improving work efficiency. Training in the principles of sustainable agriculture, along with knowledge in the use of modern agricultural tools, helps farmers make the right decisions, as well as respond appropriately to climate and market challenges.

As a result, all of the above measures increase farmers' incomes by increasing production efficiency, minimizing resource costs and improving product quality. At the same time, they define the prerequisites for creating more stable and rational management, which is crucial for farmers in the Turkestan region, since climatic and environmental conditions are quite unfavorable. Due to the fact that farmers can reliably plan the further development of their farms using the proposed methods, their standard of living and condition are improving.

The given analysis of the scenarios proves the great opportunity of developing new mechanisms to increase the effectiveness and sustainability of agricultural production in the Turkestan region. Emerging technologies like precision agriculture, drip irrigation, and agroforestry show positive trends with regards to statistics like crop productivity, water-wise farming, and farm income. Appropriate utilization of these innovations is sufficient in eliminating the resource scarcity issue but, more importantly, it enhances economic performance through reducing costs and enhancing profitability levels. These results have a clear implication that the region's farming practices need to incorporate these advanced technologies to promote sustainable agriculture and economic development for the future.

At the same time, traditional knowledge is of tremendous importance as the source that fills the gaps in the application of modern technologies. Soil health improvement through techniques such as, agroforestry, and integrated pest management, which mainly focuses on weeding out the use of chemical products, all work towards the development of a healthy system for agriculture. These approaches are traditional and fit well into sustainable agricultural solutions since they are cheap and eco-friendly. This research shows that combining these methods with new technologies opens up the opportunity to increase levels of output without harming the environment.

The analysis also emphasizes the need for education and financial incentives, and policy changes for farmers. This, therefore, implies that although these practices may be known to function effectively, smallholders may not accrue these benefits because of inadequate financial and human capital. It is clear that at a micro-level there has to be a framework that supports agriculture in the region that does not deny traditional/agrarian practices any place but also is open to innovation in technologies and has distinct support structures that can sustain agriculture in the long run.

The traditional knowledge of farmers, which includes many elements of sustainable agriculture, can be merged with the modern scientific understanding of sustainable systems to create effective solutions for the sustainable intensification of agriculture. The chemical inputs used in industrial agriculture can still be used but within a broader framework of a sustainable system where their use is minimized in favor of more environmentally friendly options. Innovative and sustained efforts to reduce the wastage of food are also required to reduce the burden on agricultural systems.

Author Contributions

Conceptualization, G.Z.A. and A.M.Y.; methodology, A.M.Y.; software, P.T.B.; validation, A.A.A., G.Z.A., and P.T.B.; formal analysis, A.M.Y.; investigation, A.M.Y.; resources, G.Z.A.; data duration, G.Z.A.; writing—original draft preparation, G.Z.A..; writing—review and editing, A.M.Y.; visualization, supervision, Z.T.A. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement

Not applicable.

Conflicts of Interest

We declare that the authors have taken all the required permissions (if necessary) before submitting the manuscript.

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