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*Edited by İbrahim Kahramanoğlu,
Murat Helvaci and Olga Panfilova*



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Aims and Scope of the Series

The importance of agriculture cannot be overstated. It helps sustain life, as it gives us the food we need to survive and provides opportunities for economic well-being. Agriculture helps people prosper around the world and combines the creativity, imagination, and skill involved in planting crops and raising animals with modern production methods and new technologies. This series includes two main topics: Agronomy and Horticulture, and Animal Farming. This series will help readers better understand the intricacies of production agriculture and provide the new knowledge that is required to be successful. The success of a farmer in modern agriculture requires knowledge of events happening locally as well as globally that impact input decisions and ultimately determine net profit.

Meet the Series Editor



W. James Grichar has been employed with Texas A&M AgriLife Research for over 45 years with an emphasis on research in agronomy, plant pathology, and weed science. He obtained his BS from Texas A&M in 1972 and his Masters of Plant Protection in 1975. He has published 195 journal articles, over 330 research reports and briefs, 11 book chapters, and over 300 abstracts of profession meetings. He also directs research in many crops including corn, grain sorghum, peanuts, and sesame. He has held various positions in different professional societies including the American Peanut Research and Education Society, Southern Weed Science Society, and Texas Plant Protection Conference in addition to being Associate Editor for Peanut Science and Weed Technology. Significant accomplishments have included spearheading efforts to determine the optimum planting time for soybean production along the upper Texas Gulf Coast. These efforts have shown growers that soybean yields can be improved by 10 to 20% by following a late March to early April plant date. He also has been instrumental in developing a herbicide program for peanut production in the south Texas growing region. Through the development and use of herbicides that are effective against major weed problems in the south Texas region, peanut yields have increased by 25 to 30%.

Meet the Topic Editors



İbrahim Kahramanoğlu is an associate professor at the Faculty of Agriculture, European University of Lefke, Northern Cyprus. He is an expert in horticultural production, postharvest biology and technology, and good agricultural practices. His main research interests are postharvest physiology and handling of fruits, natural and novel technologies for handling and storage, digital and precision farming (agri 4.0) for sustainability, and value-adding to horticultural crops. He has authored various books, book chapters, conference papers, and scientific publications related to his experience.



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Dr. Olga Panfilova, Doctor of Agricultural Sciences, is employed at the Russian Research Institute of Fruit Crop Breeding (VNIISPK) as a leading researcher in the Laboratory of berry breeding and variety studies. Her academic and scientific work is oriented towards horticulture, breeding, and various related studies, including agricultural technology, plant physiology and biochemistry, plant anatomy and morphology, plant introduction, plant adaptability, drought resistance, heat resistance, and winter hardiness, among others.

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Preface

Agricultural production systems are undergoing significant transformation in response to environmental degradation, population growth, and the urgent need for sustainability. Declining soil and water quality, increased frequency of extreme climate events, the persistent threat of pests and diseases, and significant postharvest losses are among the most critical challenges of agricultural sustainability. Agronomy and horticulture, two closely related disciplines, stand at the heart of efforts to meet these challenges by enhancing food productivity, quality, and environmental stewardship.

Agronomy, with its focus on field crop production and soil management, and horticulture, encompassing the cultivation of fruits, vegetables, and ornamental plants, both play significant roles in ensuring food security and improving rural livelihoods. In particular, innovative cultivation systems, resource-efficient nutrient management, climate-resilient varieties, and sustainable practices are essential to building robust agricultural systems. At the same time, bridging the gap between research and practice remains an important goal in advancing the efficacy and impact of modern crop production.

This volume brings together selected research contributions that explore various aspects of these evolving disciplines. The chapters in this book discuss hydroponic systems designed for efficiency and environmental compatibility, the role of molecular breeding in improving salinity tolerance, sustainable nitrogen strategies for sugarcane and cucumber production, and the implications of climate change for long-term agricultural planning. Additionally, soil use and management, a fundamental component of any agricultural system, are addressed in the context of regional practices and sustainability goals.

While the contents of this volume cover diverse crops, regions, and research methods, a unifying theme connects all contributions: the pursuit of sustainable solutions to ensure resilient and productive farming systems. The editors hope that, in addition to providing up-to-date information, this resource will encourage more creativity and cooperation among agricultural scientists, researchers, educators, and policymakers.

We extend our sincere thanks to the authors who contributed their work to this volume and to all reviewers and supporters who helped make this publication possible.

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Chapter 1

Impact of Climate Change on Sugarcane Cultivation

Devanushi Dutta and Pranab Dutta

Abstract

Sugarcane is one of the most important cash crops grown in India and occupies the second position after Brazil. The changing climatic condition affects sugarcane cultivation in many directions. Sunscald, frost injury, and chlorosis are the prominent results of adverse climatic conditions like high temperatures or extreme low temperatures. This article depicts the influence of climatic change on sugarcane cultivation as well as the probable mechanism that plants take up to cope with the changing scenario.

Keywords: frost injury, high temperature, sugar recovery, sunscald, chlorosis

1. Introduction

Sugarcane (*Saccharum officinarum* L.), a member of the grass family (Poaceae) and class Monocotyledones, is an economically important crop grown in almost all tropical and sub-tropical countries spread across the world. Commercial breeds of sugarcane are derived from crosses of *S. officinarum* and *S. spontaneum*. *S. officinarum* is known as noble cane bear chromosome no. $2n = 80$ [1]. This crop can be projected as the crop for the future owing to its capacity not only to produce sugar but also a renewable source of energy in the form of ethanol, electricity, and many biobased products. Sugarcane is one of the important cash crops grown in India. Uttar Pradesh is the sugar bowl of India followed by Maharashtra and Karnataka together produce around 80% of the sugarcane in India that helps to attain the second largest producer country of sugar after Brazil. However, the Government of India had claimed that India would be the largest producer of sugarcane in 2022–2023. Nearly 2.8 lakh farmers have been cultivating sugarcane in an area of 3.93 million ha with annual production of 170 million tones with productivity around 67 t/ha (indiaagronet.com). The crop is presently cultivating across the states of India having diverse agro-climatic conditions contributing to the national GDP is 1.1% [2]. Sugarcane is cultivated broadly in two agroclimatic zones viz. tropical and sub-tropical regions where the Tropical region contributes about 45%-55% and subtropical region contributes 55%–45% However, sugarcane is cultivated in five different agro-climatic zones throughout India viz., North Western, North Central, North Eastern, Peninsular and Coastal zones.

Sugarcane is a water-loving plant. It demands sufficient water particularly during the active vegetative growth stage. Lack of sufficient water results in poor yield and

lower sucrose recovery. Likewise, it requires an optimum temperature for proper growth and development. Inadequacy of any one of the physiological parameters can hinder growth and development of the crop which leads to poor economic yield and less sucrose recovery. So, adequate moisture as well as temperature is required to obtain proper yield.

2. Climatic requirements for sugarcane

2.1 Temperature

Temperature requirement is varied according to the different critical stages of sugarcane, viz. germination, tillering stage, early growth stage, active growth and elongation or maturation stage. Each of these stages has a different temperature requirement. For example, optimum temperature requirement for bud sprouting or germination is 32–38°C. But, germination slows down below 25°C. But, the temperature above 38°C increases respiration and thereby reduces photosynthesis. In contrast, relatively low temperatures in the range of 12–14°C is desirable in the ripening stage to accumulate more sugar [3].

2.2 Water requirement

The soil must have sufficient water during germination. Depending upon the type of soil, agro-climatic zones, and method of planting material used, water requirement varies. To produce 1 ton of cane on average 60–70 tons of water is needed. The crop should be irrigated immediately while the available moisture content reaches 50% level. In tropical India, total water requirement is varying from 2000 to 3000 mm for optimum growth of cane. Whereas, in sub-tropical India, the water requirement is 1400–1800 mm during the crop growth, and for *adsali* crop the requirement of water is 3200–3500 mm (NFSM.gov.in).

Sugarcane cultivation in tropical area required frequent irrigation. During germination, i.e., 1–35 days after planting irrigation is required in every 7 days interval. In the next stage, i.e., in tillering stage or 36–100 days after planting, irrigation should be applied once in 10 days interval. When the crop attains grand growth stage, i.e., 101–270 days after planting, irrigation should be applied once in 7-day interval, and at the end of the crop stage or 271 days after planting, water requirement is gradually reduced. So, one irrigation at 15 days interval is sufficient adjusting to the rainfall pattern.

2.3 Humidity

Nearly 80–85% relative humidity (RH) is required for cane elongation during grand growth stage. RH above 40% coupled with warm weather favors vegetative growth of cane, and 45–65% relative humidity coupled with limited water supply is favorable during the ripening phase. Broadly two different sets of climatic requirements are necessary to complete the life cycle of the plant. One is bright sunshine hours in the warm season for a long duration with high humidity and optimum rainfall in the growing season while the ripening season needs the least precipitation, dry weather with relative humidity of about 51% [4].

2.4 Sunshine

Sugarcane is a sunshine loving plant. Greater the incidence of radiation, higher is the sugar recovery. Bright sunshine hours of approximately 7–9 hours are essential for both growth and ripening stages [4]. Bright sunshine hours accelerate photosynthesis and this ultimately leads to increase sugarcane yield. Cloudy weather reduces the number of tillers while the bright sunshine hours for 7–9 hours is essential for maximum tillering, grand growth as well as maximum stalk formation [4].

3. Favorable conditions for maximum sugar recovery

Dry weather with low humidity, maximum bright sunshine, and cooler night with wide diurnal variation accompanied by little or no rainfall during ripening period is required for maximum sugar recovery. These conditions favor high sugar accumulation. Adverse climatic conditions like very high temperature or very low temperature deteriorate the juice quality, thus affecting the sugar quality. Hot and humid condition also favors disease and pest infestation which ultimately affect juice quality and sugar recovery (Directorate of sugarcane development, Govt. of India, Lucknow, 2013).

4. Effect of climate change in sugarcane crop

Climate change can have significant impact on sugarcane production in the world (as shown in **Figure 1**) especially in the developing countries due to non-availability of suitable cultivar to withstand natural hazards like drought, wind and frost injury, and high temperature. Poor forecasting systems and mitigating strategies also add difficulties to mitigate the situation [5].

4.1 Erratic rainfall

Erratic rainfall leads to drought-like situation is considered as most important stress factor for sugarcane cultivation. As mentioned earlier, water requirement is varied according to stages of the crop, and changes in plant physiology due to water stress were noticed by the different researchers. Domaingue [6] stated that the number of internodes is reduced if water deficit increases. Misra et al. [7] also observed that 43.51% reduction in the number of internodes in drought-affected canes. Jones et al. [8] clearly mentioned about the reduction in the crop biomass production up to 35% under water stress condition.

High temperature also leads to increase the evapotranspiration rates that reduce the amount of water available in soils, making the planting of sugarcane increasingly difficult and newly planted crop demand more irrigation.

Crop suffers from drought in early and mid-growth stage results in low sucrose yield. On the country, moderate drought in late growth stage can improve sucrose content.

A study carried by Endres et al. [9] by exposing six sugarcane varieties at different growth stages, viz. tillering stage, stalk elongation, grand growth stage, and ripening stage to drought. He recorded a reduction in leaf length and leaf width especially in the stalk elongation and grand growth stages. Misra et al. [7] also observed similar

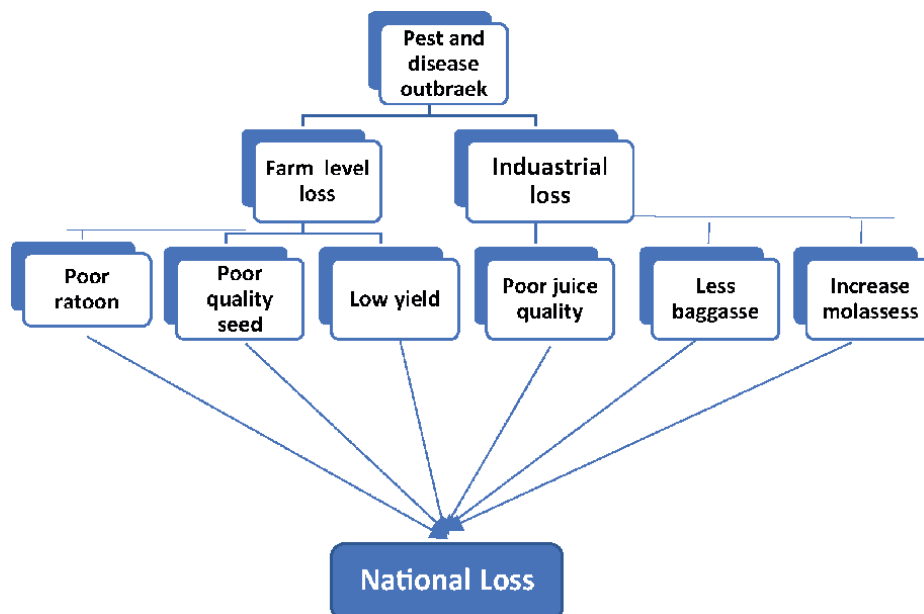


Figure 1. National losses due to pest and disease outbreak (concept: *Sadam Hussain, climate change and agriculture, Intech Open*).

results, wherein leaf width decreased by about 31.11% in drought-affected sugarcane compared to sugarcanes grown under normal conditions.

Crop root is the first part that detects water deficit in the root rhizosphere and sending signals to other parts of the plant [10]. The closing of the stomata is one of the response mechanisms of plants to minimize further water loss.

Zhao et al. [11] observed that water stress reduced the number of large tillers (>20 cm) but increased the number of small tillers. It was also reported that the roots were found in the top (0–30 cm) as well as middle soil layer (30–60 cm) for canes grown in irrigated condition whereas root length was found below the 30 cm soil layer in drought-treated plants grown in rhizoboxes [12].

4.2 Effect of high temperature

Extreme high temperature affects plant system in many ways (**Figure 2**) from the seed germination to yield characters all are affected by rise in temperature. It is well established that the optimum range of temperature varies for different stages of sugarcane crop. For example, the optimum temperature required for germination (sprouting) of cane sett is between 28 and 32°C. Temperature above 38°C reduces the germination and also affects the vegetative growth by reducing photosynthetic rates and increasing the respiration [4].

Although the tillering capacity of sugarcane mainly governed by genetic factors, temperature fluctuation may also affect numbers of tillers produced by a particular variety.

During ripening period temperature requirement is low, i.e., 12–14°C due to which sucrose accumulation is more.

Fageria et al. [13] and Clements [14] reported that sucrose accumulation is optimum within the temperature range of 12–14°C but it declines gradually above 26.6°C.

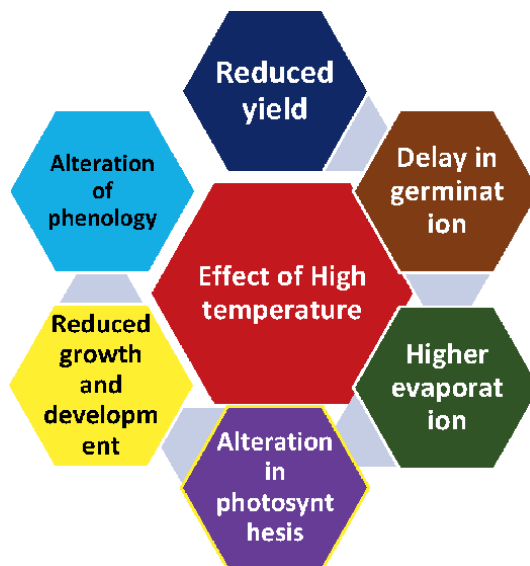


Figure 2.
Effect of high temperature.

This is also supported by the findings of Binbol et al. [15] and Gawander [16]. They observed that at high temperature sucrose is converted into fructose and glucose and enhances abiotic diseases.

4.3 Frost

Sever cold weather inhibits bud sprouting in ratoons and arrest cane growth. At temperature 1–2°C leaves and meristem tissues may be killed.

5. Mechanism to counteract adverse climatic conditions

5.1 Changes in plant internal machinery to cope up high temperature

Like the human and animal, plants can also sense increase or decrease in ambient temperature by using a complicated set of sensors that are located in various cellular compartments. Plants try to counteract heat effect by producing osmolytes and antioxidants [17]. Farooq et al. [18] reported that proline, glycine betaine, and soluble sugars are deposited more in heat-affected plant to protect the cellular damage. Chlorophyll present in the thylakoid membrane of chloroplast harvest light energy and transform into energy that plants utilizes to various function. Under normal growth condition, synthesis of chlorophyll is equilibrium, But under stress conditions, level of chlorophyll content decreases leading to chlorosis [19]. Exposure to high-temperature chloroplast are unfolded and proteolytic enzyme degradation of chloroplast may occur [20].

Rise in temperature compels the sugarcane crop to some changes in their internal cellular morphology. It was recorded by Bitra and Gerats [17] that the rising temperature up to 35°C and above causes injuries to cell membrane, disruption of cell

membrane permeability, and microtubules organization and also affects elongation and expansion of the plant. High temperature also generates dangerous oxygen species and affects sucrose quality and sugar extraction. Sucrose phosphate synthase (SPS) and sucrose phosphate phosphatase (SPP)—these two enzymes are required for sucrose synthesis, and it was reported that both these enzymes are affected by change in temperature [21]. Chloroplast serves as the key component for metabolic centers and plays key role in sensing heat stress. CO₂ assimilation, thylakoid membrane fluidity, electron transport, and photochemical reactions are the major areas that is affected by heat stress. To respond heat stress, heat-shocked proteins (HSP) are evolved in sugarcane plants. The heat shocked transcriptome factor (HSTF) regulates the expression of Heat Shocked Protein Gene. Researchers are going on the function of HSP and HSTF that regulates the response system to heat stress in plants.

5.2 Mechanism to cope up with drought

Sugarcane crop has diverse adaptive traits to cope up with water stress conditions. Since sugarcane is a water-loving plant, a deficit of water could lead to poor cane yield. So, drought-tolerant sugarcane varieties have minimum transpiration rate with maximum stomatal diffusive resistance [22]. This trait ensures the conservation of water in the plant system during stress conditions.

Reduction in stomatal conductance is another important aspect identified as the immediate response during drought conditions to conserve moisture in the system through decreased transpiration rate [9]. Plant water potential is directly correlated with stomatal conductance and leaf water turgor, thus limiting stomatal opening and significantly reducing gas exchange and subsequently photosynthetic rates [23]. Relative water content (RWC) is an important parameter to easily distinguish drought-tolerant and drought-susceptible varieties. A study conducted by Dapanage and Bhat [24] showed that RWC value was higher in irrigated crops as compared to plants grown in non-irrigated conditions.

6. Effect of climate change in plant pathogen and insect pest

Sugarcane is a long duration crop. It takes about 12–18 months to mature depending on variety. On the basis of sowing time, it is known as *Adsali* (June–August) or 18 months crop and *Eksali* (December–February) or 12 months crop. After harvesting also, generally, 2–6 ratoons are followed in Indian conditions. Therefore, the crop experiences varying temperature and humidity throughout its life span. Fluctuation of temperature and humidity invites many pest and pathogen to attack the crop.

Disease-causing pathogen propagules like spore and spore survival, spore germination, host penetration, growth within the host, sporulation, and ultimately dispersal—all are affected by abiotic conditions such as temperature, moisture, light, wind, and nutrient.

Herbivore arthropods like sugarcane borer, stalk borer, and Mexican borer can cause significant crop loss in abiotic stressed crops due to drought. The fecundity of *Eoreuma loftini*—the Mexican rice moth is positively correlated with increases in drought as the drought prevails, the number of dry leaf availability for egg laying increases. Showler and Castro [25] observed that under irrigated conditions 82.8–90.2% less egg in of *E. loftini* was reported than non-irrigated drought-affected crop.

Increased pest and disease infestation is recorded due to the abrupt weather changes. Incidence of smut disease (*Sporisorium scitamineum* (Syd.) is increasing due to rise in temperature [26], and it was also found that the disease was more severe on sandy soils than on organic soils because of high temperature and relatively dry conditions.

Likewise, the prolific dry weather aggravates the symptoms of ratoon stunting disease. On the other hand, severe storms and hurricanes can spread leaf scald, caused by *Xanthomonas albilineans* [27].

Most of the sugarcane diseases appeared in severe form from time to time depending on the prevalence of suitable climatic conditions for pathogen attack. For example, sugarcane orange rust disease in Florida was much severe in the 2012 and 2013 growing seasons than other years due to warmer winter and higher humidity [5].

The severity of rust disease is associated with winter temperature and sufficient relative humidity. Sugarcane orange rust in 2012 and 2013 in South Florida was the most severe one since its first record in 2007 [28]. Warmer winter and high humidity is the crucial for the rust spores surviving and fast development [29], which was prevalent in that endemic areas.

A survey report conducted by Florida sugarcane industry reported that sugarcane growers used fungicides to manage rusts, but it was found that the cost of application of fungicides in three split doses per hectare was found to be equivalent to the loss of three tones of cane yield/ ha costing around \$63 million in terms of monetary return in 2013.

In India also, the fluctuation of temperature has increased rust incidence during the past few years. Dattaray Jondhale, a sugarcane farmer of Herwad village in Kolhapur district of Maharashtra, explained his experiences to Indian Climate Dialog in 2019 that the rust disease of sugarcane occurred as numerous lesions on individual leaves giving it brown or rusty appearance. That leads to the premature death of the leaf, reducing the number of active leaf per plant, the number of stalks per plant, and length of stalk drastically reduced in susceptible varieties.

In such cases, the number of live leaves per plant is seriously reduced, while in very susceptible varieties there may be fewer stalks and reduced diameter and length of the stalks. It was also reported that rust is more severe in the young stages of the plant than declining with increasing crop age. A mild winter will likely allow rust to survive for a long time and re-emerge as a problem.

7. Physiological disorders of sugarcane due to changing climatic conditions

Environmental or physiological stresses cause immense quantity and quality loss of this crop worldwide. Some of the physiological disorders commonly observed in affected cane fields are discussed below.

7.1 Banded or cold chlorosis

This type of physiological disorder occurs due to high or low temperature. Waraitch and Kanwar (1977) first reported banded chlorosis in sugarcane clone S-98/70 of Punjab due to the severity of low temperature (minimum 0.50C). Later on 2011, banded chlorosis has been noticed in Maharashtra, India during 2nd week of March when the minimum temperature was recorded within the range from 10-12°C during December-January in the most popular tropical varieties Co 86032 and CoC 671 (Web report of VSI, Pune). The same condition has also been reported in 2019 when the minimum temperature remained below 5°C during December- January

[30]. Tissue chlorosis extends the both sides of the midrib of the leaf followed by leaf discoloration from yellow–green to white. Chlorotic bands may be visible near the base of the older leaves toward the tip of the leaf.

7.2 Sunburn or sunscald

Two types of sunburn can be generally observed in the affected field. They are leaf scorch that affects the foliage and sunscald that affects the bark. Drying of leaf lamina initially on the leaf apex of newly unfurled leaf and then progressed toward the middle of leaf lamina. Injured leaf used to dry within 2–3 days from leaf apex to bottom. Here, the injured leaves did not regain and the injury was irreversible.

7.3 Frost injury

Frost-injured plant cells are generally dehydrated as the ice crystals are formed in tissues of the plant that are usually filled with water. This results in distortion of the cell membrane followed by the collapse of plant parts. Frost-injured sugarcane crop develops water-soaked areas with light brown discoloration of tissue, and on splitting open the frost-injured plant, water-soaked areas developed with light brown discoloration of tissue, and the growing point may turn black resulting in hollow stalk on maturity. The emergence of side shoots from the top two to three eyes is one of the characteristics of frost-affected canes.

8. Strategies to mitigate adverse climatic condition

Diverse technology can be adopted to mitigate adverse climatic conditions. Planting stress-tolerant varieties is the first and foremost criteria to be considered while thinking for mitigating adverse climatic condition. As mentioned earlier, critical need of water at different stages of the cane growth is the pre-requisite to harvest a good return. So, improving irrigation facility with high efficiency and with proper drainage facility is the utmost need.

Incorporation of clonal propagation or tissue culture, molecular biology, and gene transformation technologies to improve breeding and selection efficiencies and to introduce desirable genes of interest carrying improved agronomic trait [31] so that the breeders and scientist could come up with new sugarcane cultivars that can be easily fitted to climate change.

Genetically modified (GM) sugarcane varieties such as glyphosate resistance, disease and pest resistance, water stress tolerant, high sucrose content were developed to mitigate adverse climatic condition. Budeguer et al., in 2021 [32] mentioned about the genetic transformation of sugarcane crops. In his study, it was mentioned that Brown and Birch in 1992 described the development of herbicide-resistant genotypes by microprojectile bombardment of selected genes and incorporation in suitable varieties to produce sugarcane crop with selected traits of transgenic sugarcane with desirable traits. This was followed by development of glufosinate resistant sugarcane genotypes by *Agrobacterium* mediated gene transfer technology, So, in general both *Agrobacterium* mediated or biolistic method are successfully used in development of transgenic sugarcane cultivars.

Studies by Zhou and Li [31] indicated that on treating seed cane by ethephon-ethylene-producing substances at low concentration increases drought tolerance of cane.

They also reported that foliar application of ethephon reduced cell membrane injury caused by water stress, thereby increasing water potential in leaf tissue. Cell protective enzymes such as peroxidase and polyphenol oxidase activities are also enhanced.

Weather forecasting during the cultivation period is utmost necessary for the farming community to earn a good harvest from their field. For this, scientific use of Artificial Intelligence and Machine Learning (AIML) should be popularized amongst the farming community.

Breeders can apply information technology (IT) to develop computer database system incorporating growth and physiological traits of different cultivar to identify elite clones having tolerance or resistance mechanism to biotic or abiotic stress [33].

Last but not least, the combination of basic breeding techniques, physiological screening of improved trait, and new technologies of molecular biology and biotechnology can mitigate the negative effect of climate change and improve sugarcane yields, productivity, and sustainability [34–36].

9. Conclusion

The sugarcane industry is not only concentrating on sugar and jaggery production but is gradually transformed into a bio-based industry that will produce electricity, bio-ethanol, bio-manure, and bio-chemicals that open up more research wings to be a profitable agribusiness agriprenurship development which ultimately makes economic upliftment of developing countries. Therefore, it is an urgent need to focus more research on the development of stress-tolerant sugarcane varieties in the present-day situation of global climate change.

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Chapter 2

Salinity Tolerance in Legumes: Classical and Molecular Breeding Perspectives

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Abstract

Legumes, essential for global nutrition, confront challenges like environmental stresses like extreme temperatures, drought, and salinity. Salinity, affecting 8.7% of the planet's area, poses a severe threat to legume cultivation, impacting physiological functions, nutrient balance, and nitrogen fixation. This chapter comprehensively explores the complex responses of legumes to salt stress, highlighting adaptive mechanisms such as osmotic stress tolerance, ion exclusion, antioxidant regulation, and hormone modulation. The breeding strategies, including molecular techniques like QTL mapping, association mapping, and transgenics, offer promising solutions to enhance salt tolerance in legumes. The knowledge regarding salt tolerance breeding is well-documented in cereals but not in legumes, emphasizing the identification of genomic regions associated with tolerance and the effective utilization of molecular tools. Wild relatives provide valuable tolerance genes, requiring detailed understanding of their roles at different developmental stages. The multi-environment screening and integration of diverse breeding approaches, including genomics, transcriptomics, metabolomics, transgenics, and CRISPR-Cas9, is essential for developing legumes capable of thriving in saline environments and exhibiting high-salt tolerance.

Keywords: legumes, salinity, osmoprotectants, screening techniques, breeding methods, molecular tools, transgenics

1. Introduction

Legumes though cultivated in substandard arable soils, serve as a vital source of nutrition for billions of people across the globe and are a good source of protein, dietary fiber, carbohydrates, vitamins, and minerals. Globally, in an annum, legumes are grown in approximately 5.8% of gross cultivable poor land area [1]. In India,

pulses are cultivated on around 28.7 million ha, with a production and productivity of about 25.4 MT and 885 kg/ha, respectively (www.indiastat.com). Various legumes viz., pigeon pea (*Cajanus cajanifolius*), black gram (*Vigna mungo*), green gram (*Vigna radiata*), chickpea (*Cicer arietinum*), soybean (*Glycine max*), field pea (*Pisum sativum*), cowpea (*Vigna unguiculata*), horse gram (*Macrotyloma uniflorum*), moth bean (*Vigna aconitifolia*), lablab bean (*Lablab purpureus*), lentil (*Lens culinaris*), French bean (*Phaseolus vulgaris*), and khesari (*Lathyrus sativus*) are grown worldwide as either sole or intercrop. Legume cultivation will also improve the soil structure and infiltration rates, but its production has fluctuated over the past few decades depending on environmental conditions [1]. Any changes from the ideal environmental conditions, whether it is an abundance or shortage, is considered abiotic stress, leading to negative impacts on the growth and development ultimately affecting the productivity of plants [2]. Various environmental stresses like soil salinity, extreme temperatures, and excess and deficit water available situations, have influenced the production of legumes. Salinity is considered the most perilous stress. Legumes are highly sensitive to salinity stress compared to cereals. When the concentration of salts in soil is too high, it can have negative impacts on plant growth, yield, and the physical properties of the soil [3]. Cultivating salt-tolerant plants is crucial for utilizing salt-affected agricultural land sustainably, maximizing land use, conserving resources, and enhancing resilience to climate change [4]. More than 833 million hectares of area around the globe are salinity-affected (8.7% of the planet) and majorly found across arid or semiarid environments of Asia, Latin America, and Africa [5]. The accumulation of salts predominantly occurs through natural processes over a prolonged period. For example, during the process of weathering, rocks discharge various soluble salts at different degrees. The major discharges are Na (sodium), Ca (calcium), and $MgCl_2$ (magnesium chloride) while carbonates and sulfates are released at a lower intensity. NaCl is the prevalent type among them. Rainwater also contains 10 mg/kg of sodium chloride, thus for every 100 mm of annual precipitation, it would leave behind 10 kg/ha of salt deposition in the land. Saline water irrigation influences the salt contents in the water table which negatively affects the crop performance [6]. Saline soils are characterized by a higher electrical conductivity (EC) i.e. more than 4 dS/m, which is approximately equal to 40 mM NaCl. The dominant ions found in such soils are Cl^- , SO_4^- , and in a few cases, NO_3^- . Salinized areas are expanding by 10% each year due to multiple factors like insufficient rainfall, increased surface evaporation, natural rock erosion, inadequate agricultural practices, and improper irrigation using saline water. If these grave concerns continue, it is projected that more acreage of cultivatable land (>50%) will become saline in 2050 [7]. In India, 2.956 Mha is saline affected and 3.771 Mha is sodic soil which equates to 2.1% of its geographical area [8]. Sodic soil, on the other hand, is characterized by its bicarbonate content, high pH, and ESP values greater than 15. The characteristics of saline and sodic soils are furnished for a better understanding in **Table 1**. The complexity and presence of low genetic variability for salinity restrict the use of classical breeding techniques for developing salt-tolerant lines in legumes. Furthermore, the lengthy breeding cycles in classical breeding and other environmental influences hinder the progress in developing salt-tolerant crop varieties. Understanding the molecular mechanisms behind salinity will pave the way to genetically control or modify the genes responsible for salt tolerance in legumes, thereby enabling the development of salt-tolerant varieties through advanced breeding methods or genetic engineering techniques [9]. Genetic engineering facilitates the introduction of salt-tolerance genes into plants, enabling them to cope with high salinity levels in the soil. These genes typically encode proteins or mechanisms that regulate

Soil type	Electrical conductivity (EC)	pH	Exchangeable sodium percentage (ESP)	Impact on plant growth
Saline soils	≥4 dS/m	<8.5	<15	The growth of roots and shoots is impeded by stress caused by both osmotic and ionic factors
Sodic soils	<4 dS/m	>8.5	≥15	Poor soil structure suppresses root growth

Table 1.
The characteristics of saline and sodic soils.

ion uptake and transport, maintain osmotic balance, or detoxify ions within plant cells, ultimately enhancing the plant's ability to thrive in saline environments [10]. The omic techniques like transcriptomics, proteomics, and metabolomics, are valuable for comprehensively understanding salinity tolerance responses in legumes. It allows the researchers to understand and analyze the gene expression patterns, protein profiles, and metabolic processes of legumes under salinity conditions [11]. Transcriptomic studies analyze the expression levels of genes in plants exposed to abiotic stress, revealing key genes and pathways involved in stress responses. By identifying these genes, researchers can target them for genetic modification to enhance the plant's ability to tolerate salinity conditions [12]. Both proteomics and metabolomics are advanced techniques that enable the comprehensive study of proteins and metabolites in plants [13]. During the salinity stress, each genotype will show differences in protein abundance and metabolite composition. Comparing the proteomic and metabolomic profiles of different genotypes under salt stress can elucidate common pathways or mechanisms involved in salt tolerance, facilitating the development of more tolerant genotypes [14]. In light of the above, this review aims to consolidate the facts of salinity, its ill effects on legume performance, legumes' ability to withstand salinity stress, and the employable crop improvement strategies to combat salinity-induced stress.

2. Effects of saline stress on legumes

Salt stress elicits a various response in agricultural crops. High salinity levels (HSL) are detrimental to plants. HSL affects crucial physiological functions, nutrient balance, hormonal regulation, and biological nitrogen fixation in legumes [15]. These alterations induce flower abortion, reduce carbon fixation, produce a few flowers and pods, & ultimately hinder crop production (**Figure 1**). Generally, salinity stress occurs in two phases *viz.*, osmotic phase and ionic phase. During the initial stage, the presence of salt outside the plant's root area can influence its reaction to salinity by restricting water absorption through roots, leading to reduced shoot growth, and delaying new leaf emergence and new lateral buds. Subsequently, in the later stage, the accumulation of salt within the plant tissues can cause toxic effects. It is evident that salinity affects every phase of plant growth, encompassing germination, vegetative growth, and reproductive growth [7]. However, it has a greater impact on seed germination and seedling growth compared to later stages of plant development [16]. During the germination stage, the rate of germination decreases, which negatively affects development of roots and plants establishment. This occurs when there are high levels of ions that hinder water absorption. As a result, both ion toxicity and osmotic stress are induced. At later stages

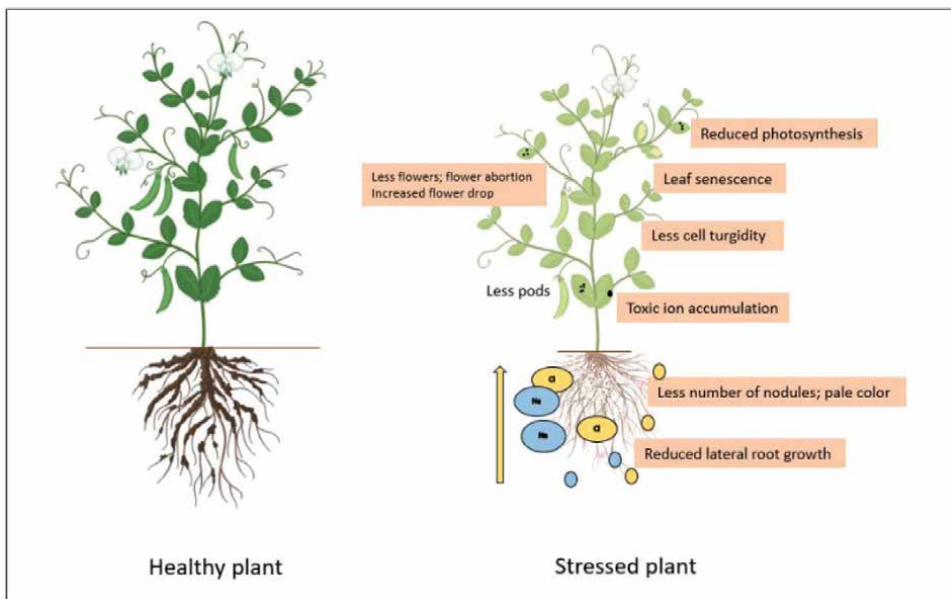


Figure 1.
The impacts of salinity on legumes (created with <https://www.biorender.com>).

of plant development, an excessive buildup of ions in the shoots hampers the process of photosynthesis, leading to premature aging of leaves. The inhibition of plant growth is frequently linked to a decline in photosynthetic activity. During the reproductive stage, due to nutritional imbalance, flower abortion will be more, leading to a reduced number of flowers and ultimately reducing the yield. Salinity reduces the number of pods and seed weight in soybean [17]. Similarly, Ghassemi-Golezani et al. [18] reported a reduction in protein and oil content. Mshelmbula et al. [19] evaluated the effect of salinity on the germination, growth, and yield performance of cowpea using different concentrations of NaCl. The NaCl stress reduces growth parameters and root nodules, due to an increased influx of toxic ions, and efflux of cytosolic solutes in plant cells. Nodulation is the imperative process in legumes which helps in fixing nitrogen required for the entire crop cycle. However, the mechanism of nodulation and nitrogen accumulation is altered by the salt stress in soybean and alfalfa [20]. Bolanos et al. [21] studied that the nodule weight and nodule number have decreased in pea plants exposed to salinity and many nodules appeared pale in color when compared to control. Nitrogenase enzyme activity in nodules can be quantified readily with the acetylene reduction method. Acetylene reduction activity (ARA) was significantly reduced when the *Phaseolus vulgaris* genotype was treated with 50 mM NaCl [22]. Additionally, nitrogen fixation and other antioxidant enzyme activity in nodules were also impacted. In summary, salinity negatively affects legumes by disrupting seed germination, photosynthesis, nutrient absorption, nutrient balance, and ultimately reducing crop yield.

3. Tolerance mechanisms

Plants employ various strategies to thrive in saline conditions and those strategies can vary depending on the plant species. They can be either adaptive or specific

mechanisms. The genetic control mechanisms linked with salinity tolerance are intricate and typically involve multiple genes and functions.

3.1 Osmotic stress tolerance

Osmotic stress occurs when there is a difference in salt concentration between the plant's cells and the surrounding soil or water. This difference creates an imbalance of water, leading to a condition where water moves out of the plant's cells, causing dehydration and impaired cellular functions. The reduction in turgidity modifies hormone levels and gene activity by elevating the presence of abscisic acid (ABA), resulting in enhanced osmotic regulation to mitigate the impact of salinity, thereby preserving the rigidity of leaves. Osmotic stress adjustment occurs through the uptake of a few ions and the synthesis of osmolyte solutes like sugars, amides, polyols, amino acids, etc. A list of osmolytes and their crucial role in salinity tolerance is listed in **Table 2**. Osmolytes are polar and soluble organic compounds that do not influence the functionality of cellular metabolic pathways [23]. Proline and Glycine betaine serve as crucial osmolytes that participate in osmoregulation, counteracting the detrimental effects of osmotic stress specifically in many grain legumes [24]. For instance, cysteine treatment reduces the adverse effect of salinity by raising the proline content, catalase and superoxide dismutase activities, and photosynthetic pigments [25]. The efficiency of proline and glycine betaine in increasing the salt tolerance in chickpea were investigated by Dawood et al. [26]. The results showed proline treatments (5 mM) were more effective than glycine betaine in increasing the salinity tolerance of chickpea.

3.2 Ion (Na⁺) exclusion

Salinity tolerance is the function of ion exclusion (Na⁺ and Cl⁻) and vacuole compartmentalization. The sodium ions reaching the cytoplasm are subsequently diverted to the vacuole with the help of a Na⁺/H⁺ antiporter. The ion compartmentalization and exclusion strategy will help in protecting the reproductive organs [6]. The salt overly sensitive pathway (SOS) (**Figure 2**) is the immediate ion homeostasis mechanism activated in plants upon sensing abiotic stress [27]. Precise regulation

Osmoprotectants/ compatible solutes	Role in salinity stress tolerance
Proline	It acts as a free radical scavenger, balances cell redox levels of the cell and acts as a signaling molecule to coordinate mitochondrial function
Glycine betaine (GB)	Aids in osmotic adjustment and protecting the thylakoid membrane, which helps to maintain efficient photosynthesis.
Mannitol	Scavenging the free oxygen radicals
GABA	Helps in carbon-nitrogen balance and ROS scavenging and improves abiotic stress tolerance
Trehalose	Stabilizing the proteins and membranes during stress conditions. It is also involved in regulating carbohydrate metabolism.
Fructan	Scavenging ROS and osmotic adjustment

Table 2.
A list of osmolytes and their role in salinity tolerance.

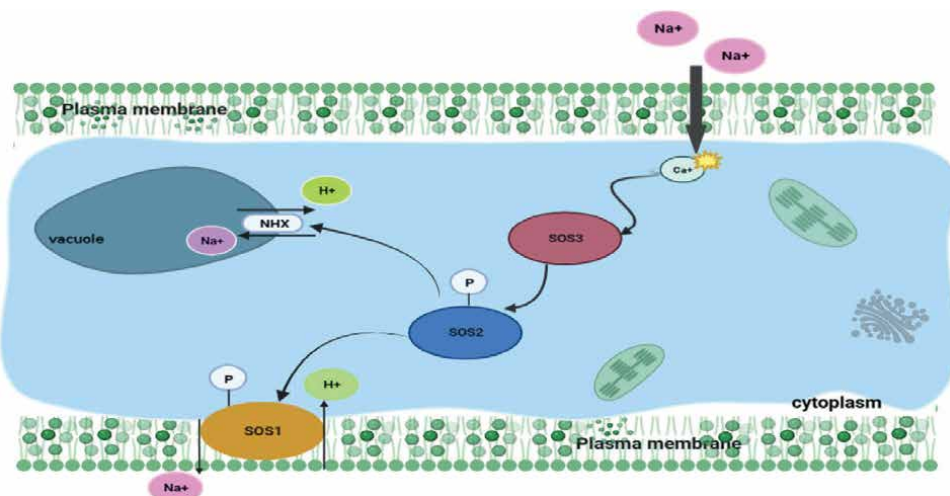


Figure 2. SOS pathway (Salt Overly Sensitive Pathway) (created with <https://www.biorender.com>).

Proteins	Functions
SOS1	<ul style="list-style-type: none"> • Encodes Na⁺/H⁺ antiporter (plasma membrane bound) • Regulates sodium ion efflux, pH homeostasis, membrane vesicle trafficking, and vacuole functions and • Enables long-distance Na⁺ ion transport
SOS2	<ul style="list-style-type: none"> • Encodes a serine/threonine kinase
SOS3	<ul style="list-style-type: none"> • It has a myristylation site at N-terminus, this site regulates salt tolerance

Table 3. The proteins engaged in SOS pathway and their roles.

of intracellular sodium and potassium ion flux is essential for the optimal activity of diverse cytosolic enzymes, cell volume regulation, and for maintaining the membrane potential. The survival of plants under salinity stress is greatly influenced by the homeostasis between Na⁺ and K⁺. The SOS signaling pathway comprises SOS1, SOS2, and SOS3 proteins (Table 3), which play integral roles in the pathway’s functioning.

The overall function of this signaling pathway involves a cascade of events. When the concentration of Na⁺ increases, it leads to a rapid rise in intracellular Ca²⁺ levels, enabling its interaction with the SOS3 protein. This interaction, facilitated by Ca²⁺, regulates Na⁺ levels along with SOS proteins. Subsequently, SOS2 gets activated by the SOS3 proteins through stimulation of the kinase activity. This SOS3/SOS2 complex phosphorylates SOS1 upon transportation to the plasma membrane. This phosphorylation of SOS1 leads to an enhanced efflux of Na⁺ by stimulating its antiporter activity which ultimately reduces the Na⁺ toxicity.

4. Antioxidant regulation of salinity tolerance

Due to salinity stress, there will be a rapid accumulation of reactive oxygen species (ROS) in the cytosol. The predominant ROS are hydrogen-peroxide (H₂O₂), hydroxyl

radical ($\cdot\text{OH}$), superoxide-radical ($\text{O}_2^{\cdot-}$), and singlet-oxygen (O_2). Their production is cytotoxic but they also serve as signaling molecules that stimulate signal transduction pathways in response to stress [28]. Excessive ROS generation during stress will lead to the degradation of lipids in the cell membrane, proteins, and nucleic acids. However, salt-tolerant legumes possess their own antioxidant defense system, which helps scavenge ROS and protect cells from oxidative damage. Various enzymatic and nonenzymatic antioxidants involved in a scavenging activity are carotenoids, tocopherols, flavonoids, flavones, ascorbic acid, glutathione reductase (GR), monodehydroascorbate reductase (MDHAR), glutathione peroxidases (GPX), superoxide dismutase (SOD), ascorbate peroxidase (APX), and catalase (CAT) [24]. Thus, the oxidative stress caused by the ROS is tackled by these antioxidant activities.

5. Hormone regulation and salinity tolerance

Abscisic acid (ABA) is noticed as an immediate response to saline and drought stresses which subsequently triggers numerous adaptive responses in plants [27]. In legumes, ABA plays a major role in multiple stress responses, including metabolic alterations, closure of stomata, and activation/regulation of several stress-inducible genes thereby the correlated protein syntheses are regulated. Such a regulation helps the plants to adapt to the salinity stress through enhanced osmotic adjustment.

6. Screening methods for identification of salinity-tolerant genotypes/donors

To develop plant varieties that are tolerant to salinity stress, it is important to establish reliable screening methods that can effectively assess their tolerance to high-salt levels. Duration and growth stage are important factors for evaluation and screening for salinity tolerance [29]. Generally, salt stress is assessed by comparing productivity with saline and non-saline conditions. In the case of HSL, the survival capacity is often used as a reliable measure. It is considered that seedling screening for salinity tolerance is noteworthy as seedling establishment under salinity is the basic requirement for a better crop establishment and yield. Various selection criteria including seedling survivability score, assessing proline content, Na^+ , and Cl^- accumulation, and production of H_2O_2 can be used to assess the salt tolerance at seedling level. Rapid screening methods like the salinity induction response (SIR) technique and hydroponics are the commonly used techniques to identify putative donors in a breeding program.

6.1 Salinity induction response (SIR) technique

This technique was developed and standardized by the University of Agricultural Sciences, Bengaluru for various cereals and legumes [30]. In the salt induction and recovery (SIR) technique, young seedlings are first exposed to a mild level of salt stress, which serves as an initial “induction stress.” After this exposure, the seedlings are then subjected to a high concentration of salt for a particular duration. Following this period, the seedlings are transferred back to a normal water environment to allow for recovery. The extent of recovery growth observed in the seedlings is then used as a measure of their salt tolerance. Manasa et al. [30] screened 40 mung bean lines at the

seedling level using SIR technique and identified a few lines with better biomass and pod yield than control.

6.2 Screening using hydroponics technique

Screening plants for salinity tolerance in field conditions can be challenging due to soil variations and environmental factors. As an alternative, laboratory-based techniques like hydroponics offer a more controlled environment with uniform salinity levels in the growth medium. However, to accurately assess plant traits, it is crucial to identify a specific stage in a plant's growth cycle that is most sensitive to salt stress. In this technique, salt is added to the nutrient hydroponic solution [31] in which the seedlings are grown and scoring is done based on the percentage of leaves wilted. The scoring for assessing the salt tolerance level in seedlings is given in **Table 4**.

6.3 Salt tolerance index (STI) and Salt injury index

Under the salinity condition, STI is calculated as the ratio of the total dry weight of salt-stressed plants to their respective controls [32]. Salt injury index is calculated using the formula, (1-STI).

6.4 Physiological parameters

Plants exhibit remarkable physiological changes, including changes in signaling pathways and production of antioxidant enzymes, in response to varying levels of salinity which enable them to thrive in different saline conditions [33]. Thus, parameters like chlorophyll content, proline content, total sugars, production of H₂O₂, other antioxidant activities, and stomatal conductance at different growth stages serve as reliable measurements for evaluating salt tolerance in legumes.

7. Breeding strategies for enhancing the salt tolerance

Various breeding strategies offer promising solutions to overcome productivity losses due to salinity. The following sections highlight different breeding strategies and omics approaches that are employed to enhance salt tolerance in plants. Conventional breeding methods rely on the careful selection and crossbreeding of plant varieties with desirable salt tolerance traits. Through successive generations, these breeding programs gradually amplify the presence of salt-tolerant genes within

Percentage of leaves wilted	Scoring
76–100%	1
51–75%	3
26–50%	5
1–25%	7
Normal healthy leaves	9

Table 4. Evaluation of salt tolerance levels in seedlings using assessment scores.

plant populations. Additionally, selection and screening techniques enable the identification of salt-tolerant donors or germplasm collections which can serve as valuable genetic resources for breeding programs.

7.1 Mutation breeding

Mutagenesis involves inducing genetic mutations in plant populations, leading to a wide range of genetic variations. Some of those mutations may lead to enhanced salt tolerance. Through careful screening in salt-stressed conditions and selection of mutated individuals, breeders can identify and incorporate beneficial mutations into breeding programs. Thus, it facilitates the development of salt-tolerant varieties [29].

7.2 Assessing the genetic potential of wild relatives for salt tolerance

The existence of ample genetic variability is a crucial element for the successful advancement of crop improvement initiatives. Crop wild relatives are the potential genetic resources for crop improvement [34]. Many reports specify that they harbor resistance genes for various traits like disease, salinity, drought, and heat tolerance. Through various breeding approaches like hybridization or molecular techniques, these desirable traits can be introduced into cultivated species.

This transfer of traits from wild relatives enables the transfer of valuable genetic characteristics, such as disease resistance, tolerance to abiotic stresses, improved nutritional content, and overall agronomic performance, into cultivated crops. Some wild species harboring the salt-tolerant genes in legumes are listed in **Table 5**.

Linkage drag is an unexpected character transmission that is witnessed in most of the crop improvement programs involving wild species. Such linkage drags either restrict the direct utility of segregants or warrant employing other breeding strategies to overcome the issue of unwanted trait transmission. Evolution of introgression lines (ILs) with the targeted traits with a better yielding potential will increase the chance of utilizing the wild species in commercial plant breeding programs. The progress in genetic inheritance, evaluation methods, software tools, molecular markers, germplasm modification, and mapping has significantly contributed to the enhancement of salt tolerance and other abiotic stress traits.

S. no	Crop	Wild species	Reference
01.	Red gram	<i>C. acutifolius</i> ; <i>C. sericeus</i>	[35]
		<i>C. scarabaeoides</i>	[36]
		<i>C. albicans</i> ; <i>C. cajanifolius</i>	[37]
		<i>C. platycarpus</i>	[38]
02.	Chick pea	<i>C. microphyllum</i>	[39]
03.	Cowpea	<i>V. marina</i> ; <i>V. luteola</i> , <i>V. vexillata</i>	[40]
		<i>V. trilobata</i> ; <i>Vigna vexillata</i>	[41]
		<i>V. unguiculata</i> subsp. <i>sesquipedalis</i>	[42]
04.	Soybean	<i>G. soja</i>	[43]

Table 5.
 Sources of salinity-tolerant traits identified in wild species.

8. Molecular and omics tools for salinity breeding

8.1 Genetic mapping and identification of QTLs associated with salt tolerance traits

Earlier genetic study indicates that the inheritance pattern on salinity tolerance is governed by many genes and is a complex quantitative trait [9]. The genetic basis and mechanism of these quantitative traits can be improved by identifying the genomic regions associated with the trait. The use of various DNA markers like random amplification of polymorphic DNA (RAPD), simple sequence repeats (SSR), and restriction fragment length polymorphism (RLFP), etc., relevant to several abiotic stresses has been reported in various legumes.

In chickpea, a RIL population was developed to map the salinity tolerance QTLs by utilizing two extreme parents ICCV 10 and DCP 92-3. The former genotype is saline tolerant and the latter is susceptible and identified 28 key QTLs [44]. An F6:F7 population of 97 RILs, obtained from a cross between faba bean (*Vicia faba* L.) cultivars Icarus and Ascot, was utilized for QTL mapping and identified seven QTLs associated with salt tolerance [45]. Atieno et al. [46] developed an RIL population by hybridizing Genesis836 and Rupali chickpea varieties using DArT and SNP markers. The former genotype is saline tolerant and the latter is susceptible. A total of 21 QTLs controlling various yield-related traits under salinity were found on CaLG04. In soybean, on chromosome 3, a major QTL flanked by Barcsoyssr_03_1421 and GMABAB (SSR markers) conferring saline tolerance was reported by Shi et al. [47]. This marker trait-associated information can be utilized to enhance genetic gain in the salt-tolerance breeding programs in legumes.

8.2 Association mapping (AM)

AM is the high-resolution method for mapping QTL that relies on the principle of linkage disequilibrium (LD) [48]. AM utilizes GWAS with SNPs and candidate genes analysis (CGA) for mapping. GWAS utilizes the genetic variation of a population (involving many individuals) to assess the association between genotype and phenotype(s). While, in CGA, markers are selected either based on their genomic location or based on published QTL studies. Ravelombola et al. [49] evaluated salt tolerance in cowpea MAGIC population (involving 234 lines) using GWAS, and identified a large variation for salt tolerance conferring traits. Candidate genes related to Na^+/Ca^+ , K^+ independent exchanger, and salt tolerance gene *Vigun01g093100.1*, calcium-dependent protein kinases were identified. Nine candidate genes were identified in soybean during seed germination in response to salt stress. Of them, *Glyma08g09730.1*, *Glyma08g12400.1*, *Glyma18g47140.1*, *Glyma09g00490.3*, and *Glyma09g00460.1* were verified with respect to salt stress [50]. In the mungbean germination stage, Breria et al. [51] used GWAS approach with 5288 SNP markers to understand the QTL(s) responsible for salt tolerance. Significant SNPs associated with salt tolerance were identified at chromosomes 7 and 9 containing genes *Vradi07g01630* (ammonium transport protein), *Vradi09g09600*, and *Vradi09g09510*. A total of 283 soybean lines were used for the GWAS study using the SoySNP50K chip Zeng et al. [52] showed nine genomic regions corresponding to leaf chloride and chlorophyll concentrations.

8.3 Omics tools for salinity breeding

8.3.1 Transcriptomics

RNA-seq has been widely used for studying the differential expression of genes. It provides information related to allele-specific expression, isoforms, and other novel/key promoters which are not possible through transcriptomic studies [53]. During salinity stress, the control of gene expression is influenced by different pathways involving many transcription factors (TFs) like *DREB*, *bHLH*, *AP2/ERF*, *bZIP*, *GATA*, Homeo-box, *HD-Zip*, MADS-box, Trihelix, *MYB*, *WOX*, *NAC*, *YABBY*, *WHIRLY*, zinc finger, and *WRKY* [54]. These TFs play a significant role in ROS production, chlorophyll content, and lipid peroxidation. Thus, they enable the plants to withstand unfavorable conditions and regulate the developmental process in response to abiotic stress [12]. Zeng et al. [55] investigated the RNA-Seq data of the RA-452X Osage population of soybean and revealed numerous genes that exhibited differential expression in the salt-tolerant line. Through gene annotation, they identified several key potential genes (*Glyma.04G180400*, *Glyma.02G228100*, *Glyma.03G226000*, *Glyma.03G031400*, *Glyma.03G031000*, *Glyma.04G180300*, *Glyma.05g204600*, *Glyma.17G173200*, *Glyma.08G189600*, and *Glyma.13G042200*) involved in tolerance mechanism. Similarly, Jia et al. [56] explained the salt tolerance mechanism of f-box genes in soybean by analyzing 12 salt-responding F-box genes. Kaashyap et al. [57] studied the effect of differentially expressed genes in chickpea indicating various salt stress response genes like thaumatin, enzyme inactive 2- (*AOP2*), jasmonic acid-amido synthetase (*JAR1*), aminocyclopropane-1-carboxylate oxidase, potassium transporter gene playing a crucial role in enhancing salt tolerance. Many genes are transcriptionally activated in response to salinity, resulting in the production of altered metabolic proteins under salt stress conditions. These proteins play a regulatory role in downstream gene expression and enhance stress tolerance mechanisms [13]. Under salinity stress in common beans, *PvbHLH* genes (63 Nos.) were expressed differentially. Among that, the participatory role of *PvbHLH-54* and *PvbHLH-148* under salt stress was evaluated using qRT-PCR [58]. Likewise, in the case of chickpea [59], the expression levels of *WRKY*-TF genes were found to be differentially regulated in response to salinity stress. In functional nodules of soybean under salt stress, Dong et al. [60] examined the dynamic regulation of miRNAs. They discovered eight potential miRNAs associated with the stress signaling pathway, ion and osmotic balance, and ABA signaling. Spatial transcriptomics and functional profiling help in identifying differentially expressed genes and pathways and uncover spatially regulated biological processes by integrating both mRNA expression data with corresponding histological information of the tissue [61]. This is an advanced technique that combines traditional RNA sequencing with spatial information to study gene expression within the context of tissue architecture. While conventional transcriptomics provides gene expression data from bulk samples, spatial transcriptomics allows researchers to analyze gene expression patterns within the spatial context of tissues or organs. It enables the generation of spatially resolved transcriptomic data, providing valuable information about the location of specific gene expression within a tissue or organ. Employing this technique will greatly advance our understanding of salinity tolerance in legumes.

8.3.2 Proteomics

Proteomics provides insights into the dynamic protein changes associated with fundamental biological pathways as well as the posttranslational modifications of proteins induced during stress. These modifications are critical for plants to effectively adapt and acclimatize to diverse abiotic stresses [62]. Proteomics helps to unravel the strategies employed by plants at the cellular and tissue level to thrive under salt stress. Also, it facilitates the identification of key genes and proteins associated with salt tolerance. Differentially expressed proteins studied in different legumes are listed in **Table 6**. These genes are cloned and introgressed/transferred to various salt-sensitive genotypes. Qiu et al. [68] identified *GsMAPK4* protein kinases are the positive regulatory factors for salt tolerance in soybean using two-dimensional gel electrophoresis (2-DE) and mass spectrometry (MS). In the same way, ROS scavenging and photosynthetic capacity of *GsCBRLK* proteins in response to salt stress were studied using an iTRAQ-based proteomic approach in soybean by Ji et al.

Crop	Proteomic technique	No. of identified proteins	Major findings	Reference
Soybean	iTRAQ	278	Proteins related to stress signal transduction and membrane proteins were upregulated which leads to ROS scavenging and tolerance to other biotic as well as abiotic stresses including salinity tolerance.	[63]
Chickpea	LC-MS/MS	364	Salinity-tolerance-associated proteins like chlorophyll a-b binding protein, ATP synthase, LEA, ascorbate peroxidase, and ribonucleoproteins are the key regulators of salt-response, signaling, and energy metabolism.	[64]
Alfalfa	iTRAQ-LC-MS/MS	438	The salt tolerance mechanism depends on the proteins associated with antioxidants, detoxification enzymes, glutathione metabolism, and secondary metabolism.	[65]
Cowpea	MALDI-TOF/TOF mass spectrometry	5	Up-regulation of pentatricopeptide repeat protein, flavanone 3-hydroxylase ATP synthase, vacuolar ATPase, and outer-envelope pore protein enhance salt tolerance. These proteins are mainly related to energy metabolism, ion homeostasis, defense, and transport of ions.	[66]
Soybean	LC-MS/MS	972	Differentially expressed proteins in leaves and roots include proteins linked to cation and anion channels, calcium-sensing proteins, receptor kinases, abscisic acid receptors, and flavoprotein oxidoreductases confirming their involvement in salt stress tolerance.	[67]

Table 6.
Differentially expressed proteins studied in different legumes.

[14]. Proteins like rubisco activase, Ru5PK (ribulose-5-phosphate kinase), and OEE (oxygen-evolving enhancer) protein 2, are expressed in salt-tolerant cowpea genotypes indicating their integral roles in energy metabolism and photosynthesis [69].

8.3.3 *Metabolomics*

Metabolomics refers to the analysis of metabolites for the evaluation of biological reactions triggered by abiotic stresses [62]. The metabolic responses are important indicators for evaluating salt stress tolerance in crop species. Salt stress triggers osmotic imbalances, leading to harmful changes at physiological and molecular levels in cellular components. To overcome the salt-induced osmotic imbalance and other associated ill effects, plants produce/modify a variety of metabolites. The chemical complexity and dynamic nature of metabolites limit the metabolomic platforms to profile all the metabolites at a given time [70]. Numerous studies utilizing metabolomic analyses have been carried out to examine the underlying mechanisms for salinity stress tolerance (Table 7). Metabolomic techniques like NMR spectroscopy and mass spectrometry (MS) have greatly aided in studying the metabolite profiles of plants and understanding their mechanisms of stress tolerance. The production of various metabolites including proline, lactose, ribose, lauric acid, palmitic acid, stearic acid, linolenic acid, mucic acid, glutaric acid, galactonic acid, and dehydroascorbic acid demonstrated the higher salinity tolerance in wild soybean [71].

8.3.4 *Ionomics*

The process of analyzing elemental compositions on a large scale is known as ionomics. This approach has widespread uses in the field of plant sciences like screening mutants for the targeted traits, forward and reverse genetic techniques, and understanding the mechanisms involved in elemental/ion uptake, mobilization, compartmentalization, and exclusion [10]. This high-throughput analysis provides valuable insights into the intricate processes related to plant nutrition and ion homeostasis [76]. It will also help in understanding how cells function and adapt in response to abiotic stress [77]. Various analytical tools, including X-ray crystallography, ICP-MS, neutron activation analysis (NAA), and ICP-OES are utilized for the comprehensive profiling of ions in plants. To store and manage the vast amount of ionomic data, the purdue ionomics information management system (PiiMS) serves as a dedicated database. It serves as a valuable resource for storing and accessing the ionic profiles of plants [62]. During salinity stress, there will be excessive variation in the ionic composition. In that case, this technique helps in understanding how plants deal with salt stress by studying their ion profiles, which reveal how they detoxify ions and maintain ion balance under high-salt conditions. This technique, although not widely used in plants, holds great potential for studying mechanisms behind salinity.

8.4 **Transgenic strategy for enhancing salt tolerance**

In recent times, marker-assisted backcrossing and quantitative trait loci analysis have emerged as prominent strategies to improve salt tolerance in legumes. Nevertheless, these techniques are not without their limitations, such as linkage drag, marker validation, and breeding incompatibility across different species. Consequently, alternative biotechnological approaches, such as the genetic engineering of crops through the incorporation of genes responsible for imparting tolerance to abiotic stresses, hold

Class of metabolites	Metabolite	Plant species	Function	Reference
Amino acids	Valine, tyrosine, glutamic acid, leucine, and isoleucine	Soybean	Stabilizing the intracellular pH and balancing osmotic pressure.	[71]
Polyamines (PA)	Putrescine, spermidine, and spermine	Common beans	Maintenance of ion levels, counteracting free radicals, membrane stabilization, and protection of cellular structures.	[72]
Sugars	D-trehalose	Lentil	Osmo protectant	[73]
Amino acids	GABA	Green gram	Improves growth, photosynthesis, enzymatic and nonenzymatic antioxidative defense mechanisms, and nitrogen metabolism during salinity stress.	[74]
Sugar alcohol	d-arabitol	Soybean	Osmo protectant	[75]
TCA cycle metabolites	Malonic acid, fumaric acid, citric acid, and l-malic acid	Soybean	Scavenges reactive oxygen species	[75]

Table 7.

Details of a few metabolites observed under salt stress.

great promise in facilitating the integration of functional, structural, and comparative genomics [24]. Transgenics refers to the transfer of desirable genes from related or unrelated species to the target host for enhancing the expression of desired traits. This approach is being used extensively worldwide for improving abiotic stress tolerance in plants. Gene transfer through *Agrobacterium tumefaciens* helps in achieving a significant improvement in legume transgenic experiments. However, the success rate of obtaining transgenic lines remains relatively low in various instances [78]. Several investigations have been conducted on manipulating the biosynthetic pathways of osmoprotectants to increase the production of molecules that aid in scavenging reactive oxygen species (ROS), diminishing lipid peroxidation, and preserving the structure and function of proteins (**Table 8**) [88]. Engineering salt-tolerant crops can be enhanced by, (a) good knowledge of posttranslational changes in the expression pattern of genes and proteins that ensure plant development in the salinity stress, (b) overexpression of miRNA, (c) regulating the hormone homeostasis to evade the multiple phenotypic effects of a gene (pleiotropic effects), (d) utilizing plant synthetic biology techniques to ameliorate genetic engineering approaches [23].

9. Future directions and conclusion

Salinity is the most devastating abiotic stress ultimately affecting legume productivity. Several mechanisms like osmotic adjustment, ion homeostasis, ion exclusion, and compartmentalization are adapted by legumes to thrive under salinity stress. The prime concern nowadays is to develop cultivars that can alleviate/tolerate the ill effects of salinity and increase productivity. The knowledge of salt tolerance

Gene	Source	Target plant	Role	Promoter used	Reference
<i>AtNHX1</i>	Arabidopsis (<i>Arabidopsis thaliana</i>)	Mung bean (<i>Vigna radiata</i>)	Compartmentalization of Na ⁺ ions into the vacuole.	CaMV 35S	[79]
<i>OsRwb</i>	Rice (<i>Oryza sativa</i>)	Pigeon pea (<i>Cajanus cajan</i>)	Increase the chlorophyll content, relative water content, peroxidase, and catalase activity.	CaMV 35S	[80]
<i>Glyoxalase I</i>	Mustard (<i>Brassica juncea</i>)	Mung bean (<i>Vigna mungo</i>)	Belongs to metallothionein transferase superfamily, detoxifies the cytotoxic methylglyoxal to S-D-lactoylglutathione, and involved in oxidative stress metabolism.	CmYLCV	[81]
<i>GsERD15B</i>	Soybean (<i>Glycine max</i>)	Soybean (<i>Glycine max</i>)	Improves the expressivity of genes associated with proline content, ABA-signaling, dehydration response, catalase-peroxidase, and cation transport	—	[82]
<i>AhALDH3H1</i>	Ground nut (<i>Arachis hypogaea</i>)	Soybean (<i>Glycine max</i>)	Oxidates aldehydes to protect cells from the aldehydes.	<i>AhALDH3H1</i> promoter	[83]
<i>VrNHX1</i>	Mung bean (<i>Vigna radiata</i>)	Cowpea (<i>Vigna unguiculata</i>)	Sequesters Na ⁺ from cytosol for compartmentalization in the vacuoles and maintains cellular homeostasis	CaMV 35S	[84]
<i>OsDREB2A</i>	Rice (<i>Oryza sativa</i>)	Soybean (<i>Glycine max</i>)	Accumulates osmolytes, improves the expressivity of a few key stress-inducible TFs and genes	—	[85]
<i>P5CSF129A</i>	Moth bean (<i>Vigna aconitifolia</i>)	Pigeon pea (<i>Cajanus cajan</i>)	Protects the cellular tissues through enhanced proline level. Increased proline reduces the level of free radicals.	CaMV 35S	[86]
<i>GsCBRLK</i>	<i>Glycine soja</i>	Alfalfa (<i>Medicago sativa</i> L.)	Enhancing superoxide dismutase (SOD) activity	CaMV 35S	[87]

Table 8.
 Transgenic techniques employed in various legumes to enhance salinity tolerance.

breeding is well-documented in cereals but not in legumes. With the advent of various molecular and omics techniques several markers, QTLs, and genes linked with saline stress tolerance have been identified which help improve the crop performance and productivity under saline conditions. Wild relatives possess numerous tolerance genes but due to the complex nature of the salt tolerance trait, understanding their

roles at various developmental stages is required. Identification of a wild/cultivable donor requires the development or designing of appropriate screening procedures. Breeding for saline tolerance requires multi-environment screening which enables identification of tolerance-associated genomic regions. Utilization of appropriate molecular tools will improve the success rate. The database with integrated information on transcriptomics, metabolomics, and proteomics, especially for legumes, will help researchers understand the linkage between various signaling pathways like stress-specific, hormonal, and growth and developmental pathways. Recent advanced strategies like genomics selection (involving various mathematical models) help to predict the yield under abiotic stress conditions. Speed breeding is another approach that enables the growing of more crops in a year in a controlled condition (improves the breeding efficiency). Integrating these breeding approaches with other techniques like genomic, transcriptomics, metabolomics, transgenics as well as genetic engineering approaches like CRISPR-Cas9 are essential to develop legume varieties that can thrive in saline conditions and exhibit high-salt tolerance.

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Conflict of interest

None.

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Chapter 3

Soil Use and Management in Romania

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Abstract

The application of modern soil management is integrated in the territorial organization, economy, and social underpinning of sustainable rural development needs by providing food through land conservation capacity, and quality of life. Obtaining crop production while preserving biodiversity is only possible through special treatment of each homogeneous ecological area and subsequent rational management solutions, the purpose of differentiated soil management. It emphasizes the importance of balancing crop production with biodiversity conservation through differentiated soil management, taking into account Romania's diverse climatic, biotic, and edaphic conditions. Land management strategies must consider local climatic and edaphic variations to optimize agricultural practices. Climatic, biotic, and edaphic factors that increase plant size and crop quality manifest very differently among the different regions of Romania. Soil serves as a crucial natural resource with six major functions, including biomass production, environmental protection, and providing a biological habitat. It also plays a key role in infrastructure development and as a source of raw materials. In this chapter, we explain such phenomena and the general laws of crop production. Optimal management techniques suited for each area, locality, and ecologically homogeneous territory (e.g., natural, social, and local economic factors) are presented. Soil management must be distinguished primarily based on the four major agricultural zones not only with: steppe, forest steppe, forest, and alpine, but also with consideration of other limitations and restrictions encountered (e.g., hydromorphology, salinity, alkalinity, weathering, soil texture). Soil fertility is influenced by both natural processes and human activities, impacting agricultural productivity. Increasing crop yields sustainably requires a balance of natural soil properties, climate, and proper land management.

Keywords: soil resources, limiting factors, soil erosion, differentiate soil management, soil amelioration

1. Introduction

Soil, a natural or various human-modified resources, formed on the surface of land ("skin of the earth"), is a unique natural resource, used as a means of production, a resource that was not created or produced by man and that is limited in extent.

Soil fulfils six important functions, of which three ecological functions and three functions related to socio-economic, technical, and industrial uses [1–3]:

1. Biomass production, providing food, feed, renewable energy, and raw materials.
2. Filtering, buffering, and transforming substances between the atmosphere, hydrosphere, and biosphere, protecting the environment and humans, especially against groundwater contamination and disruptions in the food chain.
3. Biological habitat and gene reservoir, hosting more species, both in number and diversity, than all other biological environments combined.
4. Foundation for technical, industrial, and socio-economic structures, playing a crucial role in their development.
5. Source of raw materials (clay, sand, gravel, ores, etc.), as well as energy and water.
6. Geological and cultural heritage, forming an essential part of the landscape we live in.

The soil has a material constitution (composition), internal architecture, and specific physical, chemical, and biological properties, constituting together with the close atmosphere, the living environment of the plants [4]. In this environment, there are vital processes of accumulation and transformation of substances at the contact of the roots with the soil solution and its solid part and there are processes of absorption and exchange of substances, processes that are the basis of mineral nutrition of plants.

Soil fertility, a specific attribute, formed over time by a complex of natural (solidifying) factors, is in a permanent dynamic on agricultural land, being influenced by the anthropogenic factor, including the processes of formation of the mineral, organic, or soil profile [5, 6].

Increasing the production of field plants, obtaining stable production over time and in conditions of economic efficiency can be achieved only by judiciously combining three important factors [3, 7]:

1. *Natural environmental factors* (environmental conditions: relief, rock, soil, etc., and vegetation factors: light, temperature, water, air, nutrients, and biological activity in the soil, meaning optimal use capacity, in conservation conditions and improving the quantity and quality of natural resources. Reproduction of soil fertility, maintenance of water, and air quality are mandatory requirements in the evolution of agroecosystems.
2. *The biological factor*, meaning the cultivated variety or hybrid and its location in relation to the “supply of the place.” Maintaining biodiversity is a condition for the long-term efficiency of agricultural production and is the basic condition for organizing crop rotations.
3. *Cultivation technology*, meaning rotation, crop rotation, tillage system, sowing, fertilization, crop protection, etc.

The management of natural resources, in the agricultural systems, is by correlating the environmental factors with the biological and technological factors, and their optimization through the applied agrotechnics is a priority in the conditions of practicing a sustainable and at the same time commercial agriculture.

In the systemic approach of cultivation technologies, they must always be included in the component of the natural system (relief, soil, climate, topoclimate, etc.) as any intervention (tillage, amendment, fertilization, irrigation, weed control, diseases and pests, etc.) aims to supplement the favourable effects of vegetation factors (light, temperature, water, air, nutrients, and biological activities in the soil) and to ensure the living and production conditions required by crops. The analysis of imbalances in nature must therefore be based on synthetic (systemic) consideration for the detriment of exclusive analytical (engineering) consideration.

The total land surface (defined as an expanse of land) includes areas covered by water within the borders of a country or within a territorial administrative unit (natural or legal). Romania's land area is 23,839,100 ha, 0.16% of the world's surface. Worldwide, Romania is ranked #83 for areal extent, and it constitutes 4.81% of the Europe's surface (ranked #12) [8]. Romania has 3195 kilometres of border. Republic of Moldova and Ukraine lie to the east, Bulgaria lies to the south, and Serbia and Hungary to the west. In the southeast, 245 kilometres of sea coastline provide an important outlet to the Black Sea. Intrinsically, land is a valuable natural resource and a precious economic asset, different from other goods.

Depending on the intended land use, categories are defined as follows:

- agricultural lands: valued for specific production appropriate for agro-technical works;
- forested lands: contribute greatly to microclimate regulation and soil conservation;
- other lands: permanently covered by water and urban areas or used for other special purposes.

Soil, as a fundamental component of land, is a unique natural resource that serves as an essential foundation for agricultural production [9]. Unlike other assets, it is not a human-made creation, making it finite and irreplaceable [10]. Land ownership should not be seen as an absolute right but rather as a conditional one, accompanied by responsibilities such as land cultivation and soil conservation—duties that hold both personal and societal significance [11]. Land management primarily focuses on optimizing land use and preserving resources, especially in the context of a growing global population and the increasing demand for efficient food production [12]. To facilitate informed decision-making, land use is often categorized, helping policy-makers and government officials better understand natural resource management, sustainable land development, and market influences on agriculture [13, 14]. Common land types of Romania are presented in **Table 1** [15–17]. Romania has 14,856,800 ha of agricultural land which represents 62.3% of the total surface; 0.65 ha per capita. At the national level, 72.5 and 27.5% of soils in Romania can be broadly classed as very poor and good/very good, respectively, based on intrinsic soil characteristics, climate, topography, and ground water (**Table 2**, [15–17]).

Arable land is subject to plowing or cultivation with different annual or perennial plants. Arable land in Romania represents 9381,000 ha, 39.4% of the total area, or

Use	Thousand Ha	% of the country surface	% of the surface by use
Arable	9381.1	39.4	63.1
Pastures	3441.6	14.4	23.2
Meadows	1507.2	6.3	10.2
Vineyards	272.3	1.1	1.8
Orchards	254.6	1.1	1.7
Total agricultural	14,856.8	62.3	100
Forests	6457.3	27.1	71.9
Waters, puddles	867.9	3.6	9.7
Other areas	1657.1	7.0	18.4
Total non-agricultural	8982.3	37.7	100
Total surface	23,839.1	100	—

Table 1.
Categories of land use in Romania.

Pretability class (pb—points of bonitation)	Category of use							
	Arable		Pastures and meadows		Vineyards and orchards		Total	
	Thousand ha	%	Thousand Ha	%	Thousand ha	%	Thousand ha	%
I—very good (81–100 pb)	357	3.8	55	1.1	2	0.3	414	2.8
II—good (61–80 pb)	3368	35.9	222	4.5	78	14.8	3665	24.7
III—medium (41–60 pb)	2373	25.3	604	12.2	115	21.8	3092	20.8
IV—poor (21–40 pb)	1726	18.4	1772	35.8	120	24.7	3628	24.4
V—very poor (0–20 pb)	1557	16.6	2296	46.4	202	38.4	4055	27.3
Total	9381	100	4949	100	527	100	14,857	100

Table 2.
Agricultural suitability of lands in Romania.

0.41 ha per capita. Most Romanian arable land is found at altitudes of 400–500 m, but can occur up to 1000–1200 m. Unquestionably, arable lands are the most important category of land use as plants grown on such lands (cereals, crops, vegetable crops, fodder, medicine plants, etc.) are essential in the human diet, animal feed, and industry. Arable land are usually deep soils with ground water below 1–2 m depth, moderate slopes (<12–15%), and devoid of salts or other substances harmful to plants.

Lands planted with vines constitute ~272,000 ha and are found in piedmont plains or hilly regions, <500–600 m altitude, in warmer climates. Sunny slopes (southern, south-west) are optimal for such vines. Orchards (~255,000 ha) are widespread, often >1000 m altitude, and also found on inclined slopes. Tree speciation differences reflect elevational gradients depending on their specific thermal requirements. For example, plum trees (*Prunus domestica* L.) can grow up to an altitude of 1000 m,

apple trees (*Malus domestica* Borkh.) are mostly found up to 200–300 m altitude, and the hair trees (*Pyrus communis* L.) were even at lower altitudes. Peach (*Prunus persica* L.) and apricot trees (*Prunus armeniaca* L.), more demanding in terms of heat, occur at lower altitudes in the warmer parts of the country.

Grasslands, including pastures (3,442,000 ha) and meadows (1507,000 ha), are found at virtually any altitude from sea level to alpine areas. Obviously, the floristic composition is elevation dependent. Typically, grass species are found on strongly inclined slopes, shallow soils, or those affected by excess moisture or salinity, such that they are precluded from use as farmlands, orchards, or vineyards.

Forests (~6457,000 ha) are widespread especially in mountainous and hilly regions with strong rugged terrain. Non-agricultural lands include surface waters, construction areas, and unproductive lands unevenly spread across the country.

All agricultural and many other types of land use are actually cultural ecosystems. In such systems, humans try to exercise control over key variables within ecosystems through territory organization and optimized soil use and management. Culturally, historical precedent plays a key role in how lands are temporally conditioned [18].

No. crt.	Limiting factors and degradation processes	Agricultural		Arable	
		Thousand ha	%	Thousand ha	%
1	Erosion by water	5663	38.1	4400	46.9
2	Landslides	702	4.7	—	—
3	Erosion by wind	387	2.6	273	2.9
4	Frequent drought	7100	47.8	5200	55.4
5	Salinization	614	4.1	400	4.3
6	Temporary excess of moisture	4100	27.6	3800	40.5
7	Subsoil compaction	2800	18.8	2060	21.9
8	Soil surface compaction	*	*	6500	69.3
9	Skeletal in the top layer of soil	300	2.0	52	0.5
10	Low and very low content of humus	7304	49.2	4445	47.4
11	Moderate and strong acidity	3420	23.0	1636	17.4
12	Strong alkalinity	162	1.1	121	1.3
13	Low nitrogen content	3348	22.5	2563	27.3
14	Low content in accessible phosphorus	4473	30.1	2956	31.5
15	Low content in accessible potassium	498	3.3	259	2.8
16	Lack of micronutrients (zinc)	*	*	1500	15.98
17	The risk of crust and closing of pores	*	*	2300	24.5
18	Removal of soil through various works	15	0.1	*	*
19	Soil coverage with solid waste	18	0.1	11	0.1
20	Chemical pollution of soil	900	6.0	*	*
21	Oil pollution	50	0.3	*	*
22	Waste pollution brought by air	147	0.99	82	0.87

* missing data.

Table 3.
 Key limiting factors of productive capacity of agricultural soils in Romania.

Restrictive factors of agricultural soils and their productive capacity in Romania are listed in **Table 3** [3, 19].

2. Ecological groups and land capacities

Differentiated soil management represents how agrotechnical measures are uniquely applied to each land parcel and local climatic conditions. Each of the vegetation factors, either from climatic, biotic, or edaphic influences, can positively or negatively affect crops, depending on the conditions under which it is conducted. From this point of view, Romania has a specific geographical situation, namely [3, 20, 21]:

1. Romanian territory is located in the southeast portion of Central Europe at the crossroads of several high- and low-pressure centres that form regularly at the borders. The influence of these air masses is altered by the presence in the central regions of the Carpathian mountain chain resulting in a diverse climate with average annual rainfall amounts between 350 and 1400 mm and average annual temperatures between 2 and 11.5°C.
2. Romania is the country with the most balanced relief, being almost equally divided between mountains, hills, and plains. The approximate ratio of geographical units being: mountains: ~31% of the country's surface; hills and plains: ~36%; plains: ~33%. This distribution gives Romania a varied relief, favouring various economic activities and a diversified climate. The Carpathian Mountains dominate the centre and north of the country, the hills and plateaus are mostly present in the east and south, and the plains are in the south and west.
3. At the national level, almost all soils in the international classification system are present in Romania (**Figure 1**) and through this we can see a real “soil museum,” each soil type having specific properties and characteristics.

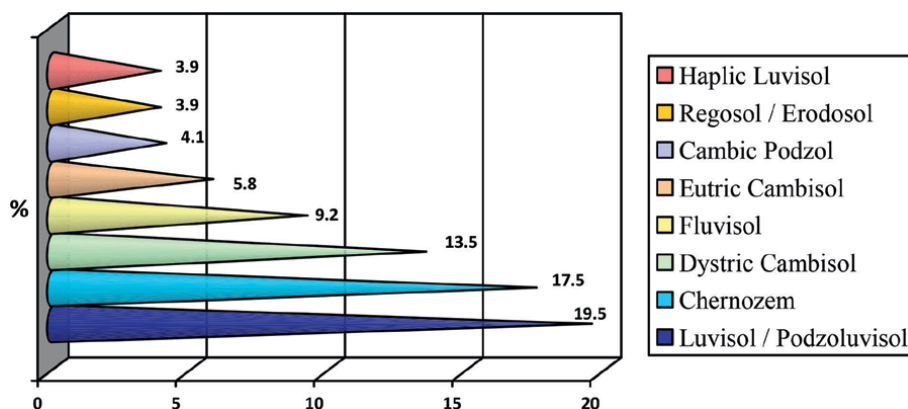


Figure 1. Principal types of soils in Romania [15].

4. On approximately 12.5 million ha (7.5 million ha arable), soil fertility is adversely affected by erosion, acidity, low humus content, extreme texture (clay, sand), excessive moisture, and chemical pollution.

These natural and anthropogenic factors dramatically influence agricultural production. Furthermore, soil, climate, topography, etc., vary widely not only across the country, but also on smaller scales, even across fields within the same farm. These differences should be considered in drafting a differentiated agriculture system. In other words, the technology used must vary according to the conditions present on each agricultural farm.

Landscapes, and specific climatic and soil zones require the zoning of agricultural crops, varieties, and hybrids. Also, technology must be adapted to minimize the limiting factor's zonal actions (e.g., deficit or excess of moisture, low humus content, and nutrients).

The landscape, through representative forms of macro-relief (plains, plateaus, mountain systems) and meso-relief (hills, dales, valleys, terraces, slopes, meadows), by expanses, dimensions, complexity, etc., significantly influences the formed soils and creates specific topographic climates favourable to certain cultures distinguishing between technology elements. The type of vegetation in a region is influenced by its geographical location as well as by local orographic, pedoclimatic, ecological, and anthropogenic factors. Woody vegetation generally reflects the influence of macroclimatic conditions, whereas herbaceous vegetation is more responsive to microclimatic factors. The geographical distribution of soils, plant species, and the relationships between environmental components and both natural and cultivated vegetation evolve over time, along with environmental changes that influence this distribution. Each plant species possesses physiological traits that enable it to survive within specific ranges of temperature, humidity, acidity, and other conditions. The interactions that link environmental to biotic components of a territory illustrate their interdependence and the essential requirements of living organisms. Climatic specifics of agricultural areas and in particular the conditions of temperature, humidity, and light delimit areas of plant cultivation. Fertilizer, space nutrition, and soil tillage preferred by plants are optimized under appropriate climatic conditions corresponding to the biological preferences of plants. Much lower yields will result from inappropriate climatic or edaphic conditions.

The application of differentiated soil management and crop zoning is necessary because Romania is characterized by a large variation in environmental conditions. Atmospheric precipitation, for example, ranges from 250 mm annually in the Danube Delta to over 1000 mm annually in the Carpathians Mountains in the north. The soil formed in a given region reflects time spent under the influence of environmental conditions and pedogenesis through a number of quantitative properties (e.g., humus content, texture, pH, degree of base saturation). As a result, cultivation technologies must be some what flexible. Soil characteristics influence primarily the development of the root system and the absorption of nutrients, but also implicitly impact plant yield and efficiency of plant cultivation. Closely related to the diversity of climate and vegetation conditions, soil varies both morphologically and in terms of agroproductive characteristics, expressed in terms of fertility. Across a relatively small geographic area of Romania, almost all soil types from the temperate climates are found to include chernozems and preluvo-soils up to poor, leachates, podzols, and brown acid soils—from the coldest regions of the country.

Natural fertility of the soil decreases gradually from the plain areas to the cold mountainous areas, as it enhances clay illuviation and leaching processes. As such, the diversity of plants that find their optimal growth and development narrows from the plains to the mountains, and field crop production becomes more expensive. Adaptation of technology for cultivation, and the creation of new varieties and hybrids represent instruments to amend zonation of agricultural plants as a result of the reduction or elimination of some limiting factors and changes to environmental suitability.

2.1 Soil management in the steppe

The steppe zone consists mainly of plains and hilly relief, representing the largest part of the Romanian Plain, West Plain, and Dobrogea Plateau. The association of soils is represented chiefly by chernozems, gley soils, aluvio soils, verti soils, solonetz, and psamo soils (SRTS, 2012).

The arid steppe zone is characterized by an average annual temperature of 10.7–11.4°C, 17–21 aridity index, and annual rainfall of 350–420 mm. The arid steppe zone includes irrigated areas from the Romanian Plain, Dobrogean Plateau, Danube Delta, and Meadow and Cotmeana Platform. The limitative climatic factors, which require differentiation toward soil management use, include: long periods of drought, high temperatures, high frequency winds, low relative air humidity, and harsh frosts during winter. It includes embossed surfaces, generally as plains or slightly inclined, unfragmented plains, isolated dales, loess substrate, and soils saturated with colloidal basic cations ($V\% = 90\text{--}100$). The grade of land is between I and IV for arable use, temperatures are high, and a precipitation deficit is common. The climate is characterized as continental, with extreme temperatures during summer ($>35^\circ\text{C}$), snow storms and frost in winter, and long periods of drought. Thermal resources range from 3800 to 4200°C ($>5^\circ\text{C}$) and 3400 to 3800°C ($>10^\circ\text{C}$). The pluviometric regime is between 350 and 450 mm, differentiated on microzones. Solar radiation is 132–136 kcal cm^{-2} in Dobrogea and 124–132 kcal cm^{-2} in the rest of the microzones [22]. The dominant soils are chernozems and kastanozioms (Balan soils). Specific crops for the arid steppe zone in the south and southeast of the country are autumn wheat, fodder plants (mash with peas), soy, barley, two-row barley, maize, sunflower, and sugar beet. Smaller surfaces feature sorghum, beans, peas, castor oil plant, and in the southern Romanian Plain, rice and cotton.

Typical steppe zone is characterized by an average annual temperature of 9.6–11.4°C, 20–25 aridity index, and annual rainfall of 380–560 mm. The area has a good and very good favourability for most agricultural crops; soil management differentiation is conducted on the basis of a specific warm-dry area. The warm un-irrigated subarea in the south and southeast of the country includes the north part of Dobrogea, the Romanian Plain to the Siret Plain, and the northwest Burdea Plain. The warm subarea in west of the country includes territories from the western part of Timis Plain and a part of Arad Plain. Land forms are represented by plains of digression, un-fragmented, with ridges and depression areas of frequent water intake. Thermal potential is between 3800 and 4000°C, average monthly temperature during the summer is 21–22°C, annual rainfall is 350–550 mm, and annual aridity index is 25 [23]. The dominant soils are chernozems and kastanozioms, but vertisols, salsodisols (solonchac and solonetz), and hydrosols also can be seen. Negative phenomena most commonly encountered in this area are salinization, excess water, temporary deficit of rainfall, and poor to very poor supply of humus, phosphorus, and potassium. Factors limiting the plant productivity also occur and require technology differentiation

systems. Favourable species for these conditions include maize for grains, fodder plants, autumn wheat, barley and two-row barley, sunflower, soybean, sugar beet, beans, flax for oil, and hemp.

Area of irrigated sands. In the Romanian Plain, there are 73,000 ha, of which 56,500 ha are in agricultural use. This area differs radically from the rest of the area, in that the relief is represented by sand dunes and inter-dunes and soils are dominantly psamosoils (80%) and chernozems (20%). These are the irrigated sands in Oltenia, along with specific pedological characteristics of sand and sandy soils, where the climate presents some peculiarities: the total annual rainfall is between 500 and 550 mm and the sum of the air temperature is 3800–4200°C. In this area, farmers often face water shortages, wind erosion, and poor supplies of soil humus, phosphorus, and potassium. Considering that the specific soil is mostly sandy and that the whole area is irrigated, it is estimated that these conditions are well suited to the following cultures [24]:

- on sands with <0.7% humus: rye, sorghum, cow peas, tobacco, castor oil plant, peanut, melon, and fodder plants;
- on sands with 0.71–1.2% humus: triticale, rye, sorghum, beans, castor oil plant, tobacco, peanuts, melons, and fodder plants;
- on sands with >1.2% humus: wheat, corn, soybeans, vegetables, potatoes, melons, and fodder plants.

The main factor limiting the growth in production of this area is water. High and safe yields are realized only under irrigation. When tilled, soil water storage must be ensured and doses of fertilization and crop density should be adjusted in relation to the application of irrigation [25]. Summer plowing should be done immediately after harvesting the crop and plowing will work with the star harrow to reduce surface evaporation. Autumn plowing usually runs deep (25–30 cm), especially for weeding crops to accumulate more water. Spring crops owing is done as early as possible to take advantage of early moisture and crop-specific maximum depth. In dry autumn sand springs, tillage with roller is required to ensure good seed–soil contact.

2.2 Soil management in the forest steppe

The forest steppe zone results from the interplay of steppe and forest vegetation zones plus a compact part of the Transylvanian Plain. The climate of the forest steppe zone represents a transition from dry to wet with average annual temperatures of 8.3–11.4°C, aridity index of 23–30, and annual rainfall of 460–600 mm. It occupies the space between 100- and 500-m altitude, including areas north of the Romanian Plain, Buzau Plain, Jijia Plain, Western Plain, and Transylvanian Plain. Key soils of the area include chernozems, phaeozems, regosols, alluvisols, preluvisols, and erodosols. These soils have clay-loam texture, slightly acid reaction (pH 5.8–6.8), and variable humus reserves, depending on soil type, from large to very small. Differentiating soil management is more complex than in the arid steppe and typical steppe as environmental conditions, topography, and soil are heterogeneous. Limiting factors of the area include drought, erosion, temporary excessive moisture, soil compaction, slope, exposition, groundwater depth, occurrence of white frost period, and early/late frosts; climate is also highly variable from one subarea to another.

The southern forest steppe includes the northern Romanian Plain and Buzău Plain. In this subarea, average annual temperature is 10–11°C, thermal resource has limits between 3200 and 3400°C, the aridity index is 27, and annual precipitation is 460–550 mm. Typically, 60% of the growing season faces some type of moisture deficit from April to September; maximum deficits occur in June. There are frequent strong winds and extreme frosts in December–January.

The forest steppe of Moldavia includes the Jijia Plain and Barlad Plateau. It has a harsher climate than the southern forest steppe. Average annual temperature is ~9°C, and thermal resource is between 2800 and 3200°C. Annual precipitation is 500–600 mm, of which 65–68% falls during the growing season. Late fall frost and early spring frosts are more frequent than in the southern forest steppe.

The forest steppe from the Transylvanian Plain is similar in terms of climate with the forest steppe of Moldavia, with average annual temperatures of ~8–9°C, thermal resource is between 3200 and 3400°C, and annual precipitation is 500–600 mm, of which 63–65% falls during the growing season. Sudden changes of temperature are less common than in Moldova's forest steppe. Less snow is blown and the frost from December–January is less severe.

The Transylvanian Plain, with an area of 395,616 hectares, is an important agricultural production area of Romania. The Transylvanian Plain is characterized by a specific climate which is extremely diverse. Contrary to its name, from an orographic point of view, the Transylvanian Plain is comprised of hilly relief. Land degradation in the Transylvanian Plain and its effects should be viewed through the prism of local physical–geographical conditions, to which extreme climatic conditions can be added. These conditions generally create a propitious framework of deployment of morphogenetic processes triggered by human activity, as well as triggered by natural mechanisms, increasing both the rhythm and their territorial expansion. As an example, consider precipitation. Although in terms of annual amount precipitation is commonly deficient, its regime exercised further promotes a negative influence on the plant carpet. From March to November, when soil is dried through agricultural tillage, the amount of rainfall discharging down the slopes is relatively high (40–50% of the total rainfall). Furthermore, torrential rains increase pluvial aggressiveness [26, 27].

Relief is also susceptible, together with the rainfall, through accentuated fragmentation degree and by slope tilting. This is especially true of southern ridges, where cultivated crop predominance combines with the advanced stages of degradation commonly observed in grasslands. Southern facing slopes also typically have a lithology rife with friable stones (e.g., sands, marls, grus). This requires special measures for soil conservation, in both autumn and early spring. Soil tillage measures should encourage the accumulation of plant debris and vegetation in early spring, but even more so in summer and autumn.

The integrated conservation and management of agricultural lands affected by current global warming is a key international priority, aligned with the principles of sustainable agriculture and climate adaptation strategies. The Transylvanian Plain, characterized by a low afforestation rate of only 6.8% and widespread degradation of farmland, exhibits the lowest resilience to climate change. Monitoring agro-climatic indicators and their evolution between 2008 and 2014, along with the analysis of collected data, form the basis for developing tailored technological recommendations suited to current favorable conditions for major crops [26].

The findings indicate that the soil thermal regime in the Transylvanian Plain is mesic, while the moisture regime is ustic. The multiannual average soil temperature is

11.40°C at 10 cm depth and 10.24°C at 50 cm depth. The mean annual air temperature is 11.17°C. The multiannual average soil moisture content is 0.227 m³/m³, and the average annual precipitation is 466.52 mm.

When compared with previous reference periods (1961–1990; 1901–2000), the study period reveals a noticeable decline in average rainfall, particularly during critical crop growth stages, along with an overall increase in average annual temperatures (Figure 2). The most significant temperature differences were recorded between June and August, ranging from +3.09°C to +3.65°C. This points to a rising trend in drought and heat events, with indicators showing that 61.11% of the values correspond to semi-arid climate conditions.

Periods of the highest climatic stress occur in February–April, July, and October–November, with 19.43% of cases showing favorable or very favorable conditions for erosion to occur. To mitigate and counteract the effects of drought—identified as a major agricultural risk in the Transylvanian Plain—the following agro-technical measures are recommended [28]:

- i. selecting crop varieties resistant to water stress and heat;
- ii. applying management practices that enhance the collection, conservation, and efficient use of rainfall;
- iii. implementing a conservation agriculture system aimed at soil protection and preventing desertification.

The forest steppe from the Western Plain is the most favorable subzone of forest steppe for cultivation in the country. The climatic conditions are the most favorable, with average annual temperatures of 10–11°C and precipitation of 560–600 mm per year [29]. Dry periods are shorter with less intense drought and soils have a greater capacity for water storage.

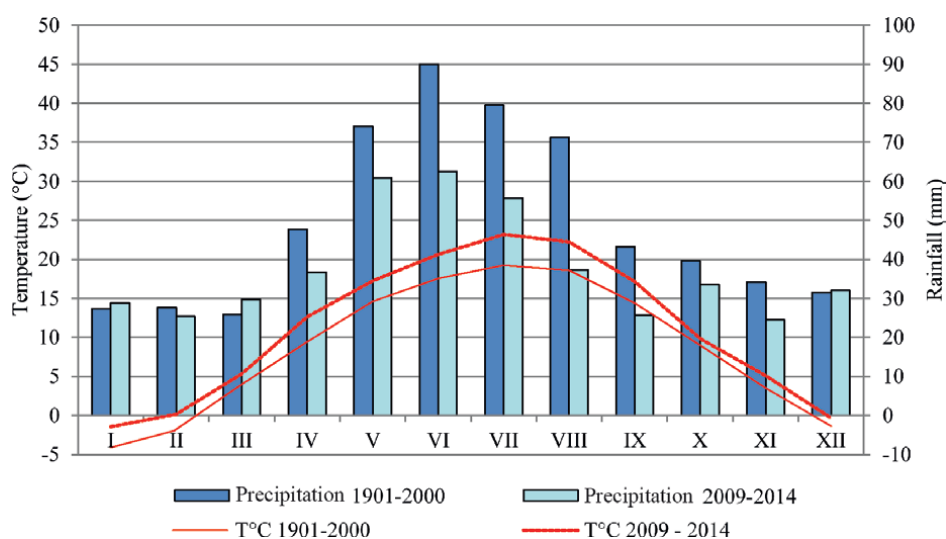


Figure 2. Thermal and rainfall variation in Transylvanian plain for periods 2009–2014 and 1901–2000 [26].

Depending on the productive potential of agricultural land, forest steppe zones are generally best suited for maize and cereals as predominant crops, followed by fodder plants, especially alfalfa and clover. Other crops grown in such areas include soybeans, peas, beans, sunflowers, sugarbeets, hemp, tobacco, flax for oil, flax for fabrics, linseed, and rapeseed.

Organic and mineral fertilizer use in the area result in most plants of ferer significant increases production. In particular, N and P fertilizers are a key. Also, irrigation and water conservation measures in the soil have a very important role in the forest steppe. Most lands in the forest steppe are situated on slopes so the tillage system must include anti-erosion agrotechnics. Furthermore, finding the optimal timing of tillage is very important for avoiding secondary compaction of the soil. Integrated weed control should be emphasized because in the forest steppe, weeds create major drops in production. Rainy spring periods aggravate the cultivation tillage, and in some years, the rains in June may increase weeds in the potato crops, and even those treated with herbicides.

2.3 Soil management in the forests and alpine zone

The plain forest area is characterized by average annual temperatures of 7.8–11.7°C, and an aridity index of 28–36 and 515–660 mm annual rainfall. This area borders the forest steppe and extends from the plains to the floor of the foot hills. The climate is hot in the southern part of the country and some what harsher than in other regions. This area is favorable for the cultivation of maize, wheat, and sugar beet, as well as crops like peas, beans, lentils, hemp, and potato. Barley and autumn rye are also cultivated in smaller areas, though less frequently. Limiting factors of the area include mixed relief, reduced field surface, excess surface moisture, lower soil fertility compared to previously studied areas, soil erosion, pronounced diverse spectrum of weeds, and vegetative development opportunities compared to previous areas.

The forest area is the largest vegetation area in the country. The overall area includes lands bounded on the outside by the forest steppe and the interior boreal mountain floor. The forest area contains a diversity of land forms and climatic conditions that favored the formation of a variety of regional soils with a high percentage of preluvisols (reddish brown, brown clay, illuviated soils) and luvisols (luvic brown, luvisols albic soils).

The forest area of hills and lower mountains (area of foot hills and hills) is characterized by average annual temperatures of 5.9–10.2°C, 35–55 aridity index, and annual rainfall of 600–1000 mm.

The mountain area covers a total surface of 70,101 km², with a population of around 2.4 millions inhabitants and an average density of 34 inhabitants/km². The share of employment in agriculture is estimated at 40.2% of the total labor force. The density of animals/100 ha is below the national average. Moreover, the average size of farms is of only 3.4 ha, out of which only 20% is arable land [20].

The southern and northern Getic piedmont varies in landscape with the piedmont plains, fragmented hills, and foot hills to the north with low to middle slopes steeply inclined. The climate is warm, with thermal resources ranging from 3600 to 3800°C in the south and from 2800 to 3200°C in the north; average annual temperature varies between 9 and 11°C, and annual rainfall is between 600 and 650 mm. Limiting factors make the area less favourable for agricultural crops and cause obvious soil management differences that alleviate the low fertility status of soils, erosion, primary and secondary soil compaction, temporary excess moisture, and soil acidity. Other limiting factors of crop production are late spring frosts and widespread weeds with

invasive potential occurring before the emergence of the crop. Various crops can be grown with good and very good results on corrected acid soils that have been properly fertilized with organic and chemical fertilizers, including wheat and triticales, barley, maize, potatoes, and forage plants, especially alfalfa and clover, and on smaller surfaces, legumes and sunflowers.

The western piedmonts, Somesan Plateau, Tarnavelor Plateau, and Moldavian Plateau present dominant forms of relief in moderate-to-strong fragmented hills and plateaus, medium- to high-inclined slopes that are affected by erosion, landslides, coastal streams, and processes such as pseudo-gleyzation and even salinization. The average annual temperature varies between 7.5 and 9°C with annual rainfall ranging between 600 and 800 mm. Thermal resources are best ensured in the western Piedmont region from 2800 to 3600°C (>5°C), followed by the Moldavian Plateau (2600–3000°C). The Somesan Plateau has the most abundant precipitation with 650–800 mm annually. Because the landscape is kneaded and sometimes rugged, the heavy and acidic soils and cold and rainy climate can cause phenomena such as erosion, excess water, landslides, primary compaction, lower pH and humus content, and assimilable forms of phosphorous and potassium.

These conditions require a certain mode of usage that limits the productive potential of the land and requires special efforts from farmers. The agricultural land is 62% arable with the rest occupied by natural pasture (23%), grasslands (10%), vines (1.5%), and orchards (4%). The agricultural land is best used for cereals, clover, maize for grain, potatoes, and vegetables, especially on soils of the floodplains and terraces. On smaller areas with soils that have been corrected by the application of calcareous amendments, sugar beet is cultivated. Similarly, in the Tarnavelor Plateau soybean and sunflower are cultivated.

Basic ground tillage should be executed in tandem with other works such as scarification of compact sub-arable layers (Bt horizon), execution of mole drains (on some soils), organic and mineral fertilization, and the application of amendments. Forest area soils with textural differentiation, and clay and low humus content have a tendency to compact, tamp, and dismantle. Reducing traffic in the field and optimizing tillage timing are very important for these soils. For spring crops plowed in the autumn on slopes, harrowing and milling must be left for springtime.

In the Somesan Plateau, the minimum tillage and no-tillage systems represent alternatives to the conventional system of soil tillage due to their conservation effects on soil features and their assured production when compared to conventional systems. The implementation of such practices also ensures a greater water supply (**Table 4**, [30]). The practice of reduced tillage is ideal for enhancing soil fertility and water accumulation capacity, as well as for reducing erosion [25, 31]. The minimum and no-tillage soil systems for the Somesan Plateau pedoclimatic conditions can be used to improve methods in low-producing soils with reduced structural stability on sloped fields, as well as a measure to conserve water and soil within the whole ecosystem. Application of minimum tillage and no-tillage systems can lead to soil conservation in the Somesan Plateau without affecting crop yields (**Table 5**, [32]), especially on soils with high initial fertility.

Production increases are obtained by using high fertilization with organic fertilizers at a dose of 20–30 t/ha and green manure, but also with the application of fertilizers containing nitrogen, phosphorous (2:1), and potassium.

Autumn crops should be sown earlier in order to allow them to develop prior to winter. Spring crops should be sown later in order to avoid white frost and late frosts. It is necessary to combat weeds that can create great damage in these areas.

Soil tillage systems	Classic plow + disc -2x (wt)	Paraplow + rotary harrow	Chisel plow + rotary harrow	Rotary harrow	No-tillage
OM, %	3.03 a	3.12 ab	3.09 ab	3.23 b	3.26 b
Significance (%)	wt.(100)	ns(103.1)	ns(102.0)	ns(106.5)	ns(107.6)
WSA, %	71.33 a	76.00 b	75.33 b	76.33 b	78.21 b
Signification (%)	wt. (100)	* (106.5)	*(105.6)	*(107.0)	*(109.6)
BD, g/cm ³	1.34 a	1.34 a	1.35 a	1.34 a	1.38 a
Signification (%)	wt..(100)	ns(100.0)	ns(100.6)	ns(100.0)	ns(102.9)
W, m ³ /ha	878 a	1.010 c	998 b	987 b	995 b
Signification (%)	wt..(100)	*(115.0)	*(113.7)	*(112.4)	*(113.3)

Note: wt—witness, ns—not significant, *positive significance, ⁰negative significance, a, ab, b, c—Duncan's classification (the same letter within a row indicates that the means are not significantly different). OM—organic matter. WSA—water stability of structural macro-aggregates. BD—bulk density. W—water supply accumulated in soil.

Table 4.
The influence of soil tillage systems on soil properties (0–30 cm).

Variants	Wheat	Maize	Soya-bean
Plow	3812 ^{ws}	6310 ^{ws}	2112
Paraplow	3856 ^{ns}	6120 ^{ns}	2251 [*]
Chisel	3795 ^{ns}	6145 ^{ns}	2198 ^{ns}
Rotary grape	3745 ^{ns}	5890 ⁰	2241 [*]
No-tillage	3786 ^{ns}	5774 ⁰⁰	2341 [*]

Note: wt—witness, ns—not significant, *positive significance, ** (distinct) positive significance, ⁰negative significance.

Table 5.
The influence of soil tillage systems on the yield of wheat, maize, and soya beans (kg/ha).

The middle and upper mountain forest area is between 800 and 1400 m in altitude and characterized by average annual temperatures of 2.9–6.0°C, an aridity index of 45–110, and annual rainfall from 800 to 1300 mm. At altitudes of ≥ 1000 m, the climate is very cold with average air temperatures exceeding 10°C for only 1–4 months per year. At this altitude, coniferous forests begin, reducing favorable conditions for agriculture. The only crops that can be grown in this area are rye, potatoes, clover and flax for fiber. Restrictive elements relate to the cold climate, excess rainfall, kneaded land, large and steep slopes, heavy soils, low fertility soils, leaching processes, erosion of surface and depth, and favorable conditions for weed invasion.

The alpine zone is characterized by a mean annual temperature of <2.9°C, 180 aridity index and annual precipitation of >1400 mm. The starting altitude of the alpine zone is at 1600 m. In this agro-environmental area, the most common adverse events are very low sunlight and air temperature, small edaphic volume, strong erosion, acidification and low/very low supplies of soil organic matter and other nutrients. The structure of the agricultural lands in this region is dominated by pastures and meadows (~85%) and arable land (below 15%). Pedo-climatic conditions of this area are best suited for fodder plants, especially clover and straw cereals, including wheat,

rye, oats, barley and spring barley. Due to the conditions of these areas, there are reduced proportions of crops like potatoes, flax, beans and grains.

3. Soil management particularities on slopes

Slopes are considered areas located on landforms with a slope of $>5\%$, or 3° . In hilly and mountainous regions, the main limiting factor of crop production is the very diverse topography with slopes in all shapes and sizes. A characteristic of this region is that slope processes allow for very active soil erosion. Hilly slopes have a significant share in the physical and geographical units of Romania, particularly the Moldova Plateau, which is seen in the curvature of the Carpathian area in the Platform tems, west hills, and the entire Depression of Transylvania. Hilly areas with slopes have a significant share in the physical and geographical units of Romania, represented by the Moldavia Plateau in the curvature area of the Carpathians in the Getic platform, west hills, and the entire Depression of Transylvania.

Approximately two thirds of the surface of Romania, 48% of agricultural land and 30% of the arable land, are situated on slopes and are exposed to erosion [33, 34]. The counties with the largest agricultural areas are located in Moldavia (Vaslui, Vrancea), Transylvania (Cluj, Bistrita-Nasaud, Alba), and Banat (Caras-Severin). Most of the arable lands on slopes are located in the agricultural zone of the forest steppe and forestry area.

On the sloping lands from Romani, it is estimated that each year about 125 million tons of soil is eroding [34], of which, around 35% is transported into the river system. Due to this, about 33% of the agricultural area is affected by slope erosion processes and landslides. The land uses that are most affected are orchards (65.6%), grasslands (58.3%) and arable lands (20%).

3.1 Soil erosion

Soil erosion is a complex phenomenon in which certain physical agents of nature, especially water and wind, are acting on the soil, leading to its destruction. As a result of this phenomenon soil material particles are detached and then transported from the place of origin and selectively deposited elsewhere. In order to form a deep middle, ground it takes about 10,000–20,000 years of concurrent actions of pedogenetical factors; yet for its total removal, it takes only 15–25 years.

Depending on the duration and the intensity of the erosion process that occurs, both natural and accelerated erosion are possible.

Natural erosion refers both to the ancient erosion (geological) that contributed to the genesis of landforms and river networks and to the slow, natural process of normal current erosion that does not cause significant changes in the morphology of the ground's profile.

Accelerated erosion (anthropogenic) occurs with greater intensity than natural erosion and is amplified by human activities. If *wind erosion*, under the influence of wind, depends mainly on the type of soil and its characteristics, then *erosion* under the influence of water (*hydric*) depends in particular on the land's slope.

Erosion processes can occur when the amount of water from precipitation is greater than the amount of water that the soil can absorb. Climatic events causing leaking (erosion and flooding) in Romania are increasingly common. The risk of surface erosion processes—basins and gutters—increases when there is more than 15 mm

of rainfall daily or more than 4 mm an hour. Moderate erosion occurs on sandy or slightly loamy soils or when heavy rains fall on lands with slopes with low infiltration.

Erosion can occur in the form of simple run-off that contains fine particles of soil, or it can become more serious by forming ruts, rills, and gullies.

In Romania, the process of erosion has intensified, especially in recent years as a result of irrational exploitation of the forest fund and land fund, as well as the application of a totally inappropriate technological system, especially on lands belonging to small- and medium-sized farms. Water erosion has increased mainly due to soil tillage from upstream to downstream, preparation of a very fine seedbed, and the removal of hedges and other protective barriers. Before performing all agricultural works, especially those of plowing or re-seeding pastures located on slopes or the overflowing plains of rivers, consideration should be given to the possibility of erosion.

3.2 Factors that influence soil erosion

Developing a differentiated soil management system as well as a sustainable agricultural system in general on arable lands situated on hillsides requires a mandatory crackdown on erosion. Accelerated erosion apparently derives from the “antagonist” relationship among three components that trigger the phenomenon:

1. *The action of rain water—as a force of destruction.*
2. *Soil and its characteristics—as a force of resistance.*
3. *The soil tillage systems—as the agro-technological means of intervention to regulate the status and characteristics of the soil rather than as a way of promoting erosion.*

Development of the anti-erosion agricultural technology system must address all factors influencing the onset of the erosion process, such as:

- *climatic factors: rainfall, temperature, and winds;*
- *the soil and its characteristics, bedrock;*
- *the relief: landform, slope, shape, and slope length;*
- *anthropogenic factors: use, tillage system, plant cultivation, erosion agrotechnics, etc.*

Rainwater represents the generating factor of destruction and soil erosion. Rainfall chiefly influences soil erosion during periods of torrential rains and snowmelt. Torrential rain influences erosion intensity and pluvial aggressiveness. That is, when rain falls in a large volume during a short time, the kinetic energy of the droplet is too large. Pluvial aggression is calculated as the product of kinetic rain energy (E_c of water droplets + E_c from the surface drip). In Romania, the lowest pluvial aggression during a 30-minute period was recorded in the Western Plain and the maximum pluvial aggression was found in Dobrogea, Carpathians and Sub-Carpathians, Transylvania, and Moldavia [34]. At least every 10 years in the Transylvanian Plain, the maximum amount of rainfall within a 24-hour period exceeds the threshold of 50 mm. These events have a significantly aggressive impact on arable land.

Temperatures exert their influence by sudden changes in amplitude (from cold to hot), which influence fragmentation of soil aggregates. All extreme temperatures (amplitude) determine sudden snowmelt and their drain on the slopes.

Wind aided by sudden changes in temperature and prolonged drought contributes to soil erosion when its speed gives it a force capable of transporting soil particles.

Soil influences the erosion processes directly through resistance to moving water's actions, and indirectly through infiltration capacity, so as to reduce surface leakage flow. The ease with which soil particles on slopes are detached and transported by the action of raindrops or water drainage is called soil erodibility or erodability degree. Erodeability degree varies depending on the soil type, and the soil tillage system must account for this indicator. The soil properties that determine the degree of erodability are texture, structure, chemical composition, and parental material. Erodeability values of the

No.	Station	Soil type	Clay, %	Humus, %	Bulk density, g cm ⁻³	Erodability index (S)	Slope, %
1.	Balda	Faeoziom cambic	51.8	3.15	1.23	0.580	12
2.	Band	Faeoziom argic	45.63	3.11	1.3	0.683	1
3.	Craiesti	Faeoziom tipic	45.27	3.11	1.2	0.749	1
4.	Taga	Preluvosoil tipic	47.25	3.69	1.23	0.652	17
5.	Triteni	Faeoziom vertic	49.34	4.15	1.2	0.602	10
6.	Filpisu Mare	Districambosoil tipic	49.67	2.68	1.22	0.654	19
7.	Matei	Eutricambosoil tipic	29.2	3.51	1.22	0.709	3
8.	Nuseni	Preluvosoil tipic	51.14	2.19	1.22	0.645	30
9.	Sic	Preluvosoil tipic	51.1	3.10	1.22	0.601	25
10.	Zoreni	Preluvosoil tipic	35.05	2.16	1.22	0.939	17
11.	Caianu	Cernoziom calcaric	40.01	2.85	1.2	0.729	17
12.	Dipsa	Faeoziom tipic	58.19	3.56	1.26	0.522	3
13.	Jucu	Faeoziom argic	55.55	2.65	1.21	0.533	17
14.	Ludus	Faeoziom tipic	40.01	3.15	1.23	0.682	3
15.	Silivasu de Campie	Eutricambosoil molic	52.37	2.64	1.35	0.587	7
16.	Branistea	Eutricambosoil tipic	51.14	2.19	1.22	0.645	1
17.	Cojocna	Faeoziom argic	51.68	3.99	1.22	0.552	12
18.	Unguras	Eutricambosoil tipic	45.99	2.05	1.22	0.787	12
19.	Voiniceni	Faeoziom gleic	47.69	2.21	1.22	0.729	1
20.	Zau de Campie	Eutricambosoil tipic	43.81	2.5	1.22	0.818	12

Table 6.
Erodability index of soil (S) in Transylvanian plain.

Transylvanian Plain's soils are typically 0.939 for preluvosoil, 0.818 for typical eutricambosol, 0.522 for typical faeoziom, and 0.533 for argic faeoziom (**Table 6**, [35]).

The relief influences the erosion process through its morphometric characteristics, amplifying or reducing the kinetic energy of water from precipitation. On landforms, erosion occurs particularly on versants and depends on the slope, length, shape, and slope aspect. However, in the absence of anti-erosion agrotechnics, erosion can also occur on crests and terraces. *Slope length* influences erosion because elongation of the drainage route increases the flow of water and therefore intensifies erosion. *Slope forms* are of special importance in the consideration of anti-erosion agrotechnics as they give valuable guidance on areas exposed to erosion.

The size and components of the slope directly influence, sometimes differently, the application of soil management systems. However, it should be noted that the slope develops solitarily from different segments, each element evolving separately while influencing the others. The four possible segments are:

- *rectilinear* (straight)—in these segments leaks are uniform with a tendency to accentuate toward their base;
- *concave*—the strongest erosion is recorded in the upstream while the downstream gets clogged with eroded material;
- *convex*—erosion is more pronounced downstream of this segment where the slope is greater;
- *form of steps*—leakage and erosion is reduced due to existing platforms.

The slope profile can be completely represented by a single segment or may be formed from a series of different segments. Thus, depending on the actual conditions, the slope's profile may be simple (when one of the four segments occupies >90% of the length of the slope) and complex (when more than one of the four segments occur along the slope).

Slope exposure is particularly important to the correct assessment of land use, and selection of crops in the rotation and cultivation technology, particularly seeding depth.

Slopes with southern, southeastern, and southwestern exposure are sunny and steep (with inclinations of 10-25-45°, respectively). At the top, they are short or medium (about 200–400 m) and have straight or convex eroded segments with concave and clogged bottoms.

Northern, northeastern, and northwestern slopes are shaded and cooler, with smooth slopes (3–15°) that are longer (about 800 m). Their concave and convex segments give the appearance of wavy relief. The particularly arable lands common on the northern slopes are hydromorphism and pseudo-gleyzation phenomena favored by both relief and lithology (fine textured parent materials) as well as hydrogeology (coastal springs).

Heat and humidity on the western and eastern slopes are intermediate. Eastern slopes are heated during the day before noon, while the western ones are heated in afternoon.

Through inclines and exposure, the slopes create a diversification of topo-climates, soil distribution, direction and intensity of pedo-genesis processes, nutrition, and land use.

Human activity is one of the factors that contributes to the onset or removal of soil during the soil erosion process. Destructive human activity on slopes includes deforestation, grubbing the land, overgrazing, and the improper application of agrotechnical systems. On arable lands, erosion is mainly caused by improper tillage systems that in turn are the result of the agricultural equipment available at the time and the organization and ownership of the land. Due to the influences mentioned above, many fields in Romania are affected by erosion to varying degrees, becoming less productive or unproductive over time. Tillage mobilizes large masses of soil and changes aeration conditions and the water and temperature regime. In areas where the land parceling system corresponds to the general orientation of level curves and application of appropriate anti-erosion agrotechnics, tillage does not erode soils and forms agro-terraces. Parcels located from the hill to the valley with soil worked in the same direction favor the onset and increase of soil erosion. Plotting roads in the direction of the highest inclination, irrational deforestation, grassland grubbing on steep slopes, and other measures effectively increase soil erosion.

3.3 Harnessing the sustainable arable lands on slopes

Harnessing the sustainable arable lands on slopes and their conservation implies that the organization of the territory and differentiated soil management will achieve the following [17]:

- *cultivation of an assortment of plants suitable for the purposes and conditions offered by the slopes and design of crop rotations with an anti-erosion role;*
- *use of anti-erosion culture systems on slopes, level curve direction in strips, grassed strips, and arable terraces;*
- *application of differentiated soil management elements, respecting regional planning projects;*
- *execution of soil tillage on the general direction of level curves;*
- *adaptation of agro-components such as: fertilization, integrated control of weeds (especially herbicide application), and the maintenance, mechanization, and harvesting of the specific land.*

Peculiarities of valorization through anti-erosion agrotechnics on arable lands on slopes are dictated by the following:

1. The need for the use and exploitation of large reserves of lands on slopes, especially on sunny slopes (with southern and eastern exposure), as well as the flow of radiant energy on these surfaces. Romanian land distribution on groups of slopes is as follows [7]:
 - million ha arable land on slopes between 5 and 10%;
 - 1 million ha arable land on slopes between 10 and 20%;
 - 470 thousand ha arable land on slopes between 20 and 30%;

- 200 thousand ha arable land on slopes between 30 and 45%.
 - On agricultural lands on slopes with southern and eastern exposures, there is an increase in daily temperatures to the vegetation period of 150–200°C compared to adjoining parcels.
2. *Soils on slopes present specific features*: Edaphic useful volume is reduced (regosols, lithosols, rendzinas) on the southern slopes, reduced structural stability of soils (podzolic and podzolic soils for north and west slopes), and an excess of moisture on the northern slopes (black soils clinohidromorfe). The diversity of soils and their characteristics is complemented by the superposition of several processes of degradation such as surface and deep erosion, landslides, excessive moisture, compaction. Significant differences arise between different groups of geomorphological units in the soil cover [15]:
- *the mountain relief* is dominated by cambisols (54.2%), followed by spodosols (18.6%) and clay-alluvial soils (14.6%);
 - *the hilly relief* is dominated by clay-alluvial soils (52%), cambisols (11%), moli-soils (10%), alluvial soils (10%), regosols (10%), halo-morphic soils (3%), and so on;
 - *the plateau relief* is clearly dominated by moli-soils (70%), followed by clay-alluvial soils 13.7%, alluvial soils 5%, regosols 5%, and 1.9% hydromorphic soils;
 - *the plain relief* is characterized by the predominance of moli soils (51%), clay-alluvial soils (17.6%), and alluvial soils (13.8%); hydromorphic (5%) and halo-morphic soils (2.5%) become relatively spread out;
 - *Danube's meadow and Delta*, besides lakes and swamps that occupy 41.1% of the surface, alluvial soils (33.7%), hydromorphic soils (11.5%), psamo-pelitic soils (8.9%), and halomorfic soils (1.7%) also occur;
3. *The annual loss of fertile soils is irrecoverable*—with implications for declining soil fertility. The amount of eroded soil / ha within 1 year varies widely, depending on the size of the slope, soil type, the soil's physical state, climatic conditions (rainfall), and crops that occupy it. The national *average* leakage of suspension silt is valued at 88 t/km² annually [15].
4. *Modification of some physical, chemical, and biological properties of the soil by surface erosion*. Structure, drainage, bulk density, and even texture suffer obvious changes. Through erosion, the fine material is colloidal and washed, leading to the deterioration of the structure. Due to this, reduced capillary porosity, an increase in bulk density, reduced permeability, reduced capillary water capacity, poor aero-hydric regime, and a negative impact on the activity of microorganisms occur. Texture changes, particularly by increasing the coarse fractions, occur after sorting the material on the slope, the appearance of genetic soil horizons or rock surfaces. Through the washing of the soils, chemical characteristics change including a reduction in the content of humus, nitrogen, phosphorus, and potas-

sium. Erosion primarily affects the horizon of humus accumulation, resulting in a rapid decrease in the nitrogen and humus content of the soil. Phosphorous and potassium content change with stronger erosion, and when engaging a large amount of soil, even the layers deeper than 30 cm can be affected.

5. *The degree of mechanization.* Mechanization restrictions are determined by the relief (slope, slope shape), deep erosion, landslides, the skeletal character of the soil in certain fields, shallow horizons suitable for processing, the excess of water from the coastal springs, or high spring humidity.
6. *Drought emphasis on slopes,* due to the lower amount of water infiltrated into the soil profile (water spillage) and the low permeability of soils, an accumulation of water reserves in the soil and the drying of small coastal streams can occur.
7. *Danger of flooding in valleys and depressions.* After snowmelt or rainfalls of high intensity and duration, eroded lands sharply feed the hydrographic network, causing great damage through flooding and silting the depressionary lands.
8. *Reduced crop production and increased production costs due to the aforementioned causes.*

3.4 Anti-erosion soil management of arable lands on slopes

Both the cultivated and natural vegetation resources have different influences on the intensity of erosion. The natural vegetation is represented by forests, pastures, and meadows that provide good protection against soil erosion, while arable land with cultivated plants typically favors the onset of erosion. It is necessary therefore that the applied soil management on slopes provides the necessary protection against erosion.

There are at least four differentiated soil management techniques for sloping grounds in hilly areas:

- *anti-erosion soil management on south and west strongly inclined slopes with very advanced erosion; water shortage in summer and autumn was pronounced with short arable horizon and annual inflow based on slopes;*
- *specific soil management for acidic soils on lands located on the northern shady and cool slopes;*
- *soil management for the disposal of humidity excess on pseudo-gleyed soils located on slightly inclined land or concave slopes;*
- *specific soil management for alluvial soil found in plains and narrow valleys.*

The impact of raindrops on arable land depends very much on the physical condition of the soil and the presence or absence of vegetation and crop residues on the soil surface. On a hard surface, the rain droplet that hits and breaks undergoes a compression, dispersing in all directions and draining downstream. When falling on a soil with loamy or sandy-loamy textures with crust on the surface, the rain drop hits the soil, pressing it, and in fractions of a second, it is able to penetrate 3–5 mm into the ground. Striking a loose layer of soil recently mobilized for sowing, a drop of rain penetrates much deeper, up to 20–25 mm, creating a rough aspect on the soil surface.

The presence of crop residues on the soil surface mitigates the impact of raindrops and prevents the water from draining from the soil surface, increasing the infiltration depth.

The slope of arable lands determines the rational use of lands and restricts technological use and mechanization.

Crop rotation and crop structure on sloping arable land. In contemporary Romanian agronomic production, rational methods of anti-erosion agrotechnics cannot be carried out only on the grounds created by the territory organization. This requirement becomes imperative for land in hilly areas, situated on slopes, where working conditions are much more difficult than on flat land areas of the steppe or forest steppe.

Special and mixed crop *rotations* can be organized for fields on sloping ground. Research has shown that mixed field rotation, from the point of view of production and reduction of surface water runoff, is optimum at 4–5 soles with at least one of those cultivated with perennial herbs grown in skipped sola. Normal and mixed crop rotations can be organized on fields with a light (up to 12%) or middle slope (12–18%). Notably, for lands with slopes >12%, it is imperative to introduce protective crop rotation. Protective crop rotations are only organized on lands with slopes >18–25%. Slopes >25% must be cultivated with only perennial grasses.

The shape, size, and location of fields should ensure the maximum level of mechanization for tillage. In order to execute mechanization, the optimal shape of a field is rectangular or trapezoidal with the long side direction toward the level curves or their general direction. In most cases, due to the unevenness of the terrain and other various restrictions (valleys, tears of soil, etc.), a field consists of several parcels. Field dimensions must be determined in each case according to the slope of land configuration.

Protective crop rotations include 6–9 smaller soles mostly cultivated with perennial grasses and 2–3 soles cultivated with annual crops.

The structure of crop rotations on slopes is determined by a number of criteria, of which the most important are:

1. *Soil protection against erosion* depends on the plant size and rate of growth, the degree and duration of soil coverage, and the cultivation tillage used. Plants that cover more ground and are sown more often stop rain drops from hitting the soil directly, slow drainage processes, and allow the rain time to seep into the soil, preventing soil erosion. Conversely, weeding plants allow the water to flow freely and erode the fertile layers of the soil.

Generally, as the slope and need for cropping patterns increase, the percentage of weeding plants should decrease, so on slopes of 21–25% their maximum percentage must not exceed 25% and the percentage of good protecting plants should be increased (**Table 7**, [7]).

Soil protection depends very much on how it is covered during the critical erosion season (the period during which rainfalls with the highest intensity).

Straw cereals protect the ground very well because they are densely sown and harvested after the rainy period in May and June, but after their harvesting, the soil remains exposed to erosion. Using successive crops wherever the water factor allows ensures the protection of soils even during the summer. The seeding of double crops directly into the stubble of the first culture is recommended.

Differences in the degree of ground protection are found even within the group of plants. For example, weeding plants are poor protectors. However, within this group of plants, it is known that maize protects the soil less than potatoes and sunflowers in May and June, because the latter two are better developed. The role

Slope, %	Cultures, %			
	Weeding plants	Straw Cereals	Legumes and technical plants	Annual for forage
0-5	60	25	5	10
6-10	50	20	20	10
11-15	40	30	20	10
16-20	30	40	20	10
21-25	25	30	30	15

Table 7.
The structure of crops on slopes.

of protection can be improved by practicing intercropping. For example, maize intercalated with beans protects the soil better than a crop of maize alone.

2. *The productions obtained.* The plants that are grown should ensure high production in order to satisfy local requirements for different agricultural products. Also, they must leave a large amount of organic matter in the soil as a source of energy for the many organisms in the soil and in order to restore the soil's humus content. Each slope should be treated separately, choosing the most appropriate crops and rotations to produce the most favorable conditions. On medium slopes with south, southeast and southwest exposure, maize, two rows of barley, barley, winter wheat, and annual legumes (peas, beans, broad beans) are recommended. On slopes with north exposure and preluvisols and luvisols straw cereals (rye, wheat, barley, oats), flax for fiber, and trefoil are recommended. On medium and highly eroded slopes, sainfoin and grass mixtures are recommended. Slopes with moderate erosion such as foothills and curvature hills are suitable for trefoil, and for the lower third of slopes beets, hemp, sunflower, and alfalfa are recommended.
3. *The possibility of mechanization.* Mechanical difficulties in the execution of tillage can occur on sloping grounds due to the configuration of the lands. From this point of view, the most affordable and easiest crops are non-weeding crops, forage crops sown with a higher density, and annual and perennial crops.
4. *Fertilization of arable lands on slopes.* Soils on slopes are very diverse. Even along the same slope, erosion can cause pronounced soil differences. Thus on the top of the slope, the soil profile is thinner and has reduced fertility, and in the lower part of the slope, the soil is thicker and more fertile.

Depending on these differences, as well as on the climate and other factors, fertilizers (type and dosage) must be applied differently. Principles of differentiated fertilization on slopes consist of different types and doses of fertilizers, as well as the period of application.

The necessity to apply fertilizer is even greater as the soil is eroded. This is because these soils are poor in nutrients and respond favorably to the intake of fertilizers.

Both organic and chemical fertilizers (especially those with nitrogen, though those with phosphorus and more rarely potassium) may be used on sloped soils.

Organic fertilizers supply plants with nutrients and also act to improve biophysical soil properties damaged by erosion, namely by increasing humus content, restoring

the structure, and increasing the permeability of water. For weeding crops, it is mandatory to use organic fertilization in high doses of 30–40 t/ha or a combined administration of a high doses of manure (20 t/ha) with moderate doses of nitrogen and phosphorus $N_{70}P_{30}$. Where there are great difficulties in transporting manure, green manure can be used (lupine, chopped plant debris) as a main crop or second crop (successive). This fulfills the same role as other fertilization strategies and also protects the soil against erosion by covering it with vegetal mass and allowing for detention in the mass of roots.

In most cases, maximum yield increases are obtained when nitrogen and phosphorus chemical fertilizers are applied together in conjunction with organic fertilizers. In the case of fields susceptible to water erosion, fertilizers are applied in higher dosages at the top of slopes as the drainage of water carries nutrients to the bottom. If the water flow is very strong, fertilizers are applied only at the top of the slope.

On slopes, there is a possibility that nitrogen fertilizers applied to winter cereals can be engaged together with the drainage water from melting snow. Therefore, it is preferable to apply the entire dosage of fertilizers in the fall under plowed soils, or half of the dose during the fall season and half in spring after the snowmelt.

Soil tillage on sloping farmland. Soil tillage, after the way it is executed on sloped terrain, is one of the main factors influencing the emphasis or reduction of soil erosion by water.

Plowing on slopes contributes to the loosening of soil and horizon broadening due to the storage of large amounts of water in the deeper layers, weed control, etc. In order to prevent or reduce erosion (which is facilitated by the tillage or mobilizing of the soil), the following rules may be implemented:

1. *The direction of plowing* is on the general direction of the level curves (in the case of smaller fields, with uniform slopes and lower inclination) or directly on the level curves (in the case of slopes with kneaded land, short soles or plots, and a high inclination of >18%). When plowing is done from top to bottom along the bumps (ditches) of the ridges' furrows, rainwater drains more easily, carrying large amounts of soil to the lower parts of the slope. In addition, for this plowing type, especially when downhill, the plow moves (throws) the furrows at large distances on the hillside. If plowing is performed perpendicularly on slopes, coulter ridges represent obstacles to water, forcing it to seep into the soil. In this way, the quantity of eroded soil is greatly reduced. In addition, plowing done along the general direction of the level curves covers gullies formed by previous torrential rains, contributing to land leveling.
2. The best quality plowing is done with *reversible plows*. On slopes of up to 14–15%, furrows can be overturned over the entire field, both downstream and upstream. Only tipping over is recommended on slopes >15%. On arable lands with a slope > 16–18%, only crawler tractors in aggregate with reversible plows should be used.
3. *The period and depth* of plowing for main crops varies according to the same criteria as for flat lands. Given the need to replenish the soil layer thinned by erosion, a plowing depth of 25–28 cm is usually recommended in order to create a deeper and loosened arable soil layer to store large amounts of water and to reduce erosion for spring crops. The depth of plowing should be adapted to the thickness of the useful soil, without prejudice to the surface's poorly fertile hori-

zons, skeleton, or parental rocks. The ratio between the width and depth of the furrow increases with the slope's increasing height.

Generally, plowing done on slopes during the fall should remain non-harrowed in order to reduce the speed of water drainage from autumn rains or snow melt.

Seedbed preparation must be performed alongside the general line of the level curves. For this purpose, on slopes up to 18%, regular agricultural machines can be used. On higher slopes, crawler tractors and special machines for working on slopes should be used.

After the fall plowing done without harrowing, the land surface appears uneven and sometimes streaked with micro-ravines in the spring. Due to this, the use of rotary and disc harrows, cultivators equipped with harrows for leveling (with the leveling blade mounted in the front of the machine and a bar with elastic fangs behind the work organs) is recommended for seedbed preparation.

Seedbed preparation works are done by moving diagonally along the plowed soil on lower slopes, at an angle to the furrows with a direction of maximum 30°. The direction of travel should be chosen according to the soil's topography in order to avoid climbing slopes >12%.

Based on the characteristics of arable land tillage on slopes, soil tillage systems on these lands should contribute primarily to the storage of a large quantity of water from rainfall in order to prevent and reduce run-off and erosion below the maximum "tolerable" value of 5–6 t/ha. Secondly, given the peculiarities of soils on slopes, soil tillage should increase aeration of the arable and sub-arable horizon and create optimal conditions for the development of roots and microorganisms.

In order to avoid loss of water and soil in the autumn, winter, and spring when using classical systems, the ground remains bare or crops are still in an early stage of development, research in recent years has aimed to reduce the depth of soil mobilization and the number of works or eliminate both simultaneously with sub-sowing protector crops, which protects the soil with plant debris [35]. Research conducted nationally and internationally has shown particularly good effects of conventional tillage systems in reducing soil loss through erosion on lands with slopes up to 12% [36–38].

Synthesized on slope groups, anti-erosion effects can be maximized if traditional anti-erosion soil management systems are applied together with the following new systems:

- the classic tillage system and sowing made on the direction of level curves on slopes of up to 5–6%;
- minimum tillage system on contours with mulch (or variants) on slopes up to 12%;
- crop strip systems on slopes of 10–12%;
- crop systems with grass strips on slopes of 12–18%;
- and terraced crop systems on slopes of 15–28%.

In hilly areas, the need for robust soil management systems to promote soil conservation is evident. These systems also promote economic and energy conservation, especially in preventing excessive degradation and soil erosion. Systems for soil

conservation tillage may have many variants including a chisel system with paraplow, a disk or rotary harrow, ridge system works, direct sowing, and so on; variant selection must be done according to behavior under certain specific conditions related to soil, climate, slope, degree of weed, crop, machinery, etc.

In sum, the features of slopes related to relief, climate, soil condition and slope characteristics require that the ground tillage ensure:

- conditions for developing crops;
- an increase in the capacity of soil to store larger quantities of water while avoiding surface and depth runoff;
- a reduction in the number of works to avoid compaction, soil structure degradation, and erosion;
- aeration by turning the furrow or the use of unconventional methods that limit work in the bio-accumulative horizon and Bt horizon while loosening without turning the furrow;
- avoidance of keeping the remaining land without vegetation during critical periods of erosion made by rain;
- the use of tillage systems that ensure exploitation of crop residues as an anti-erosion factor.

Sowing over arable land on slopes is performed in the direction of the level curves so that slope lines stop water leaks. Straw cereals are sown in dense rows using a 10–12% increase in the quantity of seed compared to that of flat land. Seed of all crops must be buried 1–2 cm deeper.

The optimum time of sowing for these fields is shorter and the aggregate productivity is lower. If the seed drill slips, it is necessary for the tractor to be driven at the correct distance from the slipping drill in order for row spacing of two neighboring rows to be normal. On large slopes, maize can be planted in gullies. Thus, sometimes higher production cannot be achieved, but soil erosion is always lessened. Gutters are performed together with sowing and covered gradually while hoeing.

Special soil management measures: In order to protect the ground surface after harvesting, it is necessary that shredded crop residues remain on the ground. The soil will never be maintained as a field of pure black or clean of plant debris. Moreover, this measure is recommended for all soils in use as arable land. A coarser seedbed is less vulnerable to erosion processes than a fine one.

Under certain conditions, it is recommended to use *protective plants*, such as rye, mustard, and lupine, *sown as hidden crops* in the fall. These are then incorporated into the soil in the spring before sowing by shallow plowing. These protective plants provide control for wind and water erosion on soils susceptible to such processes. Such a method can also reduce nitrate scrubbing.

During winter, it is preferred that soil located on downhill terrains should be covered with vegetation (remain uncultivated), so as stubble or covered with vegetal mulch and seeding to be carried out through minimum systems using rotary harrow or direct seeding.

3.5 Anti-erosion soil management systems

More anti-erosion systems of plant cultivation can be practiced on sloped lands. Each name comes from the main measure included in it to combat erosion. Each becomes necessary and effective for application on slopes. The main systems are the system of culture in the direction of the level curves, the system of culture into strips, the grass strips system culture, the system of culture on arable terraces (agricultural terraces), and the planting of protective curtains.

The system of culture in the general direction of the level curves. Agro-technical works mobilize large masses of soil, changing the conditions of aeration, water, and temperature regime. In areas where the appropriate erosion agricultural technique is applied and the land parceling system corresponds with the general orientation of the level curves, soils do not erode, and in time, agriculture terraces are formed. Where soil tillage is performed in the same direction and the parcels are located from the hill in the valley, the onset and increase of soil erosion processes frequently occur.

The system of culture in the direction of the level curves consists of performing all works in the direction of the level curves. Its use is mandatory on any slope, but using a rational structure of crops, it ensures good soil protection only on lands with slopes up to 5%. On slopes >5–8%, its application is recommended in tandem with other anti-erosional systems.

The system of culture using strips. The system of crops in strips is recommended on slopes up to 10–12%. It is possible to practice this system on long slopes that allow agricultural aggregates access from the sides. The system is always amplified with the system of culture in the direction of level curves. Plants are cultivated on surfaces in the form of strips oriented along the level curves, alternating weak protective plants (e.g., maize, 20–40 m wide) with strips of strong protective plants (e.g., maslin, 20 m wide or wheat, 20–80 m wide). Water from precipitation that falls on the surface (strip) of the land cultivated with weeds drains with eroded soil, but it stops on the strip of thickly sown plants. Here, the water infiltrates the soil, and the soil is deposited.

The width of the strips varies between 20 and 150 m, depending on the land of the slope. The strips are narrower on the lands with greater slopes. For agricultural machines to run, it is necessary that the width of the strips be equal throughout their whole length. This also helps in avoiding gussets and corresponds to a multiple of the width of the used aggregates, especially for those of sowing. The number of strips increases with slope length from 2–3 to 6–7 strips on a slope. From 1 year to another, the crops can be passed on to other strips as the crop rotation demands.

The culture system with grass strips. The grass strips culture system is commonly practiced alone on slopes between 12 and 18%, or in tandem with the anti-erosion system in strips in the wet areas where the risk of erosion is the greatest and soil protection may not be provided by only one of the two systems described above. Grass strips are narrow strips of land between 4 and 10 m wide, oriented on the level curves, which are cultivated with perennial grasses. Strips of land cultivated with culture plants are left between those bands. Grass strips, also called buffer strips, are designed to retain water with eroded soil that drains from the neighboring strip. Water infiltrates, and the soil is deposited. Grass strip width varies depending on the slope's shape and the character of precipitation. Along the length of the slope, upstream strips should be 4–6 m wide, strips in the middle of the slope should be 6–8 m, and those downstream should be 8–10 m.

The distance between strips (hence width strips, which are cultivated with plants) varies between 20 and 150 m, being lower on lands with a greater slope. On a slope,

the number of grassy and cultivated strips increases with slope length and inclination. On average slopes of 12–15%, cultivated screeds between strips should be 80–150 m wide; while on average slopes of 15–18%, cultivated screeds should be narrower (50–80 m wide) and the width of the grass strips should be greater.

The distance between the grassy strips is also determined by the shape of slopes. Thus, on slopes with a plain profile, the strips should be placed at equal distances. On convex profile slopes, grass strips are located at greater distances from the top of the slope and at lower ones at the bottom. On concave profile slopes, grass strips are located at lower distances at the top of the slope and at higher ones at the bottom.

The position of grass strips should change every 3–4 years on slopes with gradients of 8–18%. Fallow strips are maintained on greater slopes in order to perform agro-terraces over time.

It is necessary for the width of the cultivated strips to be the same over their entire length in order to facilitate the performance of mechanical works. To achieve this goal, if necessary, the width of the strips may vary along with their length.

Herbs that could be sown include alfalfa, trefoil, orchard grass, brome grass without arista, and others; one species or 2–4 species mixed are recommended (Table 8, [3, 8]).

Grass strips can be established only after land is leveled by covering the negative forms of relief, unclogging roads with improper routes, etc. The strip grass crop culture system is distinct from the one with strips, both by the presence of strips and by the fact that the grass grown on a side may belong to the same crop plant, even weeding plants, because soil erosion is prevented by the grass strips.

The culture system on terraces. This system requires terraces along horizontal surfaces arranged on slopes in order to allow for mechanical work directed across slopes. Terraces on arable lands are used for growing plants, while the ones on higher slopes are planted with trees and vines. The terraces are tilled using special machines or by plowing.

Agro-terraces are terraces made by plowing on arable lands with a slope between 12 and 25%. They become mandatory on slopes >18%, as the previously presented culture systems can no longer ensure soil protection. Agro-terraces are formed slowly over a period of 10–20 years as follows:

- the slope is divided into strips of land that are plowed, and the furrow is only overthrown downstream;
- after the first plowing of the strip, a ditch is formed at the top and a ridge at the bottom;

Average annual rainfall (mm)	Erosion intensity	Species and proportions of these species in mixtures
< 500 mm	Moderate	alfalfa 60% + orchard grass, couch grass or oatgrass 40%
	High	sainfoin 60% + 40% brome grass without arista or sainfoin, bird's-foot trefoil 60% + brome grass without arista 40%
> 500 mm	Moderate	sainfoin 60% + 40% orchard grass
	High	sainfoin 60% + brome grass without arista 40%

Table 8. *Mixtures of perennial grasses recommended for grassing strips of anti-erosion systems.*

- in the coming years, with each plowing, the ridge from below rises increasingly more and the strip slowly turns into terrace;
- the formation of terraces can be rushed by plowing several times in the same year;
- the platform strips between the future terraces are grassed and over time they turn into benches that are maintained by mowing.

In some areas of the country (Transylvania Plateau, Somesan Plateau), there has been a long tradition in making agriculture terraces on slopes of arable lands by the process mentioned above. The width of the terraces is between 8 and 30 m (depending on the slope). The width must also be a multiple of the width of seeding machine used. Widths of 30–40 m are recommended on slopes of 15–20%, widths of 20–25 m are recommended on slopes of 20–25%, and 15–20 m wide platforms are recommended for slopes of 25–30% [31]. Depending on the inclination of the field, terraces are made by the use of plows that are carried out repeatedly within 8–12 years. Terraces should be executed in the autumn after harvesting the crops.

Specific agrotechnics tillage on terraces requires consolidation of the embankments through grassing. Grassing is achieved by using a mixture of herbs made of perennial grasses and legumes from the first year of terrace use. In subsequent years overseeding should be used for the re-vegetation of the embankments in order to correct the mixed species if some do not meet the ground conditions to mobilize the terracing. Embankment maintenance is done by repeated mowing, fertilization, and plant protection treatments.

Works arising from the implementation of technologies should be seeded on terraces along the length of the terrace. The turning of tractors and machinery should be made only at the ends of the terrace, on specially designated areas that have been grassed to prevent erosion. Leveling rills result, especially in the early years of terrace execution, due to runoff caused by intense rainfall. The work is repeated after each leak that leaves uneven highlights.

Plowing on terraces should be done at different depths. Thus, deep plowing (28–30 cm) is made only to the upper half of the terrace platform, and the side slope is only superficially mobilized up to 15–20 cm.

Fertilization is differentiated on the platform surface due to lower soil fertility in the upper half of the platform where organic and mineral fertilizers in doses greater than half of that downstream are applied.

Planting shelterbelts. Anti-erosion protection curtains used in agriculture in the form of long strip plantations are sited in agricultural territories in order to remove erosion, regularize flow, reduce wind speed, and combat landslides.

Species that can enter the structure of shelterbelts depends on soil conditions [39]. Specifically, locust, mulberry, black poplar, gray poplar, black pine, etc., have been used with good results. Regular leakage shelterbelts are oriented parallel to the contour, admitting deviations of 2–4%. Within their structure, these curtains should contain as many shrubs as possible.

In order to protect the soil from wind erosion, as well as for crop protection, shelterbelts of trees grown in rows or hedges can be used. Shelterbelts reduce wind speed by up to 25–50%; the more distance between the veil of protection and the protected land, the more effective the shelterbelt. It is recommended, however, that this distance is not more than 20 times the height of the protection curtain. The effectiveness of protection depends on the curtain, as well as the air flow direction of the prevailing

wind. Relevant information on the frequency and direction of the wind that contributes to the onset and intensification of degradation processes can be obtained from local weather services and then used to determine where the cords or shelterbelts should be placed. Protection curtains also have a positive role in maintaining and developing a healthy environment for wildlife and thus encouraging biodiversity.

The benefits of the shelterbelts are evident when they reach a considerable height (around the age of 10 years):

- reduce wind speed by 25–50%, reduce erosion, and increase biodiversity;
- protects autumn crops against frost due to the ecological effect of the snow layer on them;
- reduce the evaporation and perspiration of plants (by 30%), so that agricultural production in the field increases by up to 20%; reduce water losses in soil by evaporation by 20–45%;
- diminishes the temperature amplitude between day and night by 6.2°C and the annual temperature by 2°C;
- greatly reduce the consequences of droughts, dust storms, and soil erosion both on agricultural crops and on human settlements, economic and social objectives, and communication routes [40, 41].

4. Soil management particularities on saline and alkaline soils

Salsodisols (halo-morphic soils: saline and alkaline), solonchaks (pH 7.2–8.5), and solonetz (pH above 8.5) are common types of saline or alkalinized soil types. Alkalinizing intensity is determined by Na% with respect to total cation exchange capacity (V_{Na}). If the values are between 5% < V_{Na} > 15%, we have alkalinized horizon (ac) and V_{Na} > 15% sodic horizon (na). Salinization is given by the presence of slightly soluble salts, and depending on the values among anions relations Cl⁻, HCO₃⁻, SO₄⁻, etc., the type of salinity is determined: chloride, sulfate, bicarbonate, or transitions from one to another.

Criteria for determining the appropriateness of improvement for saline and alkaline soils and the application of a differentiated soil management program are generally the following:

- $pH_{(H_2O)} > 8.5$;
- PSA – a percentage of adsorbed sodium (Na⁺, exchangeable) of >10% of T;
- content of carbonates and bicarbonates (CO₃²⁻ + HCO₃⁻) greater than 1 m.e. / 100 g soil;
- slightly soluble salt content exceeding 0.8–1% from the upper horizon and maintained at high content throughout the profile;

- slightly soluble salt content exceeding 0.3% of the upper horizon and soil salinization hazard enhanced by raising the mineralized groundwater.

Removing the deleterious characteristics of saline and alkaline soils is achieved by a complex of measures including gypsum amendment, washing the salts, and the cultivation of plants tolerant to salt (halophytes). Solonchaks especially require washing and drainage processes. Solonetzts, in addition to these measures, also require the application of amendments with gypsum (physiological response acidic materials containing sodium and calcium to replace the complex).

The main materials used as saline and alkaline soil amendments are:

- gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$),
- phosphogypsum (containing 75–80% $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ and 3–8% P_2O_5),
- elemental sulfur,
- lignite dust (containing $\text{S} > 2\%$),
- industrial waste residues containing iron sulfate ($\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$) and aluminum sulfate ($\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$).

The dosage of amendments are calculated taking into account the exchangeable sodium content in the soil, carbonate, and bicarbonate alkalinity given by the sodium and cationic exchange capacity of the soil acidification, as well as the amount of material used as an amendment.

Washing of slightly soluble salts is a radical and rapid method to improve salted areas. For the execution of this measure, the soil properties that must be determined are the development profile, the width and depth horizons with accumulations of soluble salts, the presence of restrictive horizons with attributes (very clayey, sandy, skeletal), and permeability.

Application of wash splashing in conjunction with types of land-use planning may be carried out:

1. *By submersion in the arrangement of rice type:* Washing soluble salts is carried out through a continuous vertical movement of water through the soil and infiltrated water interception in open channels; interceptor channels must be deeper than the groundwater.
2. *By flooding outside of the growing season:* applied on solonchak and strong saline solonetzts formed on fine deposits; on such lands washing must be integrated into a complex technology for improvement (leveling, gypsum amending, aeration, drainage, and washing).
3. *Through over-irrigation (sprinkler) out of or during the growing season:* Soils can be washed in autumn (two halves of $800\text{--}1000 \text{ m}^3/\text{ha}$) during the growing season (1–3 rounds), increasing watering norms at a rate of 15–20%, but avoiding the appearance of puddles.

Slightly soluble salts washing in compliance with agrotechnical indices required to ensure the quality of the work:

- where appropriate the land is subject to planning: drainage, leveling, deep aeration, and gypsum amending, by applying a round of washing after the land is prepared and cultivated with plants tolerant to salty soils;
- during the growing season irrigation is applied at shorter intervals so as to ensure both the water needs of crops and a surplus that is not harmful to the plants on the long term and is necessary for the maintenance of a downward current of water;
- after harvesting, the land remains loosened by superficial works and regularly irrigated so that water content does not fall below adequate moisture of the $\frac{1}{2}$ active humidity interval;
- the most appropriate period for washing salts by flooding is autumn and early winter when loss of water by evaporation is reduced and groundwater is at the lowest level; sulfatic salty soil types are recommended; however, the washing can be done during the summer when the solubility of sulfates is higher than in cold conditions;
- since a mobile nutrient removal is produced with washing salts, washed soil responds well to fertilizer application; nitrogen rates are increased by 20% compared to normal soils;
- the soil tillage system will avoid uncovering salts from the soil profile; aeration can resort to work without turning the furrow using a chisel, paraplow; the quantity of seed and plant density must be increased by 15–20%; seeding depth done in the spring for the cultures will be 2–3 cm lower than on normal soils.

Cultivation of some plants tolerant to salinity represents a temporary method and its application aims to achieve acceptable yields.

Plants have different capacities to support soluble salts in the soil: some are very sensitive or more resistant, and some of them—salty plants—are well adapted morphologically and physiologically to excess salts.

Soil tillage. Halomorfic soils are tilled intensively since in the summer and autumn, after dry periods, they become very compact. In the climatic conditions Romania, plowing can be executed in early autumn when the soil gets wet after early autumn rains.

Plowing depth should be chosen carefully so as not to bring soil from the depths with high concentrations of salts and lower concentrations of nutrients. A shallower depth and plows equipped with field pokers are recommended. Good results are obtained by using plows without moldboards or chisels that loosen the soil without turning furrows (**Table 9**, [42]).

If salt content is high on the surface of the soil, but with little thickness, as is for solonchaks solonchaks, deeper tillage with flipping furrows should be performed to bury the layer with salt and bring the unsaturated soil to the surface.

The use of fertilizers is very important because, together with the amendments, they are designed to improve agrochemical qualities that are inherently poor for these

Tillage	Production		Difference ± kg/ha	Semnification
	kg/ha	%		
Disked with GD 3,4	2160	111.9	230	ns
Plowed with moldboard at 22 cm	1930	100.0	wt.	wt.
Plowed without moldboard at 22 cm	2310	119.6	370	**
Plowed with paraplow at 22 cm	2140	112.4	240	ns
Scarified + paraplow	2580	133.4	650	***
Scarified	2340	121.2	410	**

Note: wt—witness, ns—not significant, *** (very)
 ** (distinct) positive significance.

Table 9.

Influence of soil core work and scarification on wheat production on moderately saline molic soil weak gleyed and moderated alkalized from Braila.

soils. Organic fertilizers in doses of 40–50 t/ha incorporated into the soil by plowing are the most favorable. If manure is associated with phosphogypsum 100–150 kg/ha nitrogen must be added. Good results are also obtained when using green manure (sweet clover, vetch, sorghum, sunflower) associated with mineral fertilizers. Among chemical fertilizers, nitrogen is the most efficient, in particular nitrogen fertilizers with ammonium sulfate, a physiological acid fertilizer. It is also possible to use ammonium nitrate, urea, and ammonia water. In Romania, on halomorfic soils, phosphorus and potassium fertilizers do not cause large increases in crop production when applied alone.

Seeds and sowing. Autumn sowing should be executed no later than the 10th of October so plants can develop normally before the cold and survive over the winter. Spring sowing should occur sooner, when humidity is high and the soil solution is more diluted. The norm of seed shall be increased by 20–30% to offset reduced germination due to salt concentration. Seeding depth should be shallower by 1–2 cm because of the tendency of crust formation.

Maintenance work must be done frequently to ensure the destruction of the crust that forms on these soils.

5. Soil management particularities on acid soils

Acidic soils in Romania represent >2 million ha (with strong acidity), 8.6% of the area. The most common soil types are luvisols (luvic brown-red soils, brown luvic soils, albic luvisols) planosols, districambosols (acid brown soils) prepodzosoils (feriiluvial brown soils), and andic podzols soils (andosol).

Knowledge of soil reaction and its improvement is particularly important because it determines the *behavior of crop plants and soil microorganisms, nutrient mobility, the effect of herbicides applied to the soil*, etc. Most cultivated plants grow and thrive in slightly acid-neutral reactions (pH 6.6–7.2). It appears, in general, that cultivated plants better support the weak acid than the alkaline reaction.

Given crop needs and the reaction of soils, acid soil amendment is economically efficient if carried out differently depending on the crop use and rotation practiced.

The criteria underlying the need for correcting acidic soil reaction and the specific quantification of urgency application are:

- a. Soil pH ($\text{pH}_{\text{H}_2\text{O}}$) <5.8, the degree of base saturation (V_{Ah}) below 75% and presence of exchangeable aluminum.
- b. Assessing the appropriateness calcareousing of acidic soils is the ratio of the sum of exchangeable bases Al^{3+} and exchanged sum ($\text{Al}^{3+}/\text{SB} \times 100$) greater than 2.5 (5) in Ap horizon.

Moderate and strong acidity is accompanied by ions mobile Al^{3+} and Mn^{2+} in soil solution over certain limits, which creates a toxic environment for crops. With respect to Al toxicity sensitivity, species of cultivated plants can be classified as follows:

- tolerant species: oats and timothy-grass;
- moderately susceptible species: maize, lupine, potato;
- sensitive species: barley, flax, peas, beans;
- species very susceptible: sugar beet, winter wheat, alfalfa.

The toxic effect of Al^{3+} disappears when the soil pH is >5.8 ($\text{pH}_{\text{H}_2\text{O}}$) and V_{Ah} is over 75%. The materials used for the correction of acidic soil reaction are shown in **Table 10** [7].

Typically, the dosage of acidity correcting amendment used for calcareous soils is between 2 and 8 t/ha. To change pH reaction of soils by one unit under normal conditions, an average of 2–2.5 t/ha CaCO_3 are sufficient on lightly textured soils and 3.0–3.5 t/ha CaCO_3 are sufficient on heavy soils.

Material	Content	Neutralization value (%)
Limestone (agricultural-calcareous, CaCO_3)	75–99% CaCO_3	90
Burnt lime (unquenchable, CaO)	90–95% CaO	150–185
Slaked lime, $\text{Ca}(\text{OH})_2$	$\text{Ca}(\text{OH})_2$	135
Calcareous tuffs	80–90% CaCO_3	80
Dolomite, $\text{CaMg}(\text{CO}_3)_2$	54.4% CaCO_3 and 45.6% MgCO_3	40–110
Marls	25–75% CaCO_3	50–60
Defecation foam	31,65% CaCO_3 , N, Ph, P etc.	50
Blast-furnace slag, CaSiO_3	20–70%CaO and 2–20%MgO	75
Precipitate of CaCO_3	74% CaCO_3 etc.	89
Residual calcium carbonate (CCR)	CaCO_3 , nitrogen	70–80

Table 10. *Materials used for making a calcareous soil.*

Agricultural practice has shown that the most valuable information regarding the amendment doses is obtained by making the following chemical analysis of the soil: the pH, the hydrolytic acidity (Ah), the content of exchangeable hydrogen (SH) and exchangeable bases (SB), the degree of base saturation (V), and the texture and the content of exchangeable Al^{3+} and Mn^{2+} .

Calcium ammonium nitrate is applied using machines to achieve a uniform spreading of the amendment. Management technology is subject to doses used, how they are used and crop structure. In general, calcium ammonium nitrate can be applied in any season, whether or not there are transporting possibilities, spreading and incorporation. The periods indicated are as follows:

- before the summer or deep autumn plowing;
- in spring before seedbed preparation;
- during winter on frozen ground for winter cereals, legumes, and perennial grasses (only agricultural-calcareous powder and foam from defecation);
- during autumn after running a work with harrow for natural grasslands;
- low doses of amendments ($\frac{1}{4}$ from Ah) applied topically between the rows of plants, in nests, or when planting seedlings;
- in orchards, calcium ammonium nitrate before planting is done during performance preparation of the soil or after planting, alongside maintenance work.

In order to achieve quality tillage, one must follow these agrotechnical quality indices:

- amendment flour should have less than 10% moisture;
- the depth where the amendment should be incorporated is determined by where the root system of the plant cultivated is developing because the Ca^{2+} ion speed moving from the upper layers to the deep ones is very slow;
- the speed of the wind during tillage should be less than 2 m/s;
- uniformity of the spread on the entire set surface should be ensured;
- in order to obtain good economic efficiency, the calculated dose should be applied at a rate of 50–100% in relation to the requirements of the plants or trees grown.

Crop rotation and crop structure. Cultivated plants, as well as those in the natural biocoenoses, grow and develop normally—some more broadly and others more narrowly—within certain pH ranges. Crop structure on acid soils must contain only acid-tolerant species (potato, lupine, rye, oats, tomatoes, carrots, barberry, raspberry vines, apple), and to a lesser extent those that prefer a reaction between mildly acid and neutral (sunflower, wheat, maize, beans, peas, hemp, spinach, celery, zucchini, watermelon, plum, currant).

Low levels in the nutrients supply, low pH, and a poor physical condition that causes less intense biological activity make acidic soils unable to raise or approach to

the soils with normal fertility without operating within the system by introduction of some crop rotation and external ameliorative plants by regulating fluid and thermo-chemical regime of the soil. As ameliorative plants, trefoil is used on soils with very low fertility, clover on soils with excess moisture, and alfalfa on fields where amendment was used.

The use of fertilizers is of paramount importance for acid soil productivity where nitrogen and phosphorus are deficient and an average amount of potassium is supplied. Fertilization with manure in doses of 30–50 t/ha associated with $N_{50}P_{50}$ provides the highest production growth by correcting the acid reaction through the process of calcareousing

Soil tillage characteristics are determined by the biological requirements of plants and limited by the physicochemical properties of acidic soils. Compaction of these soils requires the mobilization of soil at a greater depth with the restriction of not overturning the furrow. This may bring to the surface toxic oxides of Al and Mn, which, in high concentrations, jeopardize the plant's emergence (5 ppm Al). This requirement can be achieved by plowing paired with subsoiling works.

Soil tillage should be associated with the application of amendments, organic fertilizers, green and mineral manure, organic waste incorporation, and the establishment of proper rotations, only thus resulting in the attenuation of the deleterious qualities of these soils.

6. Soil management particularities on soils with excess moisture

Soils in this group are: gleiosols (lacovist, gley soils), stagnosols (pseudogley soils), clinogley phaeozems (clinohidromorf black soils), and histosols (turbo-gley soils, peaty soils), representing 3.7 million ha or 16% of the surface of Romania.

Excess moisture in hydro-soils (hydro-morphic soils) does not harm plants directly, but by occupying space, it removes lacunae air from the soil, reducing it quantitatively. Moreover, in this situation, it also changes the composition of the air and lowers the content of oxygen; reduction processes generally cause a decrease in the ratio of Fe^{3+} and Fe^{2+} . At the same time, hydro-morphic soils are heated heavily and in spring remain cold increasing the difficulty of snow melts. The excess of water and the lack of air in these depths, make plants suffer from lack of water and grow more to the surface during dry periods. Water excess favors the development of weeds and the spread of diseases and pests. Water excess determines the deterioration of physical, chemical, biological, and agrotechnical works in soil.

Criteria for determining the application of appropriate measures to improve hydro-morphic soils may include the following:

- *limiting the period of flooding to the permissible duration of 4–6 hours for vegetable crops, 8–12 hours for cereals, and 24–36 hours for trees;*
- *the presence of groundwater at depth less than 1.5–2 m;*
- *strong or excessive pseudo-gleyzation.*

Measures to improve and increase the efficacy of hydro-morphic soils aim firstly removing the causes of excess moisture, and then to combat the harmful consequences that take place in soil:

- a. *Hydro-ameliorative measures*: regularization of groundwater by drainage (open channels to remove water from neighboring perimeters and removing stagnant water) and drainage (closed channels to remove excess water from impermeable horizons).

Mole drainage is recommended in soils with a clay-illuviated horizon with at least 25% clay that is compacted, pseudo-gleyed, and impermeable in order to remove excess. This consists of the pressing some tubular galleries 8–12 cm in diameter at a depth of 0.40–0.80 m and at a distance of 2–5 m from each other by means of a special plow provided with an active part in the form of a “cannonball.” After the execution of mole drains, superficially plowing in the transversal direction is recommended. These drains recover every 2–4 years.

- b. *Agrotechnical measures* are:

1. *Leveling operation*—in order to ensure the land has a continuous slope inclination toward the general level curves and favors soil drainage.
2. *Modeling using strip ridges*—recommended on pseudo-gley and pseudo-gleyed soils, these ridges have as a purpose of making some bands with variable width ridges (12–28 m) and cross slopes of 1–3% by executing moldboard plowing or using a grader.
3. *Temporary or permanent collector ditches*—aim to collect water from gutters made by moldboard plowing.
4. *Regular deep loosening*—made on heavy or compacted soils with deficiency in porosity, successively affected by an excess and deficiency of moisture. By loosening the soil at different depths, the acquisition and retention of excess water located at the soil surface is achieved, on the one hand, the removal of excess water and the prevention of negative consequences arise there from, and, on the other hand, retains water in the soil for summer periods.
5. *Organic fertilizing + fractionated mineral + foliar (micronutrients)* is needed to improve the direct and indirect physical and nutritional status of the soil. The unevenness of soils with excess moisture requires that the fertilizer be established at the location of the worst case scenario. Water circulation in the soil profile exposes the leaching of excess nitrogen, which requires application of fractional doses of nitrogen along with the regular monitoring of the soil nitrate reserve in order to make a differentiated phasal fertilization. Application of organic fertilizer is needed to improve the physical, hydro-physical, and biological conditions of the soil.
6. *Plowing and subsoiling*—to maintain permeability and water storage capacity in sub-arable horizons.
7. *Choosing an appropriate plant selection*—pastures and fodder crops (clover, alfalfa, Sudan grass) with high ecological plasticity and long growing seasons (triticales, wheat, rice, hemp, sugar beet, maize, sunflower, etc.).

Autumn grain cereals (wheat and barley) should be placed on better drained lands. Spring grain cereals (two rows barley, oats) and industrial crops should be placed on lands that can be tilled in the early spring. Maize and sorghum should be located on lands where the removal of excess water is still difficult but where sowing can be done until around May 15. Annual or perennial forage crops should be located on lands on which the removal of excess water is not satisfactory. Species with high water consumption can be planted in the vicinity of lands with excess moisture, including willow, ash, and elm trees, where climatic conditions are favorable for these species.

8. *Enhanced measures to combat weeds, pests, and diseases.* It is important to organize a proper rotation with the introduction of ameliorative plants in the crop rotation and tillage executed only at optimum moisture. Land preparation for sowing spring crops should be made later, requiring a higher seed norm by 10–15%.

7. Soil management particularities on sandy soils

In Romania, sandy soils occupy about 443,700 ha (1.7% of the area), of which 22,600 ha are unproductive, unconsolidated sands without vegetation and bioaccumulative and 421,100 ha are agricultural lands [42]. Of the agricultural lands, 313,200 ha have arable use, and 107,900 ha are natural meadows, vineyards, and orchards. The largest areas with sandy soils are located in the south of Oltenia (about 200,000 ha), Baragan Plain (50,000 ha), southern Moldavia (14,000 ha), Danube Delta (61,000 ha), Danube Valley, Western Plain, and zone of sands from the northwest of the country (Valea lui Mihai—Carei) and valleys of the Somes, Jiu, and Arges rivers.

The landscape of these lands is rippled and made out of dunes and inter-dunes with differences of up to 10 m, which also makes the groundwater highly variable in depth. Rainwater collects in lower places, causing ponding and excess moisture, and gullies quickly form on dunes because of erosion [42].

Climatic conditions of the sandy areas are characterized by temperatures of 10–11°C and annual rainfall of 500–550 mm. Winds frequently disperse sands without vegetation.

Sandy soils (Psamo-pelitic soils) are tilled in a wide range of moisture contents (4–30%) as they are without plasticity and adhesion due to their rough texture. An underrepresented colloidal complex makes these soils poorly structured with a reduced capacity to retain water and nutrients. Humus content is about 1%. Microbiological activity in these soils is low, and strong levigation is present, so these soils should be irrigated with low and frequent norms.

Plants cultivated on these lands are rye, maize for grains and fodder, sorghum, castor oil plants, beans, tobacco, green and yellow melons, watermelons for fodder and meslin, vines, and fruit trees. On irrigated Psamo-pelitic soils, maize for grain, soybean, rapeseed, sunflower, peanuts, alfalfa, early potatoes, castor oil plant, and other vegetables can be grown with good results.

Soil tillage should be done so the soil should be without plant debris for as little time as possible. A *tillage system providing a protective layer for successive crops* of lupine, winter vetch, rye, beans, etc., is recommended as these plants can then be incorporated into the green manure. Often, these soils are compacted into sub-arable layers because the self-compaction caused by the sandy texture, mono-granular structure, and repeated crossings of the agricultural aggregates. Deep plowing executed

periodically (3–4 years) is required on compacted Psamo-pelitic soils in tandem with organic fertilization.

Organic fertilizers are applied in doses of 20–30 t/ha in combination with chemical fertilization. Chemical fertilizers should be applied fractionally— $\frac{1}{2}$ dose at crop sowing and $\frac{1}{2}$ during the growing season. Amendments should be applied in small and frequent doses on acidic or alkaline sands.

Sowing is done perpendicular to the prevailing wind direction at the beginning of the optimal period, as soils in this area are heated faster. Seeding depth is greater than on other soils.

Special measures to improve sandy soils are:

- planting of protective forest belts perpendicular to the prevailing wind and afforestation of non-hardening sands without vegetation;
- mechanical fixing through the use of para-sands;
- chemical fixation of sands through the use of chemicals that bind (cementing) sand particles or the use of absorbing substances to retain water and nutrients;
- leveling dunes and sometimes landscape design;
- enrichment with fine material (clay);
- incorporation of manure in layers;
- the application of a film of asphalt at a depth of 50–60 cm to stop water and nutrient leavitation.

8. Conclusions

By analyzing the resources of soil use and management Romania can improve soil fertility, mitigate climate change effects, and increase agricultural productivity in a sustainable way:

1. *Soil as a critical natural resource*—Soil is a finite and non-renewable resource essential for agricultural production, environmental protection, and socio-economic infrastructure. The sustainable use of soil is vital for ensuring long-term food security and ecosystem stability.
2. *Land use distribution in Romania*—Agricultural land dominates Romania's landscape, covering approximately 62.3% of the total surface (including arable land, pastures, vineyards, and orchards). Forests account for 27.1%, with the remainder consisting of water bodies, urban areas, and other land uses. This distribution reflects the country's strong agricultural tradition and the importance of natural ecosystems.
3. *Key soil degradation issues*—Romania faces several soil degradation challenges, including erosion, landslides, drought, salinization, soil compaction, and a decline

in organic matter content. These issues reduce soil fertility and threaten agricultural productivity. Additionally, chemical pollution from industrial activities and excessive fertilizer use further compromises soil quality.

4. *Regional variability in soil management*—Given the diverse climatic and pedological conditions across Romania, soil management practices must be adapted to regional characteristics. Some areas require erosion control measures, while others need improved irrigation, drainage, or organic matter restoration strategies.
5. *The need for sustainable soil management*—To ensure long-term soil fertility and agricultural productivity, a balanced approach combining modern technologies, agro-technical measures, and sustainable land-use practices is necessary. Conservation tillage, crop rotation, afforestation, and organic fertilization are among the key strategies to mitigate soil degradation and improve resilience against climate change.
6. *To implement regenerative agriculture in Romania*, considering the available resources and soil challenges, the following measures are necessary:
 - *Increasing soil organic matter content*: Adopting conservation agriculture (minimum tillage or no-till) to reduce soil disturbance and maintain its natural structure. Using compost, manure, and cover crops (e.g., clover, peas, lupins) to enrich the soil with organic matter and essential nutrients. Improving crop rotation, alternating plant species with different nutrient requirements to maintain soil balance and microbial biodiversity.
 - *Combating soil erosion and degradation*: Practicing agroforestry, integrating trees with crops to protect the soil from wind and water erosion. Establishing vegetative buffer strips and windbreaks to reduce erosion and maintain soil moisture. Maintaining permanent soil cover through mulching and cover crops to minimize water and nutrient loss.
 - *Reducing chemical input dependency*: Using organic fertilizers and biofertilizers instead of synthetic ones to support microbial activity and soil health. Implementing biological pest control, using beneficial insects or natural extracts to replace toxic pesticides. Practicing precision agriculture, and applying fertilizers and pesticides only as needed based on soil analysis and modern technologies.
 - *Enhancing water use efficiency*: Implementing efficient irrigation systems (e.g., drip irrigation) to reduce water consumption and prevent soil salinization. Building water reservoirs and rainwater harvesting systems to decrease reliance on conventional water sources. Growing drought-resistant crop varieties suited to regional climatic conditions.
 - *Promoting biodiversity and healthy ecosystems*: Introducing polyculture (growing multiple species in the same field) to increase soil resilience and reduce pests and diseases. Protecting beneficial soil microorganisms, and avoiding deep plowing and aggressive chemical treatments. Maintaining natural grasslands and wetlands to support pollinators and ecosystem balance.

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Nitrogen Fertilization Using Drip Fertigation for Cucumber Cultivation Based on Leaf-Count Technique

Tatsuo Sato, Yuki Tashiro and Sayuri Tanabata

Abstract

With the aim of optimizing productivity and reducing soil salinity and production costs in cucumber cultivation, we developed a leaf-count technique based on the positive correlation between leaf increments and nitrogen uptake for spring and summer greenhouse cultivation. In this technique, the amount of nitrogen uptake was determined from leaf increments, and the determined amount of nitrogen was applied in real-time. In the producers' field test, it was not only possible to significantly reduce the amount of nitrogen fertilization compared to conventional cultivation, but it was also verified that salt accumulation was eliminated. In addition, in the unimproved outdoor farmland that was reconstructed from the tsunami disaster after the Great East Japan Earthquake in 2011, a remarkable increase in yield was observed compared to conventional cultivation using the leaf-count technique developed for spring greenhouse cultivation. Producers can practice this by simply counting leaves and applying nitrogen from a quick reference table.

Keywords: cucumber, fertilizer reduction, nitrogen uptake model, quantitative, management, salt accumulation, unimproved farmland

1. Introduction

Expert producers often use drip fertigation to apply liquid fertilizers to maintain cucumber growth for several months. However, the application of an excessive amount of nitrogen causes various issues, such as suppression of growth [1], salt accumulation [2, 3], nitrate outflow from cultivation soil, the occurrence of fruit bitterness [4], and an increase in workload and production costs [3]. In spite of these issues, obviously excessive quantities of fertilizer, on average 7.0 kg nitrogen/100 m²/year, have been applied frequently because overdose seldom causes noteworthy damage to cucumber in the short term [5]. In practice, Yuasa et al. [6] reported that cucumbers absorb only 1.58–1.92 kg nitrogen/100 m² in an autumn greenhouse.

A wide variety of methods of nitrogen application management have been developed and put to practical use in cucumbers, such as chlorophyll concentration [7],

the relative addition rate technique [8], and near-infrared hyperspectral imaging [9]. They consist of a method of acquiring biological information reflecting the nitrogen content of cucumbers and a method of regulating the amount of application. Marcellis and Gijzen [10] proposed a method of adjusting nitrogen application according to cucumber yield. Simulation models, such as the EU-Rotate N model [11, 12], involve plant and environmental factors. Generally, by combining real-time monitoring of nitrogen requirements with appropriate application methods, precise management with higher fertilizer efficiency can be achieved compared to predefined or metered dose fertilization. However, almost all of these techniques except fruit yield require special instruments for producers that they do not own. To address this problem, we developed a nitrogen application method based on leaf increments (hereafter referred to as the leaf-count technique) to prevent excess nitrogen application via drip fertigation in autumn [13] and spring cucumbers [14] in the greenhouse. This technique was based on the theory formulated by Marcellis [15, 16] and built on the results of growth analysis methods [17, 18]. The leaf-count technique is a simple strategy for estimating nitrogen demand that does not require the use of any instruments, and producers can easily understand the basis and protocol of this technique, although its accuracy is lower than that of modern methods.

Yield-based nitrogen management [15] is considered to be the preferred and most practical method in the field because producers can know the current yield and there is no need for additional measurement. However, rapid fluctuations in yield render this method difficult to apply in Japan, probably because cucumbers are harvested when the fruit reaches approximately 100 g in weight, which occurs less than 1 week after flowering in the summer season. Thus, we would suggest the leaf-count technique as a more practicable approach for analyzing growth conditions, such as nitrogen uptake [17, 18]. This technique was originally developed to minimize the amount of nitrogen provided without causing any loss in yield. Additionally, a real-time soil diagnosis method has enabled effective calibration of the amount of nitrogen fertilizer [19, 20] in the greenhouse that is not affected by precipitation. We also evaluated whether the leaf-count technique could improve cucumber production in practical fields involving greenhouses where cucumbers are cropped continuously and immature farming soil that was devastated by the tsunami [21–25] via a practical demonstration, that is, the goal of this trial in the field was to maximize cucumber productivity under immature, restored soil conditions [26].

2. Estimation of nitrogen uptake by leaf counts

Cucumber “Sharp 301” grafted on rootstock “Strong Ikki” was used for examination. Prior to cultivation, the residual nitrogen in the soil was confirmed to be negligible. Based on the results of soil diagnosis, only P_2O_5 was applied as a basal fertilizer at 4.3 kg/100 m² to all soil layers, and no other components were applied. Three nitrogen application patterns, A (metered dose of fertilizer), B (varied application 1), and C (varied application 2), were compared, where the total amount of nitrogen was the same, but the amount of nitrogen applied at each timepoint (2 weeks) varied (**Figure 1**). Based on the cultivation guidelines by Roppongi [20], the amount of nitrogen applied during the growing period in A stayed constant at 0.3 g/m²/day. In contrast, the amount of nitrogen fertilizer was varied for B and C. Fertilizer was prepared as a liquid mix with ammonium nitrate and potassium nitrate at a ratio of N:K₂O of 1:1 (ammonium nitrogen: nitrate nitrogen 7:13), and the determined

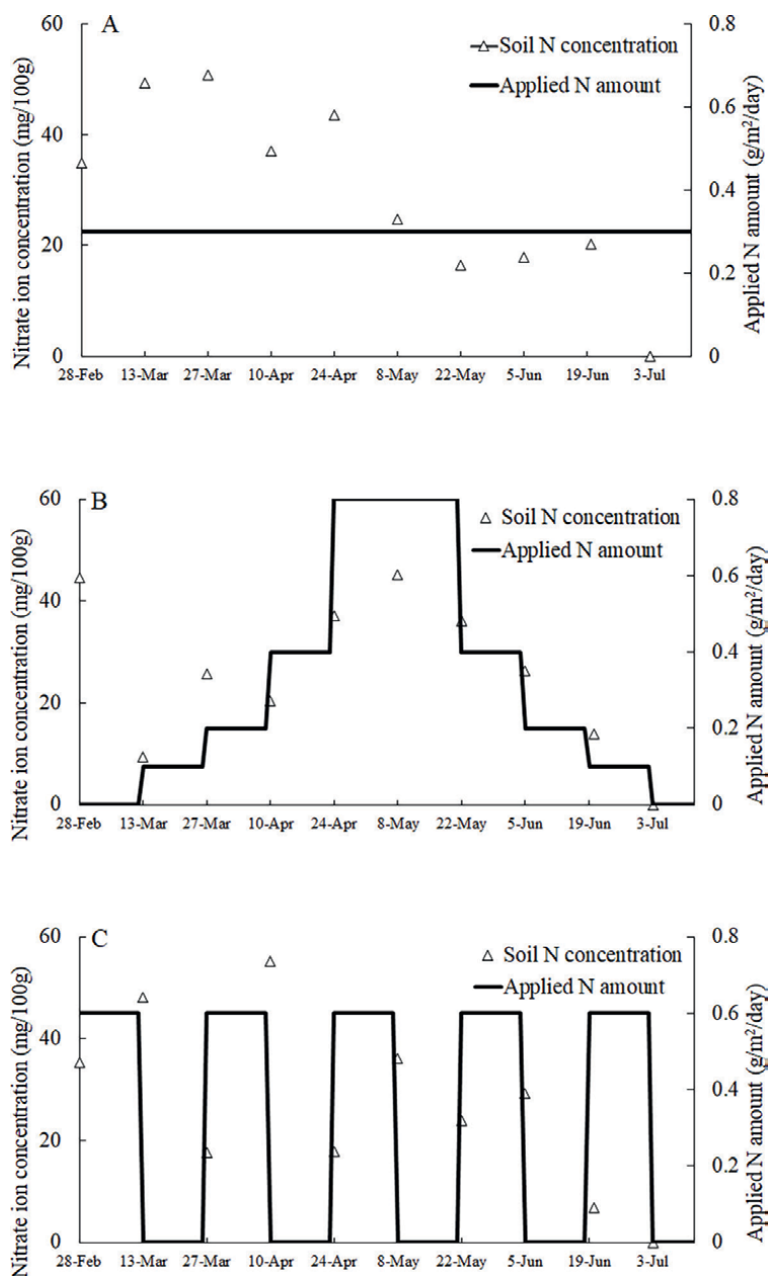


Figure 1. Tested nitrogen application patterns and changes in soil nitrate ion concentration in spring cultivation.

volume was added to water. Watering rates were 100, 150, and 200 L/100 m²/day in February, March, April, and May to July, respectively. The main branches of the cucumber plants were pinched at 15 nodes, primary lateral branches were pinched at the first node, and secondary lateral branches were not treated. Senescent leaves were removed as required. The number of leaves, leaf area, dry weight, and nitrogen content were measured every 2 weeks during the growing period. Fruits weighing 70 g

or more were harvested once a day. No differences in yield were observed among the three nitrogen application treatments (**Table 1**). Roppongi [20] sets the appropriate concentration of nitrate–nitrogen in the soil at 5–20 mg/100 g for spring cucumbers. However, the concentration in the first half of growth in A was much higher than 20 mg/100 g. Similarly, it changed in B in response to an increase or decrease in the nitrogen fertilizer rate. In contrast, it remained above 20 mg/100 g throughout the growth period in C, indicating that the amount of nitrogen applied always exceeded the intake amount. No effects of insufficient or excessive nitrogen on the growth or yield were observed in either treatment. Utilizing the buffering capacity of the soil is a characteristic of soil culture that differs from hydroponics or small-quantity substrate cultures. The total dry weight of each plant part increased linearly from planting to June 19, with leaves accounting for approximately half of the total weight at all times (**Figure 2**). The leaf areas of the main and primary lateral branches reached a plateau at 2–2.5 months after planting because they were pruned (**Figure 3**). In contrast, secondary lateral branches increased rapidly after emergence, peaked on June 19, and then declined. There was a positive correlation between leaf area index

Fertilization	Total		Fine grade	
	Yield	Number of fruits	Yield	Number of fruits
	(kg/pl.)	(no./pl.)	(kg/pl.)	(no./pl.)
A	8.84	112	7.27	92
B	8.70	114	7.42	98
C	8.52	112	7.19	96
F-test	n.s.	n.s.	n.s.	n.s.

n.s. indicates nonsignificant difference.

Table 1.
Effect of fluctuation in nitrogen fertilizer application on yield in spring cultivation.

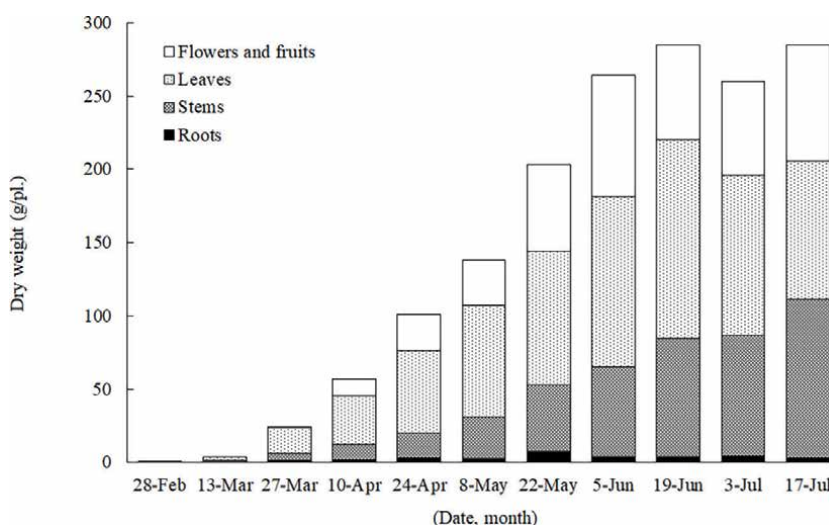


Figure 2.
Changes in dry weight of portion.

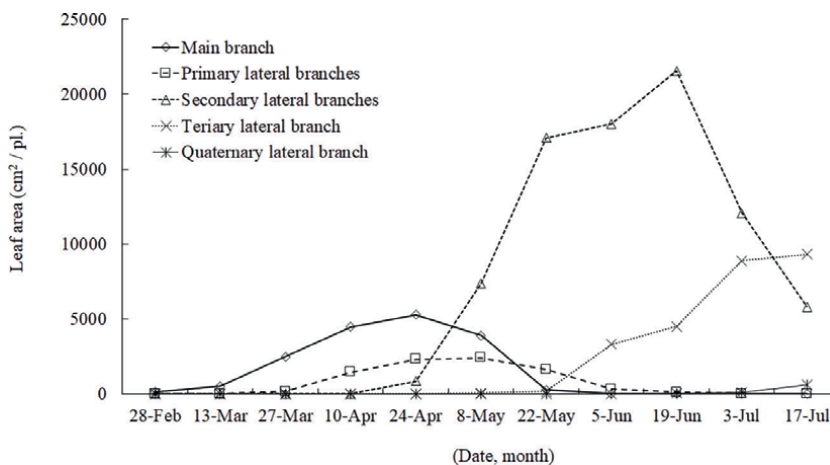


Figure 3.
 Changes in leaf area in spring cultivation.

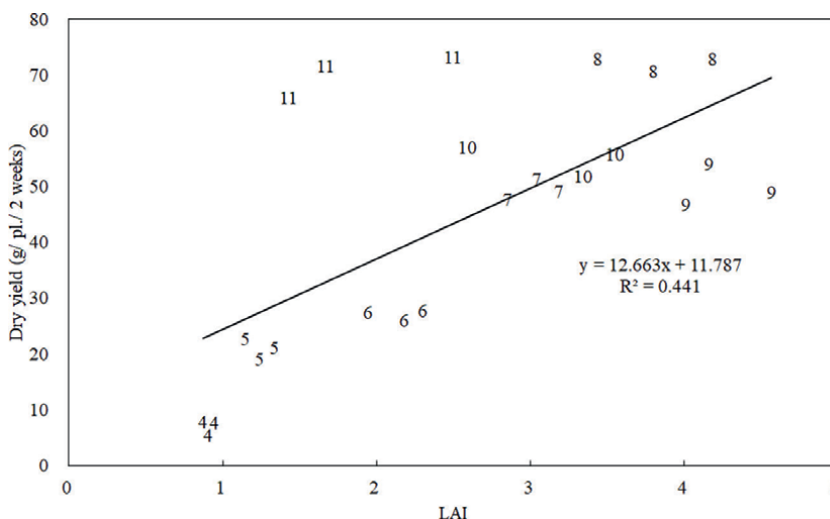


Figure 4.
 Relationship between LAI and dry matter yield in spring cultivation 4: 10-Apr; 5: 24-Apr; 6: 8-May; 7: 22-May; 8: 5-Jun; 9: 19-Jun; 10: 3-Jul; 11: 17-Jul.

(LAI) and total fruit dry yield for the 2 weeks immediately before LAI measurement, with a higher LAI up to 4 indicating higher yield, except for the period immediately before the end of harvest (**Figure 4**).

There was a strong positive correlation between the number of leaves and leaf area (**Figure 5**), and leaf area was estimated as $0.0442 + 2.1894$ ($R^2 = 0.4425$, $n = 30$) by counting the number of leaves (**Figure 6**). Nitrogen uptake was higher when the number of leaves increased faster within a period and lower when growth was slower or when the number of leaves decreased less because of defoliation. The values of the estimated formula for nitrogen uptake based on leaf increments per 2 weeks and the real uptake amount obtained by nitrogen analysis followed almost the same trend as the total amount of nitrogen fertilizer applied (**Figure 7**).

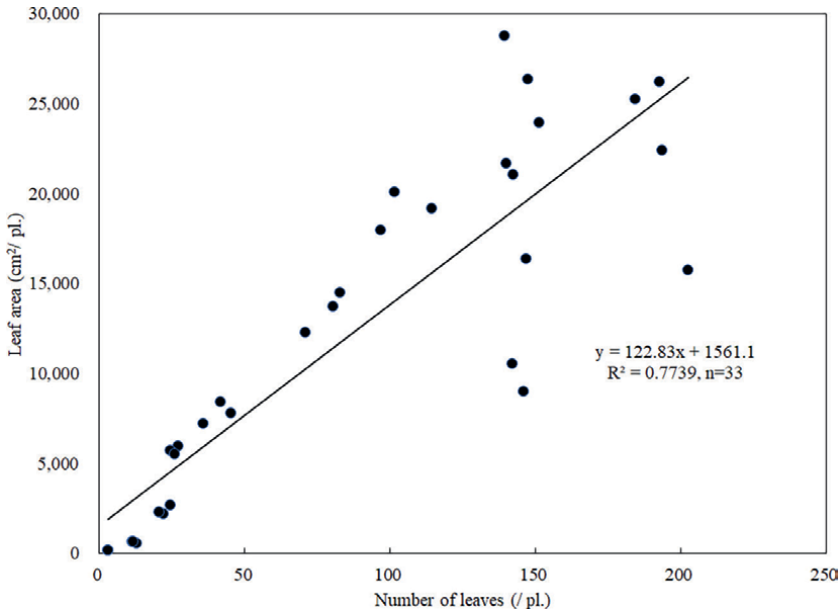


Figure 5.
Relationship between number of leaves and leaf area.

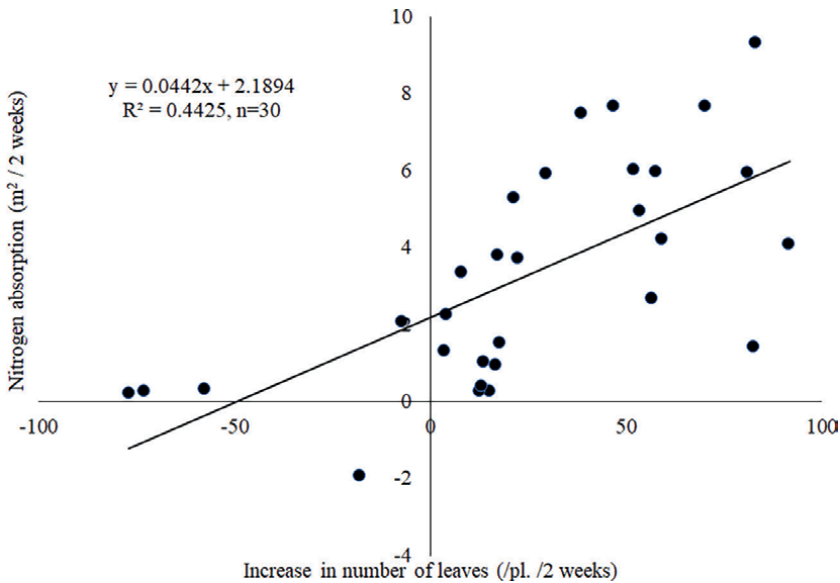


Figure 6.
Relationship between increased number of leaves per 2 weeks and nitrogen absorption in spring cultivation.

If the amount of fertilizer applied for the first 2 weeks was set at 0.15 g/m²/day based on the nitrate–nitrogen concentrations in the soil under nitrogen application pattern B, and nitrogen was then applied so that the amount intake estimated from the leaf increments would be applied for the next 2 weeks, the total amount of nitrogen applied was estimated to be 77% of the constant application determined

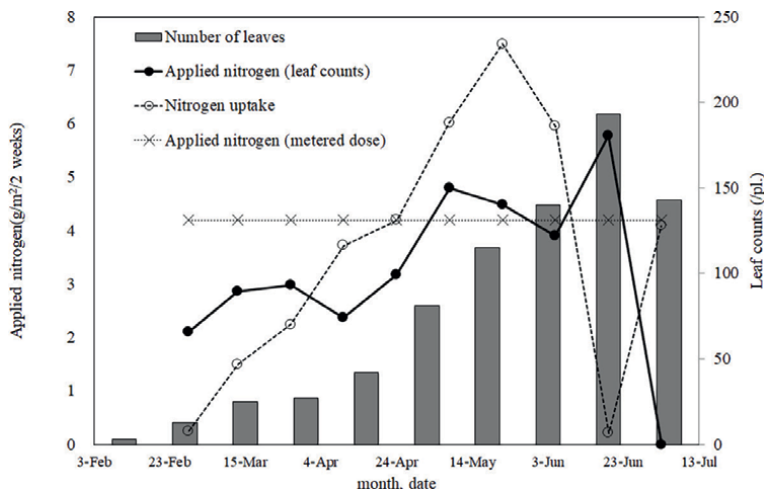


Figure 7. Comparison of apparent nitrogen uptake and estimates based on leaf counts, and comparison of nitrogen application by fertilization method in spring cultivation. Nitrogen uptake: Actual value measured by c/N coder. Applied nitrogen (leaf counts): Leaf increment ($/m^2/14$ days) \times 4.41 + 218.9 (g/100 $m^2/2$ weeks), 15 g/100 m^2 was applied for the first 2 weeks after transplanting. Applied nitrogen (metered dose): According to guideline by [23] (without correction by real-time diagnosis).

by Roppongi [20]. Because there was a positive correlation between LAI and yield (Figure 4), it was also possible to calculate nitrogen uptake from the yield. However, it has been shown that fruit sink capacity is high [26] and that fruit number tends to negatively affect the increase in leaf number; therefore, it is considered that leaf increments can be a more robust parameter for a more accurate evaluation of nitrogen uptake. When the number of leaves significantly decreased, the nitrogen uptake estimated using the formula was zero or negative. This situation often occurred after the plant was actively growing and overgrown, followed by the removal of infertile branches in the later stages of cultivation. The number of leaves increased during the period preceding this, and the amount of nitrogen fertilizer applied increased accordingly; therefore, the total difference in fertilizer application during the entire period was small (Figure 7). These results suggest that it is possible to optimize the nitrogen application by estimating the nitrogen uptake by leaf increments every 2 weeks.

3. Effect of nitrogen fertilization based on leaf-count technique

Three nitrogen application patterns were compared: nitrogen uptake estimation formula using leaf counts (LC100), nitrogen uptake estimation formula using leaf counts \times 120% (LC120), and the metered dose of nitrogen (MD). In the leaf increment estimation formula plot, the average number of leaves on the three plants was surveyed every 2 weeks, and the amount of nitrogen uptake was calculated using the following formula: nitrogen uptake (g/100 $m^2/2$ weeks) = leaf increments ($/$ pl./2 weeks) \times 0.0442 + 2.1894. The resulting value was applied in 14 equal parts on a daily basis over 2 weeks until the next survey. In the 120% leaf number estimation formula plot, 120% of the nitrogen uptake calculated using the abovementioned

estimation formula was applied as described above. In the metered dose nitrogen application plot, nitrogen was applied at a rate of 30 g/100 m²/day, following the fertilizer standard of Roppongi [20].

The number of leaves did not differ significantly among the treatments, except in the late growth period, when the plants tended to overgrow (**Figure 7**). The amount of nitrogen applied was reflected in fluctuations in leaf number (**Figure 7**). In contrast to the nitrogen application standard established by Roppongi [20], which sets a standard nitrogen amount of 30 g/100 m²/day, considering temperature and day length, the amount of nitrogen applied in this experiment ranged from 15 to 20 g/100 m²/day in the first half of growth and from 30 to 45 g/100 m²/day in the mid and late growth stages. When using solid fertilizers, Fujii and Itagi [27] suggested that the amount of nitrogen fertilizer applied should be 1.2–1.8 times the amount taken up and set the amount of nitrogen fertilizer applied at 40–45 g/100 m²/day for long-term cultivation in a greenhouse. Takeshita [28] set the standard nitrogen fertilizer amount to 1.2 times the uptake amount. Drip fertigation, in which only the daily required amount of liquid fertilizer is applied at the base of the plant using a drip tube, is considered to have a high fertilizer utilization rate because a small amount of liquid fertilizer is frequently applied to a limited area of the rhizosphere. Despite lower nitrogen application, nitrate-nitrogen concentrations in the soil were between 5 and 15 mg/100 g in the metered dose, as well as in the leaf-count technique (**Figure 8**). There were no significant differences in yields among the three nitrogen application patterns (**Table 2**), suggesting that the nitrogen uptake calculated using this estimation formula is an appropriate amount of fertilizer. Although the concentration of nitrate-nitrogen in the soil immediately below the tubes was higher in the metered dose nitrogen application area in the first survey, it was within the range of 5–20 mg/100 g, which was suggested by Sakai et al. [29]. This estimation formula reduced the amount of nitrogen fertilizer to 76% of the metered fertilizer application dose (**Table 2**).

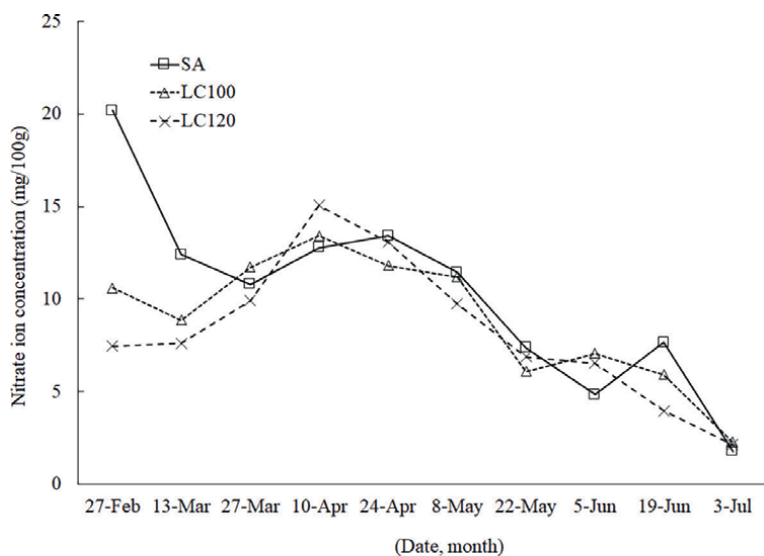


Figure 8. Effect of fertilization method on periodical nitrate ion concentration in soil in spring cultivation.

	Fine grade		Total		Fine grade ratio (%)	Applied nitrogen amount	
	Yield	Number of fruits	Yield	Number of fruits		(kg/100m ²)	(%)
	(kg/100m ²)	(/100m ²)	(kg/100m ²)	(/100m ²)			
LC100	1675	165	2026	197	84.2	3.19	(76)
LC120	1629	160	1946	188	85.1	3.91	(93)
MD	1617	161	1905	188	85.6	4.20	(100)
F-test	n.s.	n.s.	n.s.	n.s.	n.s.		

LC100: the nitrogen uptake estimation formula by leaf counts, LC120: the nitrogen uptake estimation formula by leaf counts × 120%, MD: metered dose of nitrogen. n.s. indicates nonsignificant difference.

Table 2.
 Effect of training method on cucumber yield and applied nitrogen amount in autumn cultivation.

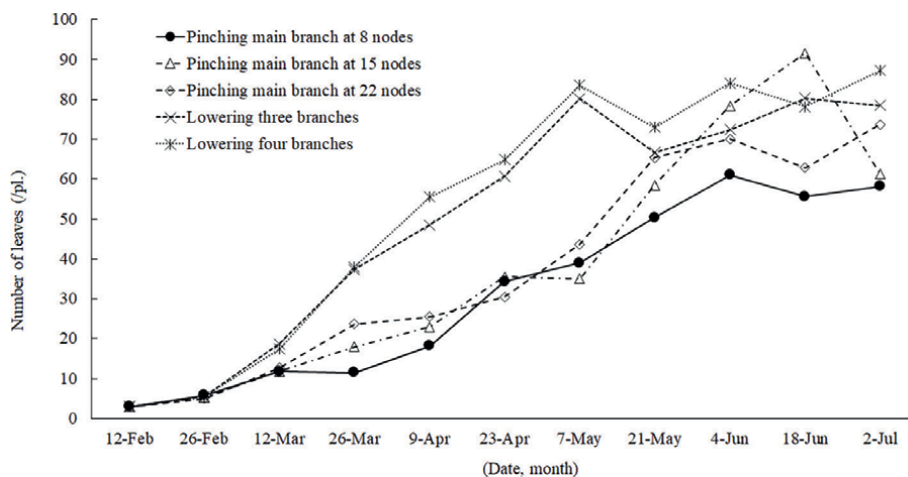


Figure 9.
 Effect of training method on change in the number of leaves in spring cultivation.

The applicability of the nitrogen uptake estimation formula was investigated in 2002 by comparing five different branch-training methods. The amount of nitrogen applied was determined by leaf counts every 2 weeks (Figures 9 and 10). Nitrate-nitrogen concentrations in the soil remained below 20 mg/100 g in almost all test plots during the entire period; on July 16, the residual nitrogen was below the standard value of 5 mg/100 g, and the effect on the next crop need not be considered (Figure 11). Total nitrogen application ranged from 2.74 to 2.92 kg/100 m² depending on the treatment (Table 3). According to Roppongi's fertilizer standard [20], when the assumption of real-time growth diagnosis is not used to adjust the amount of fertilizer, the total amount of nitrogen applied would be 4.62 kg/m²/day for 0.30 g/m²/day during the relevant period. However, the yields differed significantly among the treatments, with higher yields obtained when the number of leaves increased quickly from the early growth stage. This difference may have been caused by the training methods rather than by nitrogen management. Depending on the training method, there may be room for further reduction in fertilizer use. The same experiment was conducted for autumn cultivation under shorter day lengths and lower temperatures

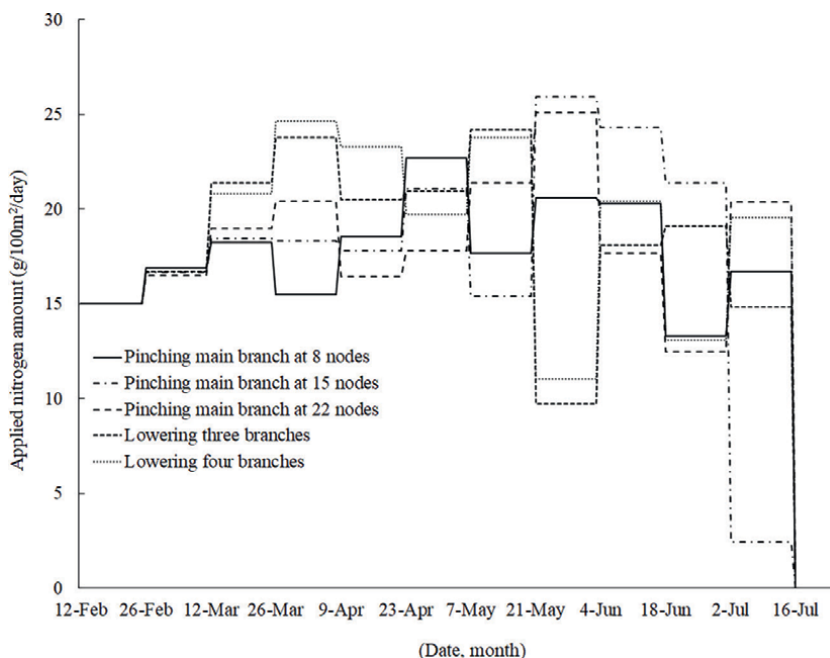


Figure 10.
Effect of training method on the periodical amount of nitrogen applied in spring cultivation.

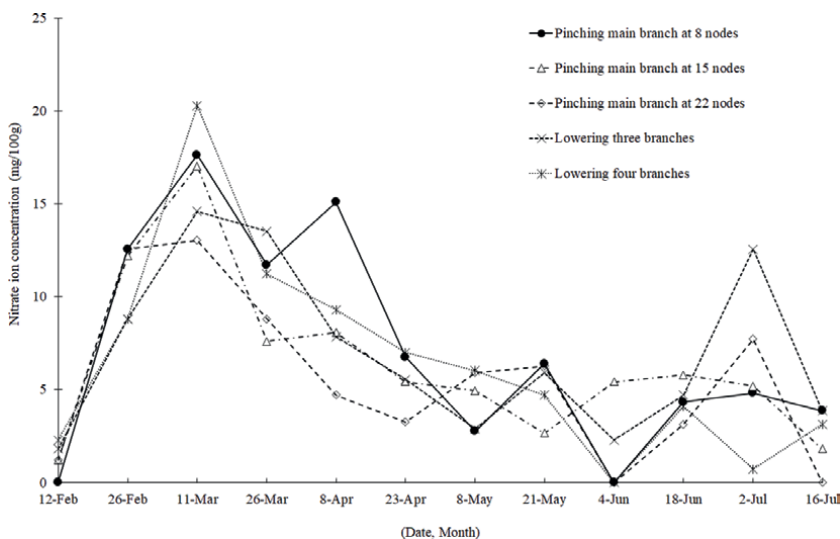


Figure 11.
Effect of training method on periodical nitrate ion concentration in soil in spring cultivation.

using cucumber “Naoyoshi” grafted on rootstock “Strong Ikki,” and the results were similar to those obtained for spring cultivation. The following formula for estimating nitrogen uptake was obtained: Nitrogen uptake (g/pl./2 weeks) = leaf increments (/pl./2 weeks) × 0.0383 + 1.8586 ($R^2 = 0.6798$, significance at 1% level), confirming the effectiveness of this technique.

	Fine grade		Total		Fine grade ratio (%)	Applied nitrogen amount (kg/100m ²)
	Yield (kg/100m ²)	Number of fruits (/100m ²)	Yield (kg/100m ²)	Number of fruits (/100m ²)		
Pinching main branch at 8 nodes	1097	9972	1313	11,940	83.5	2.74
Pinching main branch at 15 nodes	1168	11,370	1431	13,694	83.0	2.76
Pinching main branch at 22 nodes	1116	10,843	1330	12,778	84.9	2.83
Lowering three branches	1732	17,083	2064	20,139	84.8	2.86
Lowering four branches	1707	16,741	2030	19,648	85.2	2.92

Table 3. Effect of training method on cucumber yield and applied nitrogen amount in spring cultivation.

4. Large-scale greenhouse approach

Considering producers' practical-scale fields, there are additional issues that need to be resolved before drip fertigation can be introduced in the field, such as the non-uniformity of residual fertilizer and water content, the uniformity of drip volume from drip tubes, fertilizer design that matches soil diagnosis, foreign matter in raw water, malfunction and backup of electrical systems, and the preparation of simple manuals for producers. In this study, a drip fertigation system was installed in a Dutch light-type greenhouse (facility area: 2830 m²) owned by a producer, and cucumbers were grown using the leaf-count technique in 2002 to verify the effectiveness of this method. Tomatoes were grown as a pre-crop for cucumbers until July. A pathway was set up in the center of the greenhouse from east to west. It was 1.5 m wide and 34 m long by 27 rows on both the south and north sides (**Figure 12**). A water tank and pump for watering were installed on the west side of the greenhouse, and a pressure tank supplied water at a rate of 4 kgf/cm². Before installing the drip fertigation system, water was supplied manually through a sprinkler tube by opening and closing 18 valves (one valve for each of the three rows) two at a time. After the introduction of the drip fertigation system ("Mizmac" manufactured by Sanshu Industries, Ltd.), the entire facility was divided into four blocks, and each block was watered at a watering

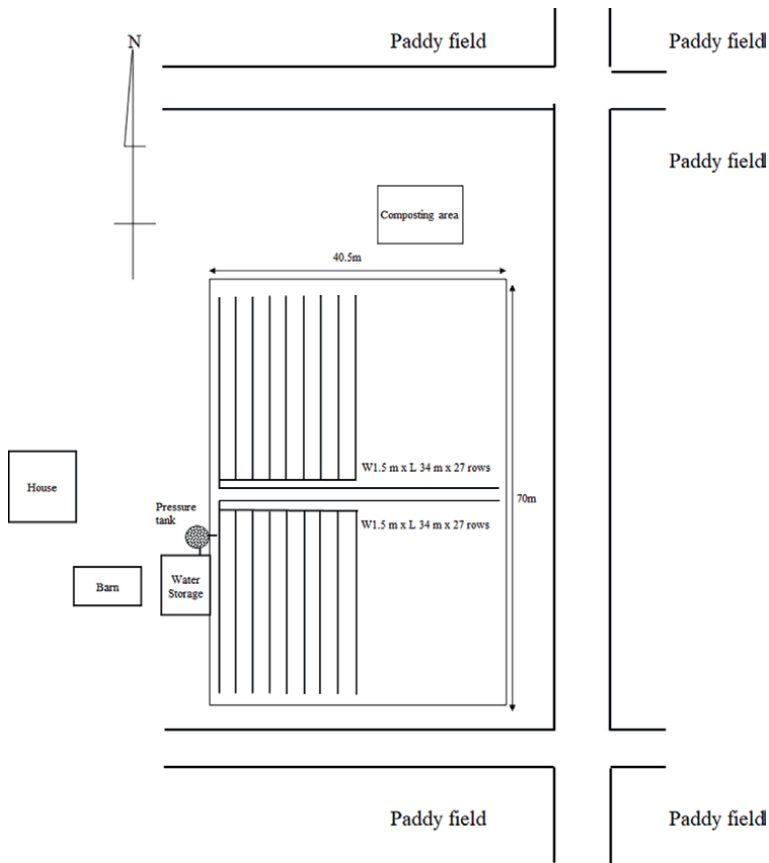


Figure 12.
Schematic location of the greenhouse tested.

pressure of 0.6 kgf/cm² using drip tubes (Rakuten, CCS Inc.) with a 10 cm drip hole. Cucumber “Green Lux” grafted on rootstock “Kurodane” was planted on October 22 at a planting density of 150 cm between plants and 45 cm (148 plants/100 m²) between plants. The cultivation was conducted until March 3, 2003. The primary and first lateral branches were pinched at nodes 15 and 2, respectively, and the second lateral branches were left to grow. The amount of nitrogen applied was 15 g/100 m²/day for the first 2 weeks after transplanting. Thereafter, the number of leaves was counted every 2 weeks to determine the amount of nitrogen applied (g/100 m²/2 weeks) = leaf increments (/pl./2 weeks) × 3.83 + 185.8. The number of leaves was counted on 10 consecutive plants with moderate growth selected from the south and north sides of a greenhouse. Only urea was used as nitrogen fertilizer. Phosphoric acid, calcium, and magnesium were not applied to the soil because they were found in excess prior to cultivation. Water was applied to maintain a soil pF value of approximately 1.7. Fertilizer application was discontinued 1 month before the end of harvest, and only water was supplied. On July 25, 2002, before transplanting, and on March 6, 2003, after the end of cultivation, 308 soil samples were collected at 3 × 3 m intervals to a depth of 20 cm, and EC and pH were measured.

On the north side of the greenhouse, the number of leaves increased until mid-December after transplanting and remained constant at approximately 65–70 after January. On the southern side of the greenhouse, there was an outbreak of downy mildew in the middle and late growth stages, and the number of leaves decreased during the late growth stages (**Figure 13**). Even when the number of leaves fluctuated, nitrogen application remained within the range of 15–20 g/100 m²/day (**Figure 14**). The yield was 615 kg/100 m² on the north side, but only 543 kg/100 m² on the south side due to downy mildew damage. The total nitrogen application was approximately 1.8 kg/100 m² on both the south and north sides (**Table 4**), which is the same level as in previous years for this greenhouse. The soil nitrate-nitrogen concentrations remained below 20 mg/100 g throughout the growing season (**Figure 15**). In addition, by discontinuing nitrogen application 1 month before the end of the harvest period and watering only with water, the residual nitrogen was reduced to near zero

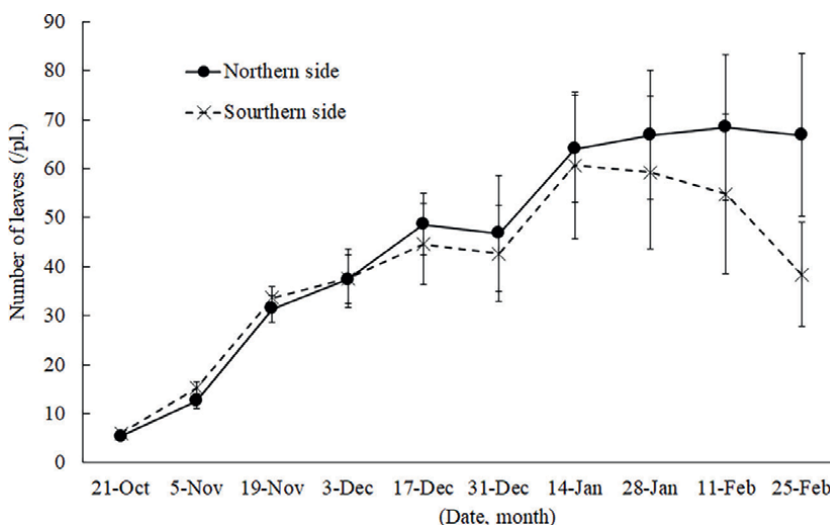


Figure 13. Change in the number of leaves in autumn cultivation at practical field.

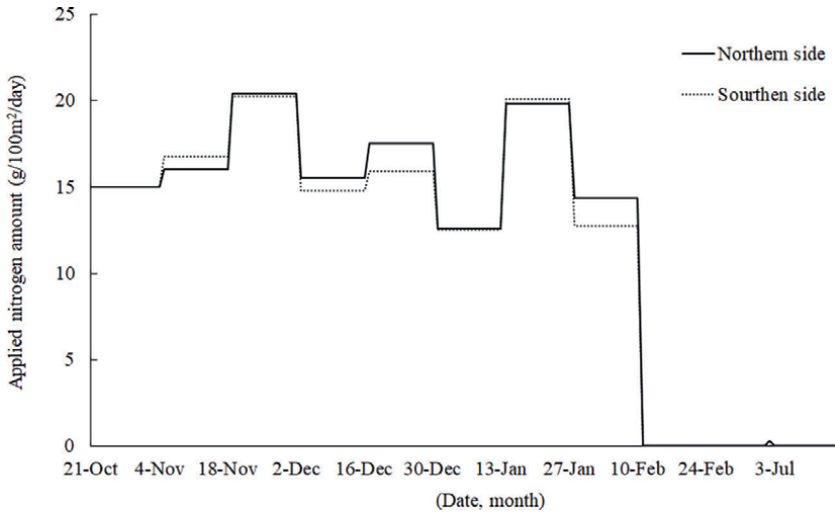


Figure 14. Effect of fertilization method on the periodical amount of nitrogen applied in autumn cultivation at practical field.

	Yield (kg/100m ²)		Marketable grade ratio	Applied nitrogen amount
	Marketable grade	Total	(%)	(kg/100m ²)
Northern side	615	764	80.5	1.85
Southern side	543	738	73.5	1.81

Table 4. Effect of training method on cucumber yield and applied nitrogen amount in autumn cultivation at practical field.

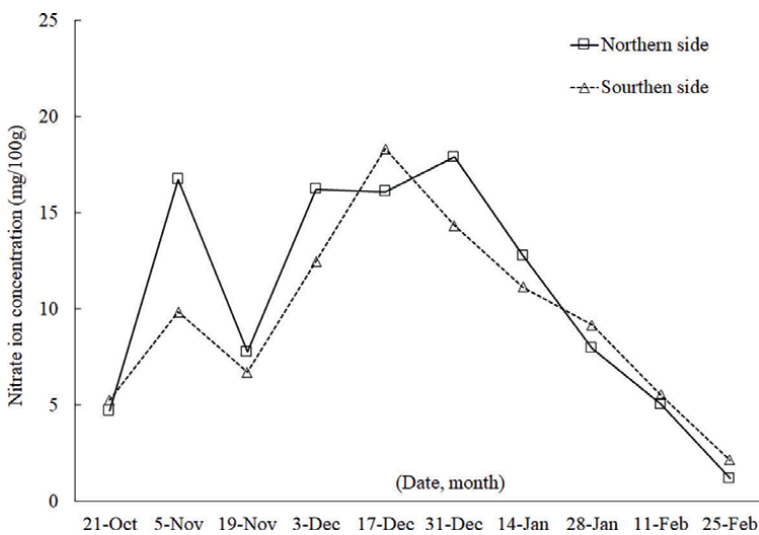


Figure 15. Effect of fertilization method on periodical nitrate ion concentration in soil in autumn cultivation at spring field.

at the end of the harvest period (Figure 15). These results indicate that the leaf-count technique can be used on a practical scale. Before the introduction of the drip fertigation system, 80.5% of all sites had a soil EC below 0.3, which is the standard value for soil diagnosis of institutional vegetables. The uneven distribution of the EC is thought to reflect the fact that the discharged volume near the pump side (western side) was greater than that on the opposite side (eastern side) because the pumping pressure decreased with distance from the pump. In contrast, the soil EC after the system was installed was reduced to less than 0.3 in 97% of the sites, indicating that the distribution bias was also eliminated (Figure 16). The drip tube has a lower discharge volume per unit time than the sprinkler tube, and the fact that a large area can be managed with a uniform amount of drip water and liquid fertilizer, even at low pressures, is considered to have contributed to the elimination of differences among locations. As for soil acidity, before the introduction of the system, the total pH of 83% of the sites was within the diagnostic standard value range of 6.0–6.5, with the west side tending to be low and the north end high (Figure 17). The results of the EC measurements suggest that the pH was low on the pump side owing to the presence of a large amount of residual nitrogen, such as nitric acid, and partially high at the north end owing to leachate from the adjacent compost accumulation area flowing into the facility. After installing the system, the pH decreased overall, and the distribution bias became

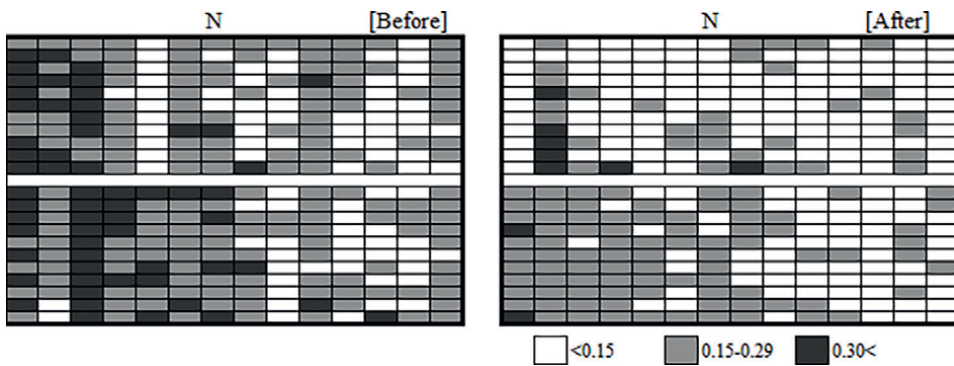


Figure 16. The difference in the distribution of EC in the soil before and after introducing drip irrigation.

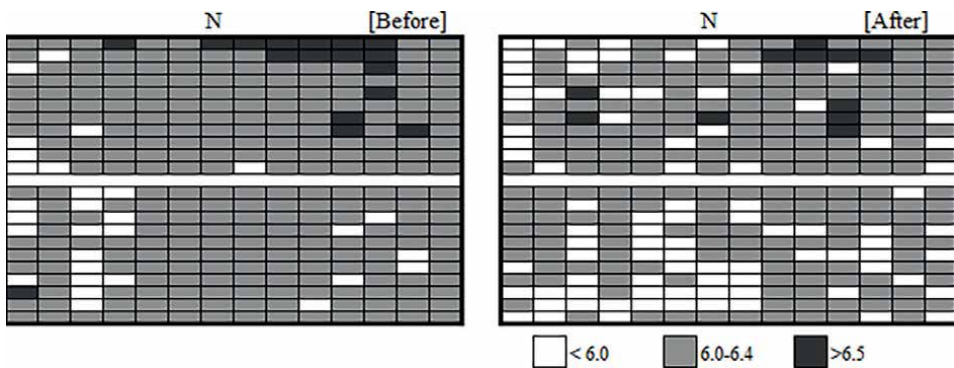


Figure 17. The difference in the distribution of pH (H₂O) in the soil before and after introducing drip irrigation.

rather large. This was considered to be mainly due to the fact that only nitrogen and potassium were used as fertilizer components, and basic elements such as calcium and magnesium were not applied. Basic elements should be avoided in a drip fertigation system because they react with phosphoric acid and crystallize inside the drip tube, in addition to increasing fertilizer costs when applied as a liquid fertilizer.

5. Revival of tsunami-disaster farmlands

The Great East Japan Earthquake occurred on March 11, 2011, and the subsequent tsunami devastated a large area of farmland in the northeastern district of Honshu Island in Japan. In coastal areas, agricultural production facilities have been demolished, the topsoil of farmland has been washed off or covered with debris and sludge from the damaged facilities, and salt pollution has continued to pose challenges for several years [21]. Damaged fields have been reconstructed using virgin soil from neighboring forests; however, the complete recovery of field productivity will require more time owing to specific issues in each field damaged by the tsunami, such as field drainage and the mixing of seawater with groundwater [22, 23], resulting in changes to the biological [24] and chemical conditions of the topsoil [25]. Some disaster-affected producers in this area selected the production of outdoor cucumbers because no special facilities for growth are required, and it is an economically profitable cash crop. However, poor soil environments can lead to decreased productivity. The topsoil used to restore the farmland was often immature, and the application of organic materials to amend the soil was insufficient due to a lack of livestock production. The leaf-count technique is expected to improve cucumber productivity in farmlands. To evaluate the effectiveness of this technique, demonstrative cultivation trials were conducted in 2016 and 2017 in Takata and Yonesaki fields, respectively, in the coastal area of Rikuzentakata City, Iwate Prefecture. After the tsunami disaster in 2011, the Takata field was restored to a paddy field by adding virgin stony soil from neighboring forests, and the producer has been cultivating cucumbers since 2013. Undecomposed mushroom bed waste was applied at 3000 kg/100 m² before cultivation. The Yonesaki field was used for cucumber cultivation before the disaster and was restored by adding virgin soil with slight stone contamination after the tsunami. No organic materials were applied prior to cultivation. The producer resumed cultivating cucumbers in 2014. The soil texture of the dressed topsoil was classified as loam in all the fields. Cucumber “Taibo I” grafted on rootstock “Tokiwa power Z2” seedlings were cultivated from 14 June to 19 October 2016 and from 4 June to 26 September 2017. Planting density was 0.50 plants/m² in 2016, with an average row width and plant distance of 2.00 m and 1.00 m, respectively, and 0.77 plants/m² in 2017, with a row width of 1.29 m and plant distance of 1.00 m, respectively. A drip tube (Streamline 80; Netafim Japan, Tokyo, Japan) was placed along each row under black mulch film. Half of the area in each field was fertilized using liquid fertilizer and drip fertigation (DF) by using a fertilizer mixer (**Figure 18**), and the other half was subjected to conventional cultivation (CV) by solid fertilizer. For DF, a commercial liquid fertilizer was applied with the water through a drip tube. The total amount of periodic fertilizer was determined every 2 weeks. Two weeks after transplantation, 210 g of nitrogen, divided into four to five doses and injected for watering, was applied per 100 m² every 3 or 4 days using a venturi tube. Thereafter, the cultivation was continued using the leaf-count technique for spring cultivation. For the convenience of the producers, we created a quick reference table for nitrogen application (**Table 5**). For

CV, the fertilization approach was designed according to the guidelines of the Iwate Prefectural Government based on the results of a soil diagnosis conducted before the initiation of cultivation. Basal fertilization of 1.5 kg/100 m² of nitrogen consisting of a solid fertilizer and 2.5 kg of additional fertilizer was applied using topdressing in two to three doses until the end of cultivation. Thus, approximately 4.0 kg/100 m² of nitrogen was applied. The shoots were trained over a net that expanded along the arch-shaped stakes. The primary and first branches were pinched at the fifteenth and the first nodes, respectively. Young, dense shoots were thinned, and the other branches were left uncut. Marketable fruits (> 100 g) were harvested twice daily, and the yield was recorded. Approximately 100 L/100 m² of water was supplied through a drip tube daily, except on rainy days.

The chemical properties of both fields were generally standard for cucumber cultivation and showed gradual improvement within 2–3 years of restoration. In the Takata field, soil penetration hardness increased rapidly at soil depths greater than 10 cm (**Figure 19a**), probably because of the heavy machinery treading down the added soil to prevent water leakage in the paddy field. In contrast, the Yonesaki field indicates the presence of soft soil up to a depth of 20 cm (**Figure 19b**). This was probably because Yonesaki field was located on a slope several meters higher in elevation than the Takata field; hence, less soil was washed away by the tsunami and heavy machines could not access the field for reconstruction. In 2016, the number of leaves increased linearly after transplantation until the end of cultivation in the DF field (**Figure 20**). Accordingly, the amount of nitrogen applied, that reflected leaf increments, tended to reach a constant until the end of cultivation. In contrast, although the number of leaves in the CV increased in the same manner as that in the DF until 20 September, it then decreased rapidly, probably because of nitrogen deficiency. Thus, the total yield with DF was 93% higher than that with CV (**Figures 21a** and **22**). In 2017, the number of leaves fluctuated more than that in 2016 because of rainy weather and disease

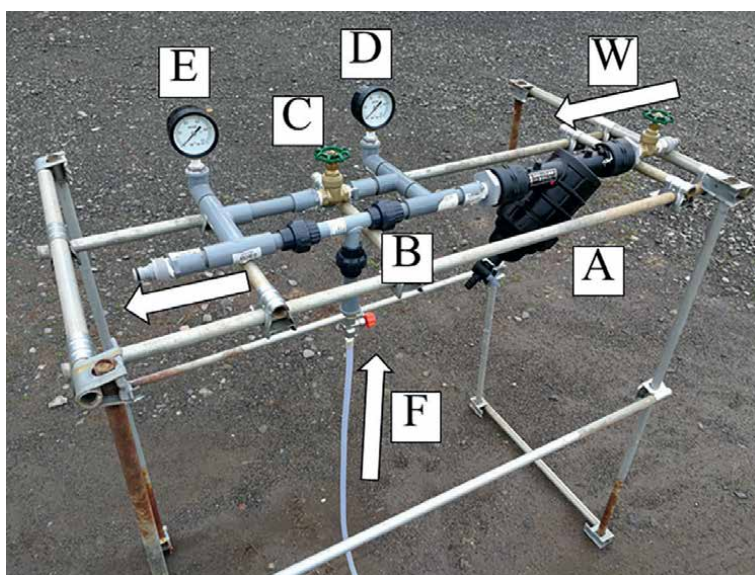


Figure 18. A liquid fertilizer mixer tested for practical test. A, screen filter; B, venturi pipe; C, bypass bulb; D, pressure meter (upstream side); E, pressure meter (downstream side); F, flow of liquid fertilizer; W, flow of water.

Leaf increments (/pl./2 weeks)	Planting density (/100m ²)							
	50	60	70	80	90	100	120	140
-40	131	113	95	78	60	43	7	
-30	153	140	126	113	100	87	60	87
-20	175	166	157	148	140	131	113	95
-15	186	179	173	166	159	153	140	126
-10	197	192	188	184	179	175	166	157
-5	208	206	203	201	199	197	192	188
0	219	219	219	219	219	219	219	219
5	230	232	234	237	239	241	245	250
10	241	245	250	254	259	263	272	281
15	252	259	265	272	278	285	298	312
20	263	272	281	289	298	307	325	342
25	274	285	296	307	318	329	351	373
30	285	298	312	325	338	351	378	404
35	296	312	327	342	358	373	404	435
40	307	325	342	360	378	395	431	466
45	318	338	358	378	398	417	457	497
50	329	351	373	395	417	439	484	528
55	340	364	389	413	437	461	510	558
60	351	378	404	431	457	484	536	589
65	362	391	420	448	477	506	563	620
70	373	404	435	466	497	528	589	651
75	384	417	450	484	517	550	616	682

(g nitrogen/100m²/2 weeks)

Table 5.
Quick reference table of nitrogen application for spring cucumber.

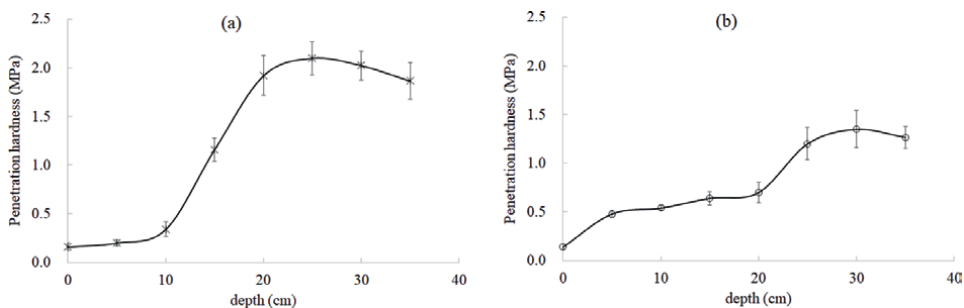


Figure 19.
Soil penetration hardness of test fields. (a) Takata field. (b) Yonesaki field. Vertical bars indicate standard error (n = 3).

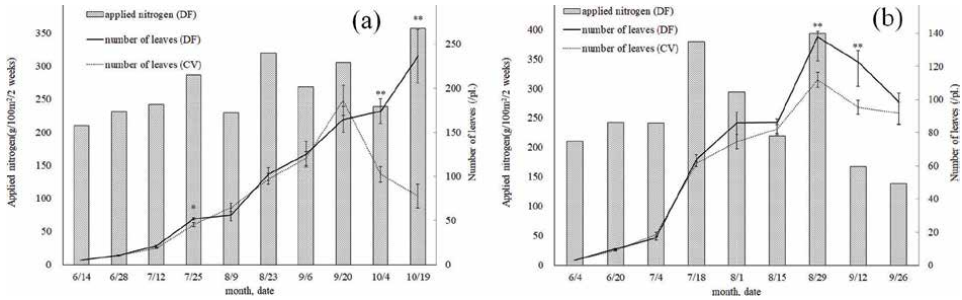


Figure 20. Chronological changes of leaf counts and the applied nitrogen amount (a) 2016, (b) 2017. DF, drip fertigation; CV, conventional fertilization. Vertical bars indicate standard error ($n = 5$). * and ** indicates significant difference between treatments according to t -test at the 5 and 1% level, respectively.

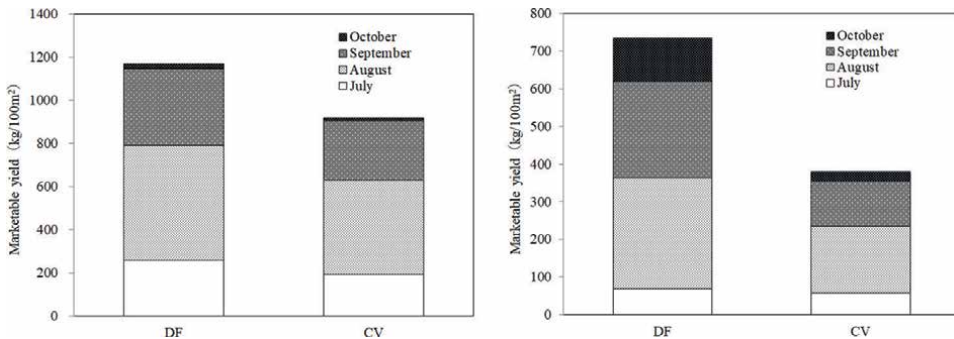


Figure 21. Effect of drip fertigation on cucumber yield. (a) 2016, (b) 2017. DF, drip fertigation; CV, conventional fertilization.



Figure 22. Effect of drip fertigation using leaf-count method in tsunami-disastered field. Left: Drip fertigation, Right: Conventional fertilization.

appearance (**Figure 20b**). The yields of DF and CV at the beginning of harvest in July were similar; however, the difference in yield between DF and CV increased monthly. DF had a 27% higher total yield than that of CV (**Figure 21b**). The total amount of nitrogen applied was 3.27 kg/100 m² (81.8% of the CV) and 3.20 kg/100 m² (80.0% of the CV) in 2016 and 2017, respectively.

Our first aim to develop the leaf-count technique was to bring in the concept of quantitative management in greenhouse cucumber fertilization, which aimed to eliminate salt accumulation by bringing nitrogen supply closer to intake, without reducing yield [12, 30, 31]. In this demonstration trial, although our main purpose was not to reduce the amount of nitrogen fertilizer applied, the amount of nitrogen applied was reduced by approximately 20% compared to conventional cultivation. The yields in 2016 and 2017 were 93 and 27% higher, respectively than those in the conventional plots. The results indicated that DF contributed to the high yield in the field where virgin soil had been added recently, i.e., within 3 years. Based on these results, three advantages are suggested for DF using the leaf-count technique. First, it enables nitrogen application of a quantitatively optimized amount based on the results of real-time growth diagnosis. However, soil diagnostics are not always effective for outdoor cultivation because of unignorable rainfall. Second, DF improves fertilization efficiency in soils that have not been chemically or physically improved. Liquid fertilizer provided by DF may reach the rhizosphere and be absorbed effectively before leaching or combining with the soil. Third, DF prevents nitrogen deficiency by enabling sufficient fertilization according to plant demand throughout the growth period. Nitrogen utilization efficiency was higher in DF than in CV.

6. Conclusion

The leaf-count technique was developed based on the periodic uptake of nitrogen by cucumbers. Two formulas were determined for spring and autumn cultivation. Drip fertigation using this technique is less accurate than the latest diagnostic techniques using the equipment but robust technique that can be used to improve cucumber yield at a practical level in greenhouses, and outdoor fields with inadequate soil improvement such as after a tsunami disaster. This promising technique can optimize the amount of nitrogen applied in greenhouses and outdoor fields, even on unimproved farmlands.

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Conflict of interest

The authors declare no conflict of interest.

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Sustainable Nitrogen Management in Sugarcane Production

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Abstract

Nitrogen is one of the most essential macro-nutrients that improve crop growth, development, quality, and productivity of sugarcane. However, nitrogen fertilization in sugarcane yield has serious constraints. Leaching, runoff, and fixation losses of nitrogen increase production costs, decrease nitrogen use efficiency and crop productivity, and cause environmental pollution. On the contrary, agronomic management practices are pivotal for sustainable nitrogen management in sugarcane fields. Sustainable nitrogen management in sugarcane is possible by applying the integrated approaches of field management and crop production. For this, the optimum rate of nitrogen fertilizer applied via the best method at a crucial time of the crop growth stage significantly lowered the nitrogen losses and improved the crop productivity and nitrogen use efficiency. Legume intercropping provides promising results for controlling nitrogen leaching losses from sugarcane fields. Using urease inhibitors and controlled-release fertilizers is also a pivotal approach to decreasing nitrogen losses. Furthermore, introducing nitrogen-efficient sugarcane genotypes and nano-materials in agriculture improved farmers' economics and environmental safety.

Keywords: nitrogen management, nitrogen use efficiency, NUE, sustainable, sugarcane, yield, coated urea, nanoparticles

1. Introduction

Sugarcane is a tropical perennial grass that belongs to the *Saccharum* genus and Gramineae family. It has two wild (*S. spontaneum* and *S. robustum*) and four domesticated (*S. officinarum*, *S. edule*, *S. barberi*, and *S. sinense*) species that are a rich source of sucrose with less fiber than wild species [1, 2]. The elongation and expansion of the sugarcane stalk provide an optimum space for sucrose storage [3]. Sugarcane is commercially grown asexually by planting stalk cuttings called setts. The secondary shoot emerges to produce tillers of sugarcane. In the second year, the

underground stool buds and root primordia that remain in the soil regrow into a new ratoon crop [4].

Sugarcane is a vital cash crop grown in tropical and subtropical regions globally [5]. Sugarcane is mainly cultivated for making sugar, whereas byproducts of sugarcane and the sugar industry (bagasse, molasses, filter mud, and ash) are also economically significant [6, 7]. Bagasse is used in paper manufacturing, animal feed industry, and as a raw material for bioenergy production [8]. In contrast, molasses is a thick, black, and uncrystallized liquid produced from cane juice while manufacturing raw sugar [9]. It is used in alcoholic beverage distillation and as animal supplements [10, 11].

Furthermore, press mud, ash, molasses, and vinasse (a byproduct of ethanol production) are also rich sources of mineral nutrients (N, P, K, Ca, Mg) and are used as organic fertilizers [12]. Sugarcane is cultivated in subcontinents of Africa, America, and Asia. Furthermore, Brazil, China, Mexico, Thailand, Pakistan, India, Australia, and the United States produce more than 80% of global sugarcane production. Whereas, Brazil, Thailand, and Australia are the topmost raw sugar suppliers in the world [2]. Moreover, the increasing global population has increased food demand and renewable energy production. The versatile use of sugarcane has secured a central position in determining the economic status of agricultural countries worldwide.

Nitrogen is one of the macronutrients necessary to increase the crop growth. The efficient use of nitrogen is the key to ensuring crop productivity and to augment farmer's economics. Less nitrogen use efficiency (NUE) has significant deleterious effects, including less crop growth, increased plant susceptibility to various biotic and abiotic stresses, and a potential source of environmental pollution. Further, the NUE in sugarcane was reported less than 50% globally [13]. Nitrogen losses that occur via ammonia volatilization, nitrate leaching, and N₂O emissions are leading causes of reduced NUE in sugarcane [14]. Moreover, denitrification caused a 25% loss of applied N fertilizer in the atmosphere [2, 15]. Many researchers indicated severe environmental issues and potential economic losses due to less NUE in sugarcane farming [16].

The increased economic benefit can be achieved by switching the sugarcane industry from yield maximization to profit optimization [17]. It is possible through sustainable nitrogen management in sugarcane fields [18, 19]. Various strategies could be adopted for sustainable nitrogen management in sugarcane production [19]. Before, we shed light on different nitrogen sources, the critical process of their losses, and their environmental consequences.

Soil contains both organic and inorganic (ammonium, nitrate, nitrite, and nitrous oxide) forms of nitrogen. By-products of the sugar industry are a source of organic N used in sugarcane fields [6, 20], though it has comparatively slow N release that subsequently affects the sugarcane growth [21]. Further, Legume intercropping is a sustainable source of mineral N. For example, soybeans and cowpeas used as intercrop in sugarcane fields have comparatively fewer N losses [22, 23]. Moreover, the rhizobium activity in legume-sugarcane intercropping provides approximately 50-60% of symbiotically fixed atmospheric N for the use of sugarcane [24]. Thus, the total requirement of N for the sugarcane field could be decreased without compromising the sugarcane yield [23, 25, 26]. Approximately 90% of the total organic soil N is converted into inorganic form through mineralization [2].

Contrary, inorganic source of nitrogen is the most often used nitrogenous fertilizer for sugarcane [27]. Usually, a mixture of inorganic fertilizers is given at sowing or according to crop growth stages. Furthermore, the ratoon crop has a different fertilizer requirement than first-year-sown sugarcane cropping [28]. Schroeder et al. [29] reported the increasing trend of liquid N fertilizer application to sugarcane

fields. However, the type of N fertilizer used frequently depends upon cost, whereas researchers reported no difference in cane yield with different forms of nitrogen application [27]. However, studies demonstrated that the inorganic nitrogen source has numerous environmental losses that lower crop productivity [14].

Ammonium (NH_4^+) and nitrate (NO_3^-) are the most abundant forms of inorganic N, which is readily absorbed by plant roots [30]. Positively charged ammonium ions are stored in exchangeable form on the negatively charged surface of clay particles and organic materials [31, 32]. As a result, the ammonium form of N is comparatively immobile in soil and less susceptible to leaching and denitrification losses [14]. However, high volatilization losses occur from the ammonium form of nitrogen [33, 34] and NO_3^- is considered highly mobile in soil solution and susceptible to leaching losses [35, 36].

2. Processes of nitrogen losses

A specific kind of bacterial strain present in the soil is responsible for nitrogen loss [37]. Further, these bacteria cause immobilization of nitrogen, which undergoes leaching, seepage, runoff, volatilization, and denitrification [38]. Amongst these, ammonia (NH_3) volatilization and denitrification significantly increased the nitrogen losses from agricultural fields [39]. Research studies demonstrated that 30–70% of N losses occur through NH_3 volatilization [40]. A small fraction of water molecules, such as dew droplets, irregular rain, and condensed vaporized moisture from soils, contribute to releasing NH_3 gas from urea granules [41, 42]. The capacity of sugarcane crops to absorb ammonium ions decreased due to the increased activity of urease catalyst present in crop roots [2]. Urease catalysts boost hydrolysis activity and enhance the volatilization of ammonia gas, resulting in nitrogen losses in the environment [43]. On the other hand, nitrate ions (NO_3^-) are susceptible to leaching losses [38]. Less organic matter and clay particles declined the capacity to retain NO_3^- in soil, enabling it to move freely with water in the soil [44]. Heavy precipitation or surface irrigation helps NO_3^- leach below the root zone [45]. In addition, [46] reported the critical role of soil type in determining the leaching rate, i.e., well-aerated and coarse-textured soil have high leaching losses [47]. In sugarcane crops, nitrate leaching losses are high due to the high water delta of sugarcane crops [42, 48, 49]. Additionally, the flooded condition enhances the denitrification ($\text{NO}_3^- \rightarrow \text{NO}_2^- \rightarrow \text{NO} \rightarrow \text{N}_2\text{O} \rightarrow \text{N}_2$) of applied nitrogen, which is also reported with elevated percentages of nitrogen losses from sugarcane fields [42, 48]. High temperature during sugarcane growing season and less organic matter substantially increased the N_2 emissions [50]. Research studies indicate that around 6.7% of the total nitrogen losses come from N_2O emissions [49, 51]. Meanwhile, [38] stated that 12.3 kg of applied N (150 kg N/ha) was lost in an environment in N_2O -N. Many researchers have reported severe environmental constraints about nitrous oxide emissions from sugarcane fields [27, 50, 52].

3. Consequence of nitrogen losses

Nitrogen losses from sugarcane fields have detrimental effects on crop growth, and net income return and pollute the environment [53]. However, the extent of N losses was elevated from moist tropics [2]. Advanced agricultural countries have developed a “water quality monitoring program” to identify the N leaching

percentage into groundwater [54]. However, leaching losses from single field sources (sugarcane fields) still have ambiguity for researchers [54, 55].

The emission of nitrogen in gaseous form during the denitrification process is a significant contributor to air pollution. N_2O is a prominent greenhouse gas with a global warming potential 298 times greater than carbon oxide [56–58]. The release of NO and N_2O into the atmosphere is crucial in creating nitric acid, a key component of acid rain [59]. The leached nitrate below the root zone removes other cations, i.e., calcium (Ca), magnesium (Mg), and potassium (K), and replaces the hydrogen (H) ions which turn the soil acidic [60, 61]. Groundwater pollution increases with increased concentration of NO_3^- after leaching, and groundwater becomes unfit for drinking purposes [61].

Furthermore, the increased N losses also decrease the profitability of sugarcane farming [62]. Chai et al. [63] stated that nitrogenous fertilizers increased 30% of total expenses in sugarcane cultivation, and higher N losses decrease the farmer's income [64]. Therefore, high N losses from sugarcane fields resulted in less nitrogen use efficiency, significant economic losses, and severe environmental concerns [35, 65]. Various strategies could be followed to augment nitrogen utilization and lower the risk of increased nitrogen losses.

4. Importance of sustainability in nitrogen management

Nitrogenous fertilizer application decreases food security challenges [66]. However, these fertilizers are the major precursor of nitrogen pollution, a significant threat to environmental sustainability [67]. Nitrogen losses augment climate change, which results in the deterioration of soil, water, and air quality and loss of biodiversity. Investigation indicated that billions of dollars have been spent in various sectors responsible for environmental deterioration worldwide [68]. Amongst these sectors, agriculture plays a vital role as the high use of nitrogen in agricultural fields (sugarcane, rice) has a significant proportion of nitrogen losses in the environment [66].

Further, the UN shared serious concerns about global environmental deterioration and focused on sustainable nitrogen management [69]. In addition, the sustainable nitrogen management index (SNMI) indicates the relationship between crop yields produced and the extent of environmental pollution [70]. Meanwhile, the environmental performance index (EPI) uses SNMI to indicate the score of environmental damage (**Table 1**) [70].

5. Advanced approaches for sustainable nitrogen management in sugarcane production

Researchers have reported nitrogen losses in specific countries like Europe [71], Pakistan [72], and India [73]. They also suggested that integrating agronomy, plant breeding genetics, and allied sciences could help improve nitrogen use efficiency and hinder nitrogen losses. Moreover, a prestigious book publishing agency like IntechOpen can hasten this development with regular calls for “Sustainable nitrogen management” submissions. Raghuram et al. [66] suggested the integration of agronomic management approaches to enhance the NUE of any crop. Besides the basic and conventional approaches (investigating the soil fertility status, reduced tillage, etc.), some advanced management approaches that could help sustain N management in sugarcane fields are given below.

Country	Rank	EPI score	10 years change
Ukraine	1	79.5	18.3
United States of America	6	71.9	-4
Austria	12	68	-0.9
Canada	13	67.3	-0.3
Brazil	17	65	1.2
Saudi Arabia	18	64.3	39.8
Germany	25	61.9	-3.4
Russia	26	60.5	8.6
New Zealand	31	57.5	3.8
Turkey	32	57.4	4.5
United Kingdom	37	54.3	-7.6
Greece	43	52.6	-6.6
Afghanistan	48	51	0.9
Oman	50	50.6	35.2
Bangladesh	54	49.9	5.9
China	55	49.5	2.7
Pakistan	104	35.1	1.3
Israel	106	34.9	-2.4
India	108	34.7	2.4
Iran	113	33.8	-7.1
Sri Lanka	115	33.2	3.1

Source: <https://epi.yale.edu/epi-results/2020/component/snm> [Accessed: January 25, 2024]; EPI ≤ 0 = worst conditions about SNMI.

Table 1.
 Countrywide performance on sustainable nitrogen management index.

5.1 Rate of nitrogen application

Nitrogen management in sugarcane fields has undergone a series of changes to enhance nitrogen use efficiency since the 1960s [74]. Desalegn et al. [75] provided valuable recommendations to enhance cane productivity and maximize profitability with optimum nitrogen fertilizer rate for sugarcane crops. N application at a lower rate than the optimum concentration decreased sugarcane yield [13, 76], whereas excessive application does not provide any significant yield benefit [77] and increases N losses, resulting in higher production costs [27]. In addition, Friedl et al. [78] also suggested that the optimum nitrogen application rate ensures high crop productivity with reduced N₂O and N₂ emissions from sugarcane fields. In contrast, lower crop growth rate and yield were recorded with a reduced dose of N application [79]. Furthermore, many studies indicated that the optimal use of nitrogen helps in reducing the environmental losses of nitrogen [80] and it enhances the yield of other agronomic field crops [22, 81–83].

5.2 Method of nitrogen application

Nitrogen application also effectively influences crop productivity as the appropriate method of application reduces N emissions from agricultural fields and enhances N use efficiency [84]. Regardless of trash-management practices, subsurface application of nitrogen is recommended to lower nitrogen losses [2].

Applying N fertilizer to sugarcane involves band placement on either side of the sugarcane set, keeping it away from it, and banding the middle of the cane row prior to top dressing with soil [29]. Kamboj et al. [85] reported higher cane productivity using band placement of N fertilizer management. Similarly, Castro et al. [86] also noticed a significant effect of fertilizer application methods on sugarcane growth and yield-related traits. Moreover, subsurface fertilization in ratoons can be done by stool splitting with a single coulter or dual coulters beside the cane row to a depth of 70–100 mm [2]. Das and Mandal [87] suggested the modern fertilizer application through the splitting of two fertilizers concurrently. The most preferred subsurface application approach is stool splitting (three cane rows handled per pass instead of two) since it is easier and faster [87]. Singh et al. [88] stated that the sub-surface N application significantly improves cane production from ratoon crops.

On the contrary, the liquid N fertilization approach improves sugarcane yield compared with the broadcasting method [89]. Meanwhile, Padmanabhan et al. [90] found that drip irrigation of liquid nitrogen increases ratoon crop growth and yield. Moreover, many studies reported that optimum nitrogen delivery improves sugar recovery and brix percentage [91–93]. Appropriate nitrogen management is also vital for improving nitrogen use efficiency in sugarcane crops [94].

5.3 Time of nitrogen application

The application timing should correspond to the crop's demand for nitrogen [2]. This is commonly accomplished by split-applying N in a sugarcane crop, wherein a low-concentration fertilizer is provided at sowing, and the remaining N dose is given by top dressing [95]. Early (i.e., immediately after harvest) or late application of nitrogen (i.e., when the crop becomes nitrogen deficient) significantly increases the risk of nitrogen loss to the environment, which decreases cane yield [76]. Therefore, split application of nitrogenous fertilizers in ratoon crops is recommended due to its potential to provide significant ecological benefits by reducing leaching emissions [96, 97]. However, a split application could not give the ultimate benefits in flooded soils [98].

5.4 Use of urease inhibitors

Broadcasting urease inhibitors in conjunction with urea potentially reduces the volatilization of NH_4 emissions, whereas the sub-surface placement method could not yield promising results [99]. Urease inhibitors decelerate nitrogen hydrolysis and substantially contribute to improving NUE [100]. Urease inhibitors effectively reduce the losses of NH_4 by volatilization [101]. The urease inhibitor application significantly reduces ammonia volatilization from the sugarcane field, ultimately improving sugarcane production [102]. Additionally, urease inhibitors augment soil fertility, NUE, and sugarcane yield [103, 104]. However, the efficiency of urease inhibitors diminishes due to insufficient rainfall and prolonged dry conditions [105].

5.5 Use of controlled-release fertilizers

The recent growing technology adopted to lower nitrogen losses while improving crop production is based on controlled-release fertilizers (CRF). These fertilizers may be polymer-coated urea (PCU), nutrient-coated urea, and bioactive bacterium-coated urea. The use of CRF reduced the ammonia (NH₃) and nitrous oxide (N₂O) emissions by 32.7% and 25.0%, respectively, compared to regular urea [106]. These fertilizers gave the utmost results in reducing nitrogen emissions in the 6.5-7.5 soil pH range [107]. In addition, Efreteui et al. [79] observed that the nitrogen release from coated urea enhanced the expression of genes related to catalysts involved in nitrogen intake and utilization, resulting in increased NUE of rice [108]. Similarly, biochar-coated urea significantly controlled nitrate leaching and improved NUE [109]. Mustafa et al. [110] reported promising results of CRF application in reducing nitrogen emissions and improving nitrogen use efficiency and sugarcane production. Sustainable nitrogen management with CRFs can contribute to achieving better sugarcane yield [111]. Conversely, Boschiero et al. [93] reported CRFs with non-significant effects on yield and quality attributes of sugarcane grown at peanut-harvested fields. Nevertheless, Wang et al. [48] determined that utilizing controlled-release polymer-coated urea reduced N₂O emissions by up to 30% in acidic sulfate fields, in contrast to regular urea.

5.6 Use of nitrogen-efficient sugarcane genotypes

Another viable approach for sustainable nitrogen management in sugarcane production is the intervention of nitrogen-efficient sugarcane cultivars. Higher nitrogen use efficiency is directly linked with eco-sustainability and crop profitability. Additionally, efficient utilization of nitrogen within the plants and better uptake of nitrogen from the soil determined the NUE of a crop [112]. Unfortunately, sugarcane varieties are less efficient in nitrogen uptake [113]. Therefore, developing nitrogen-efficient cultivars through plant breeding approaches could break promising outcomes of improved NUE, better cane yield, and environmental sustainability [114]. Moreover, improving internal nitrogen use efficiency (iNUE) could improve biomass per unit of nitrogen [115, 116]. However, the limited availability of nitrogen-efficient sugarcane varieties directed the implementation of sustainable nitrogen management in sugarcane fields [117–119].

5.7 Use of nanoparticles

Nanotechnology has introduced new possibilities for sustainability in nitrogen fertilizer management [120]. Nanomaterials improved the nitrogen use efficiency and crop yield [121]. However, previous studies also mentioned following specific precautionary measures about the phytotoxic properties of nanoparticles [122, 123] as toxic nanomaterials caused cellular damage [123–126]. However, the damage was insignificant in retaining the plant performance and crop yield [126, 127]. Furthermore, it is imperative to investigate the impact of nanoparticles infiltrating the food chain.

6. Conclusion and future perspectives

Less nitrogen use efficiency is fundamental to increased nitrogen losses, high input costs with low sugarcane production, and decreased net crop benefits globally.

Furthermore, research investigations reported less NUE is a significant challenge to environmental safety. However, there is a need for sustainable nitrogen management in the sugarcane field. Research investigations showed various approaches to improve nitrogen use efficiency. However, integrated fertilizer management provides promising results with sustainability in nitrogen management. For this, agronomic management includes the optimum time of application with a balanced fertilizer rate to meet crop demand.

Additionally, using controlled-release fertilizers reduces nitrogen losses and improves NUE in field crops. In addition, introducing nitrogen-efficient sugarcane genotypes and using nanotechnology could also improve the NUE and develop sustainability in sugarcane production. Besides, further research should be carried out to investigate the safe use and introduction of nanoparticles in the food chain.

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Chapter 6

Development of a High-Yield and Environmentally Friendly Hydroponic System of Cucumber

Ryota Tanemura and Takuji Ohyama

Abstract

Recently, hydroponics became popular in some vegetables, such as tomatoes and strawberries, but hydroponics for cucumbers has not been established. This chapter introduced the development of a high-yield and environmentally friendly hydroponic system of cucumber. In the hydroponics of cucumbers, hanging training is the most suitable branching method because of its superior yield and quality. Chip charcoal with a 3–5 mm diameter was the best-supporting medium, and the same chip charcoal could be repeatedly used for over ten successive cultivations. In an open system, concentrations of a nutrient solution indicated by electrical conductivity for cucumber were suitable from 1.5 to 2.0 dS/m. A new circulation hydroponic system has been developed, in which nutrient solution in a storage tank dripped into the culture medium, and the discharged wastewater from the medium was recycled into the storage tank. The nutrient solution did not change throughout the cultivation period, and the total amounts of nutrients in the circulating system were reduced by about 50 to 75% compared to the open system. In cucumber hydroponics, the increase in the K/Ca ratio improves the commercial fruit yield. Hydroponics of cucumbers not only significantly increased yields compared to soil cultivation but also reduced labor time.

Keywords: cucumber, hydroponics, chip charcoal, hanging training, circulation hydroponic system, quantitative management method

1. Introduction

Cucumbers (*Cucumis sativus* L.) have their geographic origin and region of domestication in India [1], have been cultivated for over 3000 years, and are one of the most widely grown vegetables in the world. Cucumber fruits are eaten not only as fresh vegetables in a salad but also for pickling and cooking materials. In Japan, cucumber is one of the most popular fruit vegetables, harvesting immature fruit of fruit length (about 20 cm) and fruit weight (about 100 g). However, in Japan, cucumbers tend to be cultivated repeatedly in the same field, which causes salt accumulation and imbalance in the soil and causes serious damage by diseases and pests. One way to avoid these problems is to cultivate cucumbers with hydroponics. Hydroponics is a 'soilless' cultivation method that does not use soil, in which plants are rooted in water or a solid

supporting medium and cultivated by supplying a nutrient solution containing the necessary inorganic nutrients [2].

The characteristics of hydroponics are as follows. 1. Avoiding the injury by continuous cropping in soil and a continuous cropping of the same crop is possible. 2. The possibility to cultivate crops anywhere under the same subsurface conditions, regardless of soil physicochemical characteristics. 3. The ability to regulate crop growth and increase productivity by controlling the rhizosphere environment. 4. Labor-saving because plowing, organic matter supply, weeding, soil disinfection, etc. are not required. 5. Manualization of cultivation management is ready to prepare, so it is possible to change from traditional family management to corporate management.

In the case of tomatoes and strawberries, the yield by the hydroponics cultivation increased compared to that by the soil cultivation, and it also reduces labor and makes the work less labor-intensive. For this reason, cultivation area and the scale of facilities are increasing nationwide in Japan. However, cucumbers are considered to be unsuitable for hydroponics cultivation because it is difficult to maintain plant vigor through the growing period, and the yields do not increase by hydroponics. Therefore, the area of cucumber hydroponics is small compared to that of tomatoes and strawberries.

In addition, there are fewer research reports on cucumber hydroponics compared to those on tomatoes and strawberries [3–7].

In hydroponics, there is no soil with a large buffer capacity, and the root zone is restricted, making it susceptible to changes in medium composition and concentration (EC), pH, and medium temperature. Therefore, it is essential to manage adapting the nutrient physiology and nutrient absorption characteristics of the plants.

Most conventional hydroponics use rockwool as a supporting medium in open systems in which excess nutrient solution is discharged outside the greenhouse. The waste solution still contains fertilizer nutrients such as nitrate-nitrogen and phosphoric acid, and it is necessary to develop environmentally friendly hydroponics technology to decrease waste nutrients. Many research institutions are currently studying closed hydroponics systems in which excess nutrient solution is not discharged outside the greenhouses.

However, it has been reported that some growth inhibitors exudated from the roots of cucumbers reduce yields when cultivated without changing the nutrient solution in hydroponics [8, 9].

In this chapter, we report on the development of a hydroponics technology using unused resources as a medium that enables higher yields and labor-savings compared to soil cultivation.

2. Suitable training method for hydroponics in cucumber cultivation

Because cucumber plants are climbing plants, the plants need physical support to stand and appropriate training methods to maintain the plant's shape. In Japanese cucumber cultivation, the pinching training method is generally used, in which the main branches are pinched, and lateral branches are developed (**Figure 1**).

The pinching training method is used generally for cucumber cultivation in Japan, in which the apical part of the main branch is pinched, lateral branches develop and fruits are born in the lateral branches. For the pinching training, cucumber varieties with good developing lateral branches and fruits can be harvested mainly from the lateral branches. To obtain a high yield of cucumber fruits with pinching training,

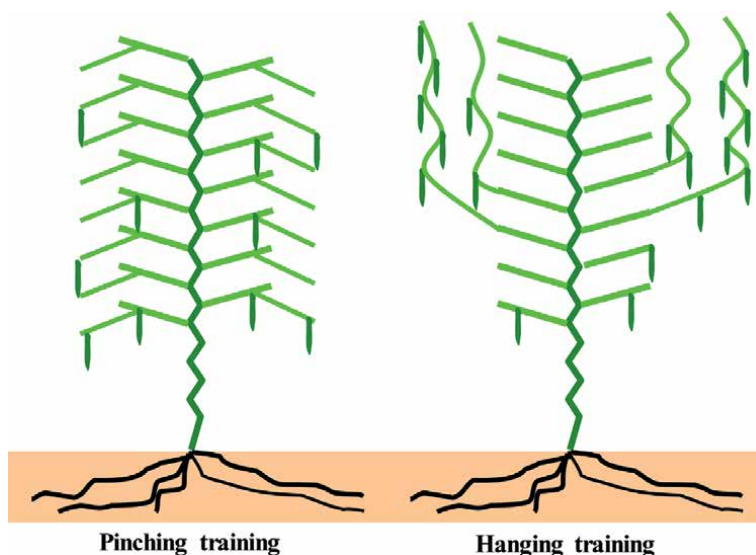


Figure 1.
Schematic diagram of training methods, pinching training, and hanging training.

it is necessary to raise the fruits in the lateral branches, which depends on the stable development of the lateral branches, especially the secondary and the later lateral branches.

Cytokinin is involved in the occurrence and elongation of lateral branches and is closely related to root volume because cytokinin production occurs primarily at the root tip. A higher amount of cytokinin is present in the xylem sap collected from the cut stem, and the more vigorous the growth of lateral branches [10]. Cucumber roots have a high oxygen requirement and most of them are distributed in the soil about 30 cm below the ground surface and more than 1 m in diameter [11]. In contrast, the root zone is extremely narrow in hydroponics compared to soil-cultivated plants, and the number of 3rd and 4th-order lateral branches by hydroponics is usually lower than in plants grown in soil (**Figure 2**).

Generally, cucumber plants cultivated with hydroponics vigorously grow, and the harvesting period starts earlier than those by soil cultivation. However, the yield and quality of cucumbers are reduced in the late harvesting period when cultivated with pinching training [12]. In contrast to the pinching training, there is ‘hanging training’ in which the main branch and some of the primary lateral branches are pinched, leaving a few primary lateral branches that are not pinched, letting them grow to the end of the harvest. And the harvesting from the elongated primary lateral branches increases while that from primary lateral branches decreases (**Figure 1**). The hanging training allows for constant vegetative growth, and plant vigor is easily maintained. Therefore, we compared the cucumber fruit yield of the different trainings between pinching training, in which the main branches are pinched, and lateral branches are renewed sequentially, and hanging training, in which a few primary lateral branches are not pinched and used as harvest branches for long period of time. The cucumber plants were grown in a glasshouse. The cultivation system was constructed using steel pipe, black polyethylene film, and nonwoven fabric in a double hammock system, 30 cm wide and 50 cm high (**Figure 3**). An equivalent mixture (by volume) of peat moss and rice husk charcoal was used as a culture medium. The amount of medium

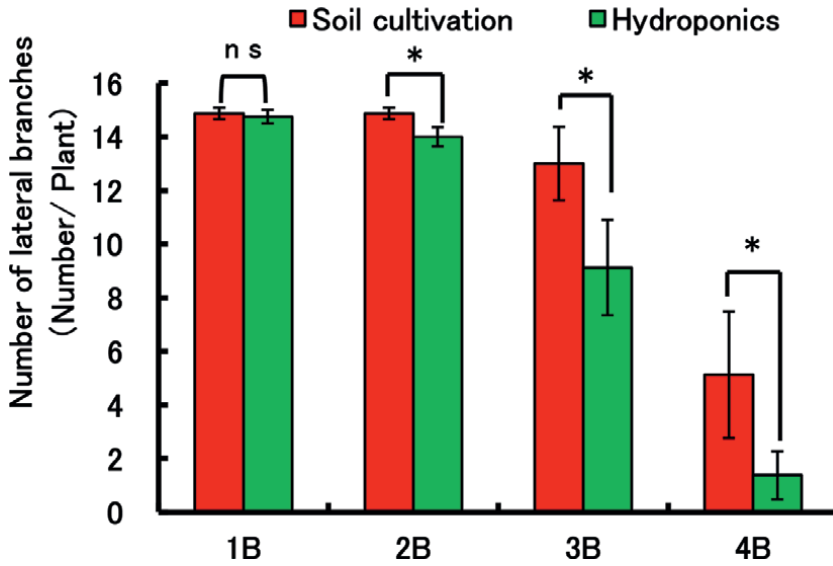


Figure 2. Comparison between soil cultivation and hydroponics on the number of lateral branches of cucumber plants. 1B: primary branches, 2B: secondary branches, 3B: tertiary branches, 4B: Quaternary branches. Bars indicate the standard deviations ($n = 3$). n s: no significant differences at $P < 0.05$ by Student's t -test. *: significant differences at $P < 0.05$ by Student's t -test.

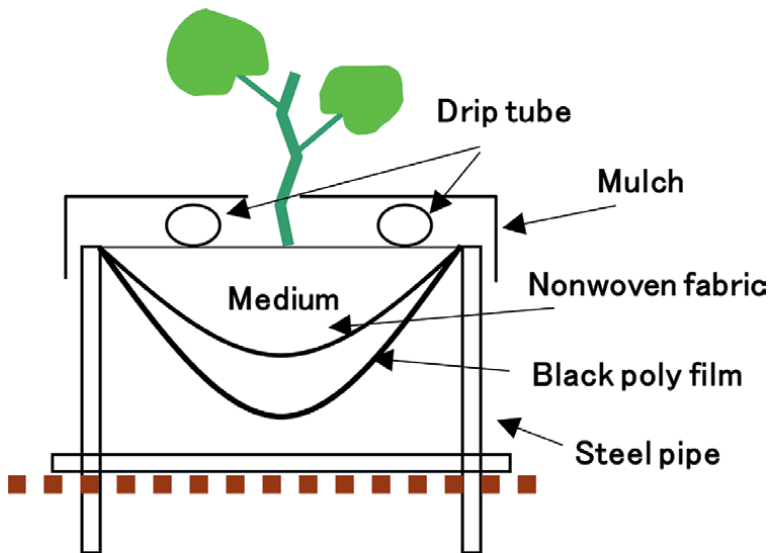


Figure 3. Schematic diagram of cultivation system.

per plant was 8 L. In this experiment, ‘High Green 22’ was used for scion, and ‘Hikari Power Gold’ was used for rootstock. For both pinching and hanging training, the main branch was pinched at 20 nodes, and all female flowers and lateral branches below the 5th node of the main branch were removed.

In the pinching training, the primary lateral branches above the sixth node of the main branch were pinched at node 1, and the secondary and tertiary lateral branches

were pinched so that three growth points always remained (**Figure 1**). When renewing the growing point, cut back to one node. In the hanging training, four of the primary lateral branches that emerged from nodes 7 to 15 were left as hanging branches, and the other primary lateral branches were pinched at node 1 (**Figure 1**). The hanging line was stretched about 2 m above the ground, and the hanging branches were swept to the left and right and clipped together. When the hanging branches had grown about 40 cm, they were taken down, and this lowering of the hanging branches was done at intervals of 5–7 days. The leaves of the nodes where the fruit was harvested were removed sequentially in both branching methods.

The OAT-B formulation was used for the nutrient solution [13], and the nutrient solution was managed using the open system, with an electric conductivity (EC) of 1.4–2.0 dS/m (**Table 1**). The nutrient solution was supplied on the top of the supporting medium using drip tubes. The amount of nutrient solution supplied was 0.5 L/plant, and the times of supply were adjusted according to the plant growth and weather conditions. In the semi-forcing culture, the greenhouses were heated until the end of March, with the heating set at 16°C from 6:00 to 9:00, 18°C from 9:00 to 17:00, 16°C from 17:00 to 21:00, and 12°C from 21:00 to 6:00. In the delayed-start culture, the greenhouses were not heated. Fruits that reached a length of about 20 cm were harvested daily and separated into commercial fruits and non-commercial fruits according to the ‘Niigata Prefecture Fruit and Vegetable Shipping Standards’. Commercial fruits were further classified into A and B categories based on the curvature and shape of the fruit [14].

Compared to the pinching training, the yield of commercial fruits from the hanging training was about 30% higher in the delayed-start culture (planting on August 18 and harvesting from September 21 to November 30) (**Figure 4**) and about 70% higher in the semi-forcing culture (planting on February 15 and harvesting from April 2 to June 30) (**Figure 5**). The appearance quality (percentage of ‘A’ products) was superior in the case of hanging training compared to pinching training.

Although the hanging training required ‘branch lowering’ twice a week, the harvesting operation was easier than the pruning method because the position of the harvested fruit was almost constant.

In soil culture, when the vine is lowered and the branch begins to grow under favorable light and temperature conditions, the branch becomes overgrown and overstretched, resulting in delayed fruit growth and a reduction in the harvest position, which can lead to lower fruit quality [15]. Even in the case of the delayed-start culture, in which the branches are induced during the long day and warm season, the fruit quality by hydroponics was excellent without overgrowth. Because the root zone is restricted, it suppresses the excessive growth of induced branches and maintains a balance between vegetative and reproductive growth [10]. In the case of pinching training, it is difficult to maintain plant vigor, and yields are easily affected by the

EC (dS/m)	T-N (mg/L)	NO ₃ -N	NH ₄ -N	P ₂ O ₅	K ₂ O	CaO	MgO	Mn	B	Fe	Cu	Zn	Mo
2.5	230	20	210	93	377	219	80	1.0	1.0	2.9	0.020	0.040	0.022
2.0	184	16	168	74	302	175	64	0.8	0.8	2.3	0.016	0.032	0.017
1.5	138	12	126	56	226	131	48	0.6	0.6	1.7	0.012	0.024	0.013

Table 1.
 EC and nutrient concentrations in nutrient solution OAT-B (OAT Agrio Co., Ltd.) formulation.

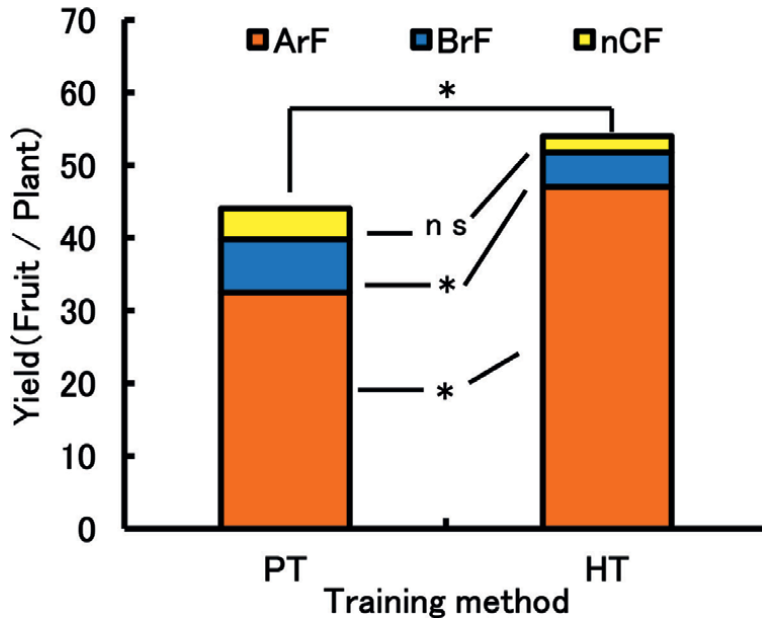


Figure 4. Effects of different training methods on yield and quality of cucumber fruits yield in delayed-start culture. PT: pinching training, HT: hanging training, ArF: A-rank fruits, BrF: B-rank fruits, nCF: non-commodity fruits. ns: no significant differences at $P < 0.05$ by Student's *t*-test. *: significant differences at $P < 0.05$ by Student's *t*-test.

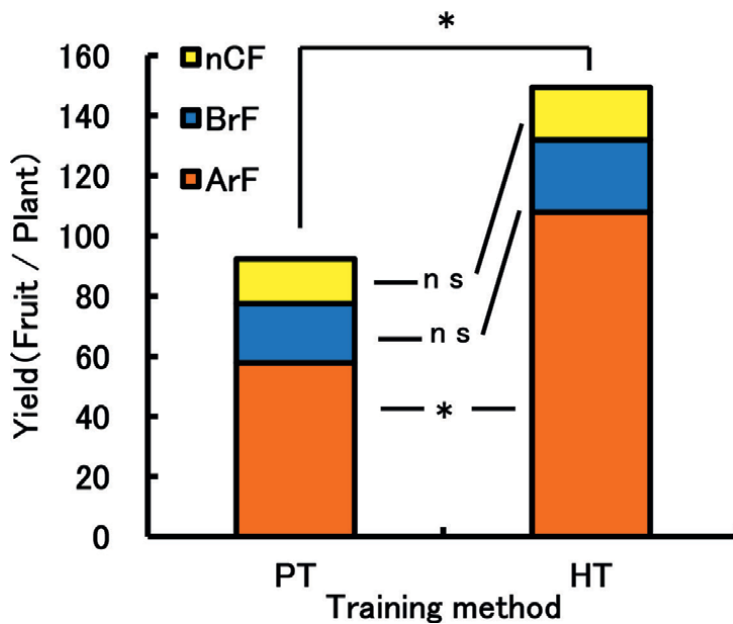


Figure 5. Effects of different training methods on yield and quality of cucumber fruits in semi-forcing culture. PT: pinching training, HT: hanging training, ArF: A-rank fruits, BrF: B-rank fruits, nCF: non-commodity fruits. ns: no significant differences at <0.05 by *t*-test. *: significant differences at <0.05 by *t*-test.

grower's skill level and the weather conditions of the year. The hanging training shows a more stable harvesting pattern throughout the harvesting period, and there is less yield variation among growers and less annual fluctuation than when cultivated by picking [16].

3. Suitable medium for cucumber cultivation

Rockwool is a popular medium for hydroponics, but its introduction cost and disposal at the time of medium renewal remain problems. For this reason, rice husks and rice husk charcoal are generally selected as a medium for the hydroponics cultivation of strawberries and tomatoes in rice-growing regions of Japan. These mediums are low cost and easy to obtain, and the used media can be reused as a soil conditioner although the charcoal production requires labor and imposes smoke problems during the firing of the husks. On the other hand, rice husks have poor water retention properties as a cucumber medium. Various organic, synthetic, and mineral substrates have been experimented with as a medium for cucumber hydroponics, and perlite, organic media, urethane foam, and lignite have been reported to be suitable as rockwool substitutes [17–21]. However, the possibility of long-term continuous cultivation in these media has not been fully investigated. As a new cultivation medium, we focused on woody charcoal chips (chip charcoal) made from thinned trees and driftwood that washes up in hydroelectric dams, which have stable physicochemical properties over long periods of time. The suitable diameter of grains as a medium was investigated in comparison to rockwool and coconut shells in semi-forcing culture, and the usable years were studied in delayed-start culture.

In the experiment, the cucumber cultivar 'All Star Ikki' was used as the rootstock, the cultivar 'High Green 22' was used as the scion for the semi-forcing culture, and the cultivar 'Excellent joint No.2' was used for the scion for the delayed-start culture. The training method was hanging training.

There was a difference in commercial fruit yield depending on the grain size of the chip charcoal, with the grain size of 3–5 mm being about 35% higher than that of 6–12 mm, and higher commercial fruit yield obtained with chip charcoal than with rice husk charcoal (**Figure 6**). There was no difference in commercial fruit yield between the first and tenth repeated cultivation in the same medium (**Figure 7**). And the cucumber fruit yields by chip charcoal were comparable to those by rockwool, and coconut shell mediums (**Figure 8**). Based on the results above, chip charcoal with a grain size of 3–5 mm is superior as a medium for cucumber hydroponics and the medium was durable for at least ten consecutive cucumber cultivations. **Figure 9** shows the photograph of a cucumber seedling planted on chip charcoal medium.

4. Concentration of nutrient solution in open system hydroponics in cucumber cultivation

In Japan, the nutrient solution supply system for hydroponics is mainly an 'open system' in which fresh nutrient solution is supplied several times a day via irrigation tubes on the top of the medium, and the excess nutrient solution is discharged outside the greenhouse. In the open system, the nutrient solution is supplied so that

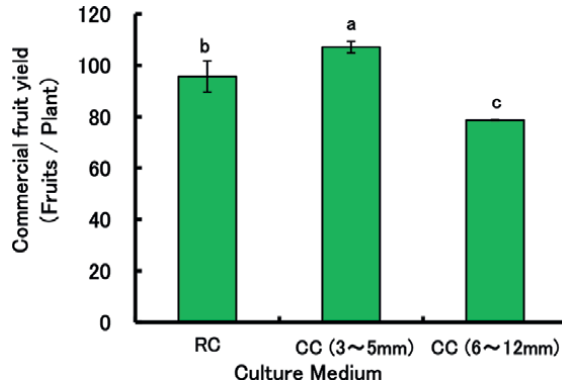


Figure 6. Effect of culture medium materials and chip charcoal grain size on commercial fruit yield of cucumber. RC: rice husk charcoal, CC: chip charcoal. Bars indicate the standard deviations ($n = 3$). Different letters above the column indicate significant differences at $P < 0.05$ by Tukey's test.

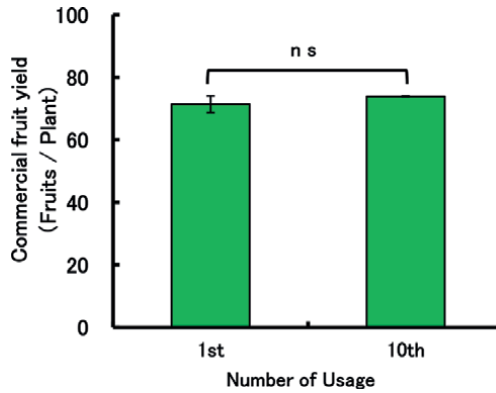


Figure 7. Effect of numbers of medium usage on commercial fruit yield of cucumber. Bars indicate the standard deviations ($n = 3$). ns: no significant difference at $P < 0.05$ by Student's t -test.

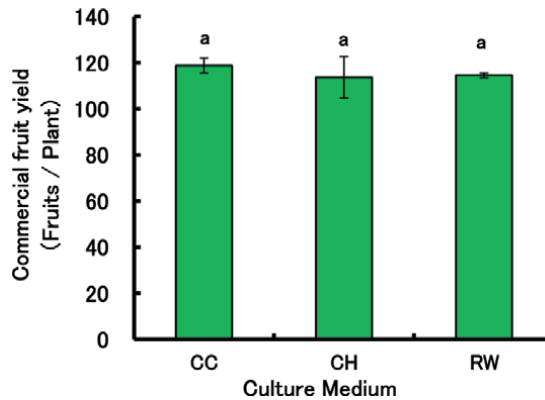


Figure 8. Effect of culture media on commercial fruit yield of cucumber. CC: chip charcoal, CH: coconut husk, RW: rockwool. Bars indicate the standard deviations ($n = 3$). Same letters above the column indicate no significant differences at $P < 0.05$ by Tukey's test.



Figure 9.
Photograph of a cucumber seedling planted on chip charcoal medium.

the drainage rate (drainage volume/supply volume \times 100) is 20–40% according to the amount of water absorbed by the plants so that nutrients with low absorption volumes do not accumulate in the medium. By draining the nutrient solution, the excess nutrients in the medium are discharged, and the growth is maintained by stabilizing the nutrient composition and EC in the medium.

Determining the concentration of the nutrient solution is very important in hydroponics, because the concentration of the nutrient solution has a significant effect on the growth and quality of the plants. The concentration of the nutrient solution is often controlled to be low when the intensity of sunlight is high, and the temperature is high, and the concentration is kept high when the sunlight intensity and temperature are low. Under high temperatures and intense solar radiation conditions, the transpiration rate of plants is greater, and thus water absorption also increases. Under these conditions where water absorption is more active than nutrient absorption, if the concentration of nutrient solution is not lowered, the EC in the medium will increase as the cultivation progresses, and the plants will have difficulty absorbing water because the osmotic potential of the medium is reduced. On the other hand, under low temperatures and low sunlight conditions, the transpiration rate is low and the root activity is reduced, so water absorption is suppressed. Under such conditions, if a concentration of the nutrient solution is low, the plant cannot absorb the required amount of nutrients sufficiently, resulting in a decrease in growth and yield. Thus, the optimal concentration of the nutrient solution depends not only on the plant but also on the stages and the environmental conditions of growth.

In cucumbers, the absorbed nitrogen is preferentially redistributed to the fruit at the beginning of harvest, and subsequently absorbed nitrogen is quickly transferred to the leaves, assimilated by the leaf blade, and translocated to the fruit [22]. Therefore, to increase cucumber fruit yield, it is necessary to supply nitrogen continuously at optimum nitrogen levels after the beginning of harvest. There have been a few reports on the optimal concentration of nutrient solution for cucumber on pinching training with rockwool

medium, but we have not found any reports on hanging training with charcoal medium [5, 6, 23]. Therefore, we studied the effect of nutrient solution concentration on growth and yield of cucumbers using a chip charcoal medium.

In the delayed-start culture, scion 'Zubari 163' and rootstock 'Tokiva Power Z II' were used, and in the semi-forcing culture, scion 'High Green 22' and rootstock 'All Star Ikki' were used. The branching method was hanging training. In the semi-forcing culture, the greenhouses were heated until the end of March, with the heating set at 16°C from 6:00 to 9:00, 18°C from 9:00 to 17:00, 16°C from 17:00 to 21:00, and 12°C from 21:00 to 6:00. In the delayed-start culture, the greenhouses were not heated. The nutrient solution was the OAT-B formulation with Mg reduced by 30%. The EC of the nutrient solution was 1.5 dS/m, 2.0 dS/m, and 2.5 dS/m for the semi-forcing culture, and 1.5 dS/m from planting to September 1, and 1.5 dS/m, 2.0 dS/m, and 2.5 dS/m after September 2 for the delayed-start culture. In the semi-forcing culture, the nutrient solution concentration was lowered gradually to 1.5 dS/m (2.5 dS/m to 2.0 dS/m to 1.5 dS/m) when the drainage EC exceeded the feed EC. The amount of nutrient solution supplied was 0.5 L/plant at each supply, and the frequency of supply was adjusted to keep the drainage rate between 20 and 40%, depending on the amount of growth and weather conditions. Drainage solutions were collected every 7–10 days, and drainage volume, EC, and nutrient concentrations were analyzed.

In the delayed-start culture, with rockwool medium, the EC of the nutrient solution corresponds to the balance of water and nutrients absorbed by cucumbers when the EC is 1.5–2.0 dS/m. Therefore, the EC of the nutrient solution supplied and the EC of the medium can be controlled to the same degree, and the fluctuation of the EC of the medium is small [23]. The concentration of the culture nutrient solution does not need to be changed between planting and the end of harvest, and high yields can be obtained by controlling the nutrient solution concentration in the range of 1.5–2.0 dS/m. Increasing the nutrient solution concentration during growth will stress the roots and reduce yields [5, 6]. Even in the chip charcoal medium, by controlling the nutrient solution concentration at 1.5 dS/m until the beginning of harvest and 2.0 dS/m thereafter, the discharged EC (EC in the culture medium) (Figure 10)

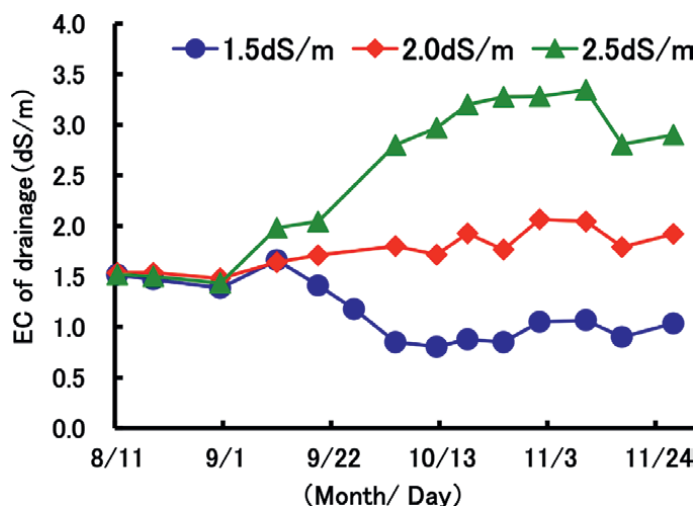


Figure 10. Changes in EC of drainage in delayed-start culture of cucumber plants.

and $\text{NO}_3\text{-N}$ concentration showed little difference from the supplied EC and $\text{NO}_3\text{-N}$ concentration (Figure 11). On the other hand, when the nutrient solution concentration was kept at 1.5 dS/m until the end of harvest, the discharged EC was lower than the supplied EC after late October, but the yield was highest (Figure 12). It is assumed that in the chip charcoal medium, as in the rockwool medium, the roots were stressed

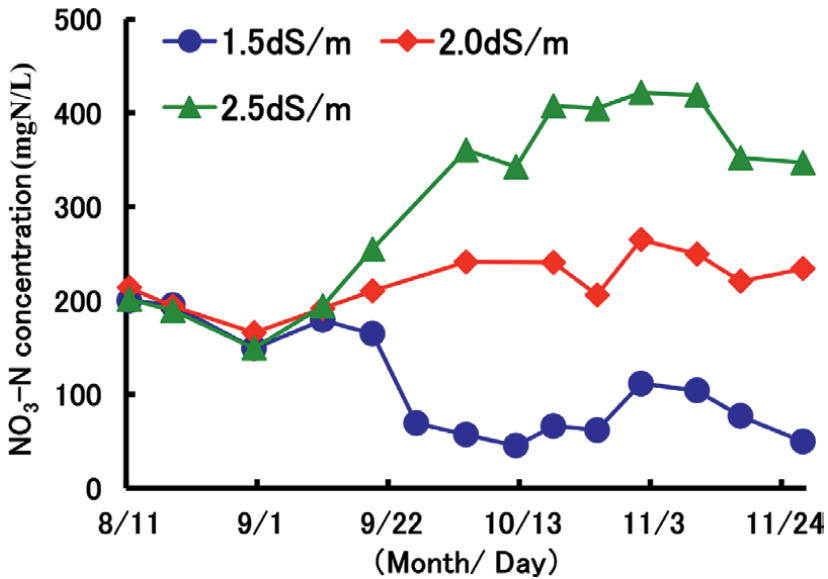


Figure 11. Changes in $\text{NO}_3\text{-N}$ concentration of drainage in delayed-start culture.

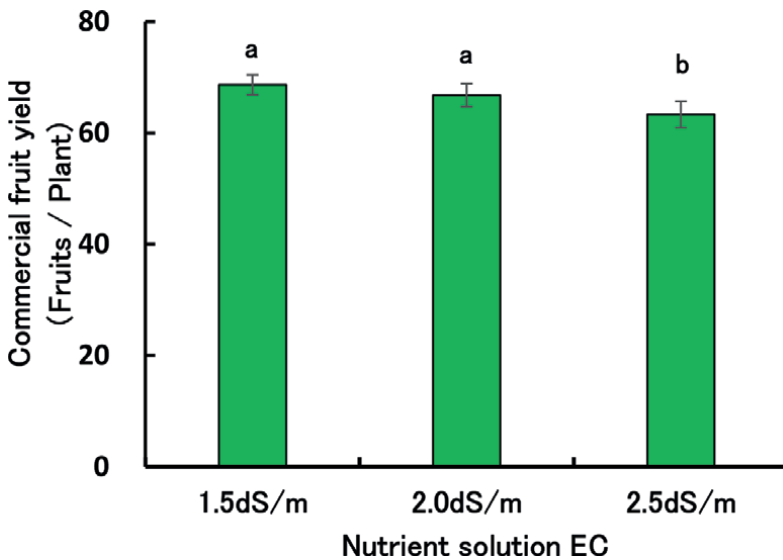


Figure 12. Effect of concentration of nutrient solution on commercial fruit yield of cucumber in delayed-start culture. Bars indicate the standard deviations ($n = 3$). Different letters above the column indicate significant differences at $P < 0.05$ by Tukey's test.

by increasing the concentration of the nutrient solution during growth, resulting in lower yields. Therefore, the nutrient solution concentration in the delayed-start culture should be 1.5 dS/m EC from planting to the end of harvest, and if harvest is completed in November, there is no need to increase the nutrient solution concentration during the low-temperature period.

In the semi-forcing culture with pinching training, lateral branch occurrence is significantly inferior at a nutrient solution concentration of 1 dS/m or less after planting, and the highest yield is obtained at a post-planting concentration of about 2 dS/m. The concentration must be reduced to 1.5 dS/m in the latter half of growth due to the increase in discharged EC (EC in the culture medium) [5, 6]. Examination of nutrient solution concentration in hanging training indicated no difference in yield in the concentration range of 1.5–2.5 dS/m (**Figure 13**). However, at 1.5 dS/m, by late March, when harvesting began, the discharge EC was decreased to 0.5 dS/m, about 1/3 of the supplied EC (**Figure 14**), and the NO₃-N concentration also decreased significantly (**Figure 15**). Insufficient absorption of nutrients and water necessary for fruit development leads to an imbalance between vegetative and reproductive growth, resulting in aborted fruits and curved fruit and a decrease in fruit yield and quality [24]. Although there were no differences in yield or quality in this study, there is a possibility that under some weather conditions, nutrient absorption may be insufficient to decrease yield and quality. Therefore, the nutrient solution concentration should be 2.0 dS/m after planting and 1.5 dS/m after late April, when the discharged EC tends to increase.

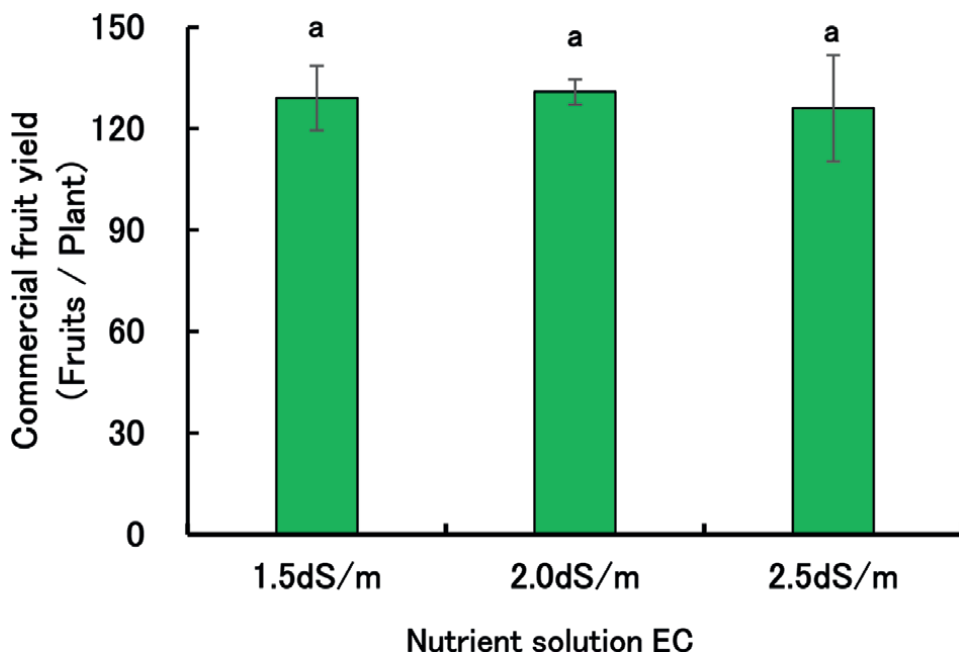


Figure 13. Effect of concentration of nutrient solution on commercial fruit yield in semi-forcing culture. Bars indicate the standard deviations ($n = 3$). Same letters above the column indicate no significant differences at $P < 0.05$ by Tukey's test.

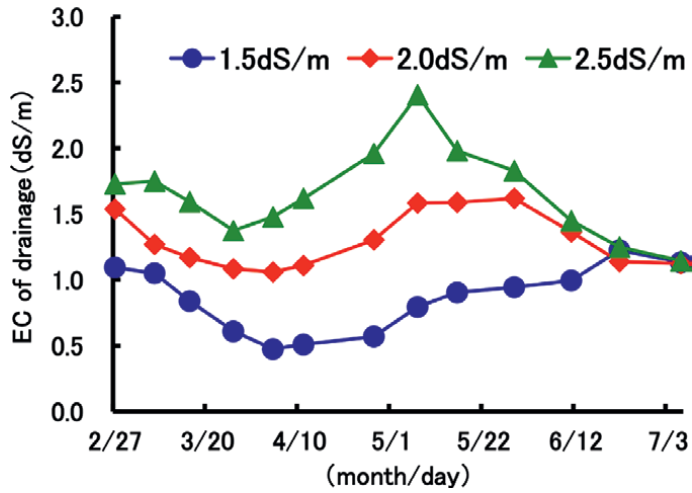


Figure 14.
 Changes in EC of drainage in semi-forcing culture of cucumber plants.

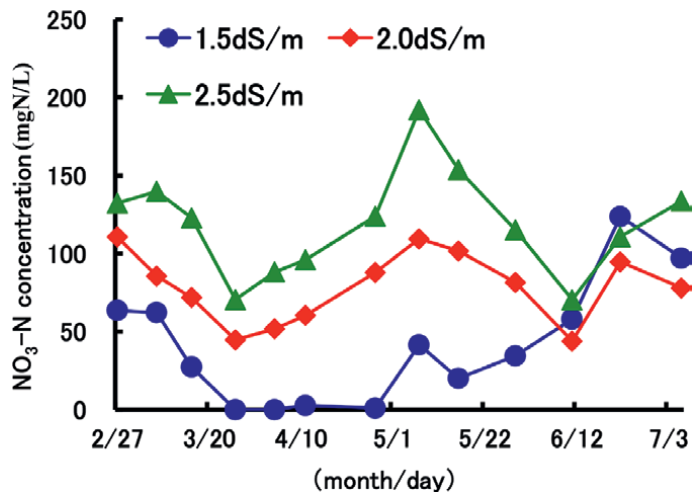


Figure 15.
 Changes in NO₃-N concentration of drainage in semi-forcing culture of cucumber plants.

5. Amount of nutrients supplied in circulating nutrient solution management

As mentioned above, most of the hydroponics systems in Japan use an ‘open system’ in which excess culture medium still containing some fertilizer nutrients is discharged outside the greenhouse. So, the open system requires more water and fertilizer than the plants absorb. In addition, nitrate and phosphate ions are contained in the discharged solution, which are the factors contributing to the eutrophication of groundwater and rivers. Therefore, it is desired to establish environmentally friendly circulating hydroponics that reuse discharged solutions without dumping them.

Closed hydroponics systems in solid media have been developed as recirculating systems in which the collected discharged solution is sterilized with ozone, adjusted, and reused [25], and non-circulating systems in which the culture medium is stored in a cultivation tank and reused [26–28], and non-circulating systems with a capillary feed [29]. In the concentration control method, the nutrient and water absorption rate changes depending on weather conditions even at the same concentration of nutrient solution, and the imbalance between vegetative growth and reproductive growth due to excess or deficiency of nutrients can cause a decrease in yield and quality [30]. For this reason, a quantity control method has been adapted for a closed hydroponics system, in which the amount of nutrients required by the plants is supplied, rather than controlled by the concentration of the nutrient solution [31, 32]. Quantity control methods supply the necessary amount of inorganic nutrients to plants at each growth stage on a regularly scheduled weekly or daily basis. In tomatoes, a certain amount of inorganic nutrients is applied daily or weekly to prevent overgrowth, maintain yield, simplify nutrient solution management, and reduce fertilizer amounts compared to the concentration control method [33]. Similarly, in cucumbers, it is important to maintain compact leaves and good light-receiving conditions to keep a balance between vegetative and reproductive growth and to ensure efficient translocation of photosynthetic products to the fruit. Therefore, the quantitative management method is an effective method of nutrient solution management in cucumber cultivation by closed hydroponics systems. In this section, we examined the amounts of nutrients supplied in the quantity control method of circulating nutrient solution management.

The open system was compared as a control. In the circulation method, a tank was set up and the nutrient solution was supplied on the top of the medium using drip tubes. The excess nutrient solution that could not be retained by the medium was returned to the tank, and tap water was added to cover the loss due to absorption by the plants (**Figure 16**). In the circulating system, the nutrient solution in the tanks

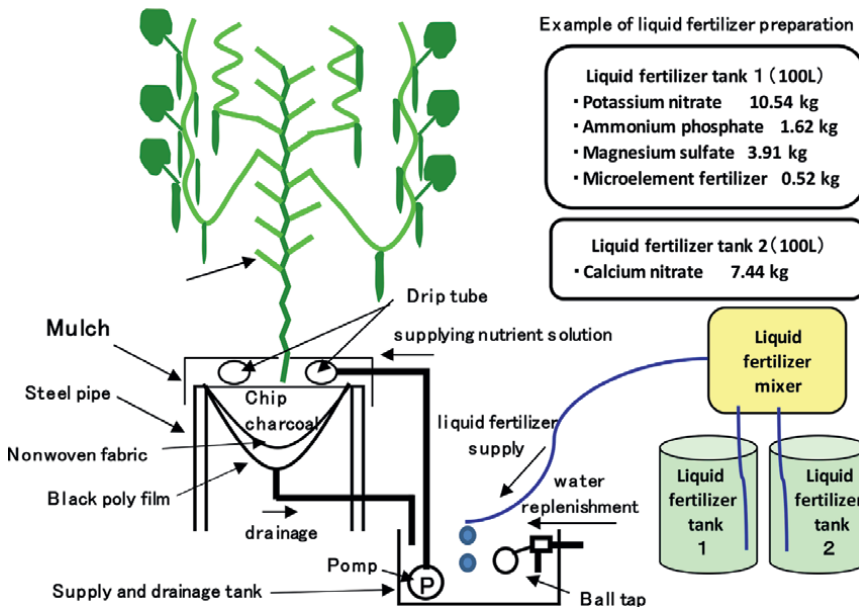


Figure 16. Schematic diagram of circulating cultivation system and branching method for cucumber plants.

was not disinfected and was not exchanged until the end of the harvest. The amount of nutrient solution supplied was 0.5 L/plant at each supply, and the frequency of supply was adjusted to keep the drainage rate between 20 and 40%, depending on the amount of growth and weather conditions. The amount of nutrient solution supplied in the circulating system was 0.5 L per plant every 45–60 min between 5:00 and 21:00.

In the delayed-start culture (planting on August 8 and harvesting from September 5 to November 30), the period from planting to early harvest (September 10) was the first period and the period after September 11 was the second period, and six test plots were established combining two treatments of nitrogen (N) supply (mg/day/plant) in the first period (low quantity: 115, high quantity: 172.5) and three levels in the second period (low quantity: 172.5, medium quantity: 215.6, high quantity: 258.8).

In the semi-forcing culture (planting on February 14 and harvesting from April 10 to July 24), the period from planting to the start of fruit harvesting (April 23) was the first period, and the period after April 24 was the second period, control and low (first period:140.4, second period: 322.0), medium (first period:172.5, second period: 402.5), and high (first period:207.0, second period: 483.0) quantity plots with different N supply (mg/day/plant). The concentration of nutrient solution in the control was determined as 1.5 dS/m. The OAT-B formulation (**Table 1**) was used for the nutrient solution, and in the circulation method, the concentrated nutrient solution was added to the tanks every two to three days in amounts according to each test plot. The amount of nitrogen applied in the circulating system was adjusted by the concentrated nutrient solution, so nutrients other than nitrogen were also increased proportionally. 'All Star Ikki' was used as the rootstock cultivar, 'High Green 22' was used as the scion cultivar for the semi-forcing culture, and 'Excellent joint No.2' was used for the delayed-start culture. The training method was hanging training. N concentrations were measured by sampling the nutrient solution in the wastewater and circulation tanks every 3–4 days, and N absorption was calculated.

The yield of the delayed-start culture was not affected by the amount of nutrients supplied in the first period and was similar to the control in the second period medium and large quantity plots, while it was inferior in the second period small quantity plot compared to the control (**Figure 17**). The yield of A-grade fruits was higher in the high quantity in the first period compared to the low quantity in the first period (**Figure 17**). Commercial fruit yields of the semi-forcing culture were similar in the medium-quantity and high quantity to the control (**Figure 18**). In the control, about 38% of the supplied nutrient solution was discharged unabsorbed by the cucumbers in both the semi-forcing culture and the delayed-start culture. Compared to the open system, the circulation method with quantity control obtained the same commercial fruit yield with about 50% of the nutrient supply in the delayed-start culture and about 75% in the semi-forcing culture. In such cases, N absorption was 70% of that of the control in the delayed-start culture and 77% in the semi-forcing culture.

This suggests that a circulation system based on quantity control can reduce unnecessary absorption of nutrients that do not lead to fruit production and can manage the nutrient solution with high nutrient utilization efficiency. Although the initial cost of circulating nutrient solution management is a little higher than the open system due to the need to underground the tanks, it is expected that the introduction cost can be recovered in a short period of time due to the reduction of fertilizer application cost.

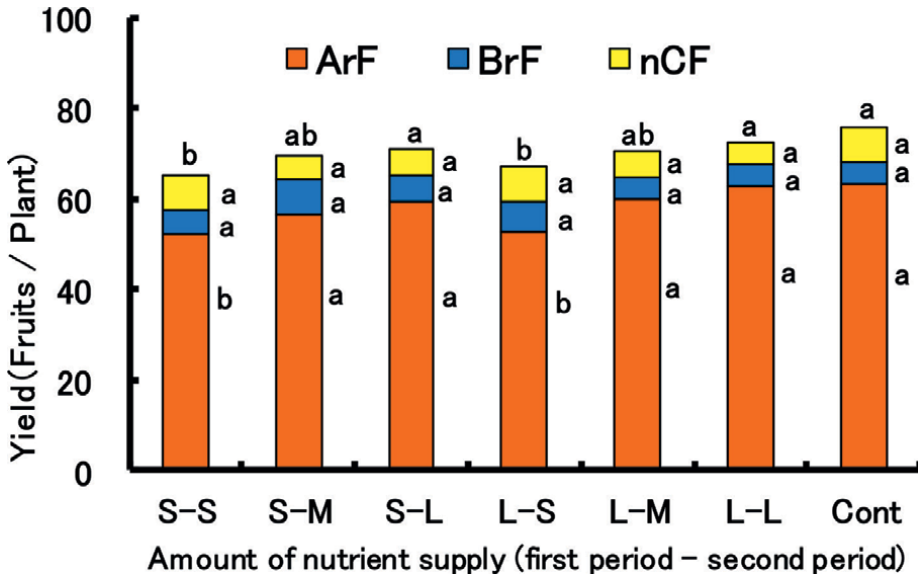


Figure 17. Effect of the amount of nutrient supply on the yield in delayed-start culture of cucumber plants. ArF: A-rank fruit, BrF: B-rank fruit, nCF: non-commodity fruit. S: small quantity, M: Medium quantity, L: large quantity. Different letters above the column indicate significant differences at $P < 0.05$ by Tukey's test.

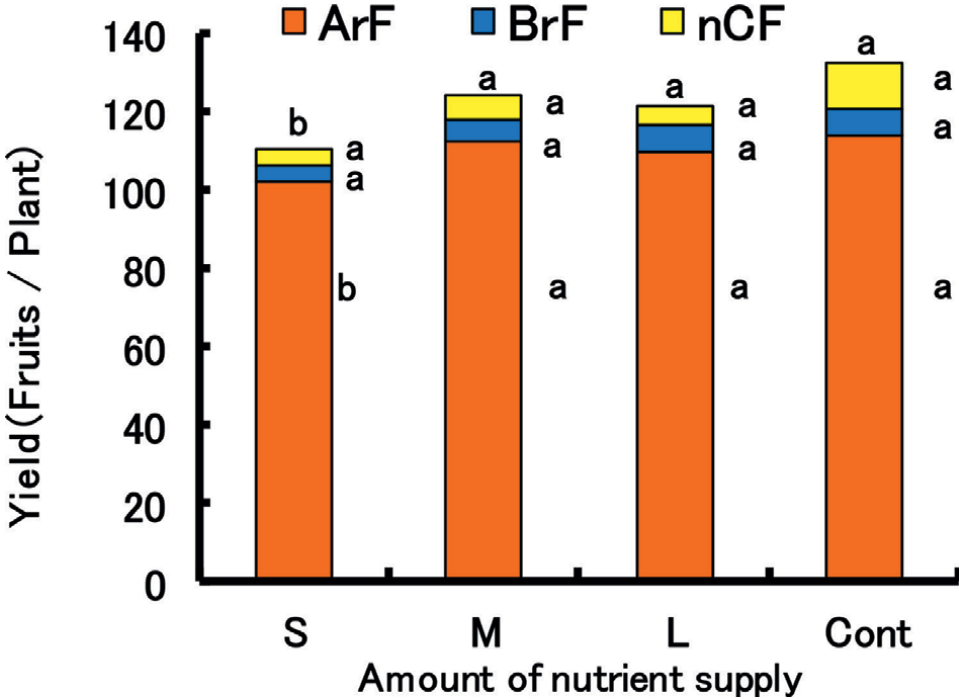


Figure 18. Effect of the amount of nutrient supply on the yield in semi-forcing culture. ArF: A-rank fruit, BrF: B-rank fruit, nCF: non-commodity fruit. S: small quantity, M: medium quantity, L: large quantity. Different letters above the column indicate significant differences at $P < 0.05$ by Tukey's test.

6. K/Ca ratio of nutrient solution in circulating nutrient solution management

If the nutrient absorption characteristics of the plant and the formation of the nutrient solution do not match, specific nutrients will accumulate in the medium and affect the growth of the plant. Cucumbers absorb a lot of potassium, and increasing the potassium concentration in the nutrient solution increases yield [34, 35]. In addition, when the nutrient solution used for tomatoes and strawberries is used in circulating nutrient management for cucumbers, the concentration of calcium was higher than that of potassium in the nutrient solution [36]. Potassium chloride and potassium sulfate are used for potassium fertilizer in soil cultivation, while potassium nitrate is often used for potassium in nutrient solutions to prevent the accumulation of chlorine and sulfur in the medium. Calcium nitrate is used as the calcium in the nutrient solution. So, the K/Ca ratio can be increased without affecting the other components by increasing the potassium nitrate and decreasing the calcium nitrate in the nutrient solution. Therefore, we studied the formation of a suitable nutrient solution for circulating nutrient solution management in cucumbers. ‘All Star Ikki’ was used as the rootstock cultivar, ‘High Green 22’ was used as the scion cultivar, planted on February 8, and harvested until July 25. Three study plots were established with K/Ca ratios (me ratio) of 1.3 (K 9.2 me, Ca 7.3 me), 1.7 (K 10.4 me, Ca 6.1 me), and 2.4 (K 11.7 me, Ca 4.9 me) in the nutrient solution. In all three study plots, micronutrient was in accordance with OAT-B formulation, with N 171 me, P 4.1 me, Mg 3.1 me (Table 1). Nutrients were managed by quantity control, supplying a culture equivalent to 75–160 mg/plant/day of N from planting to April 1 and 420 mg/plant/day from April 2 onward.

The result indicated that physiological damage, probably caused by Ca deficiency, occurred on leaves from the middle of June at a K/Ca ratio of 2.4. Harvesting started on March 23–24, and there were no differences by culture medium composition, with higher K/Ca ratios resulting in higher commercial fruit yields (Figure 19). Based on

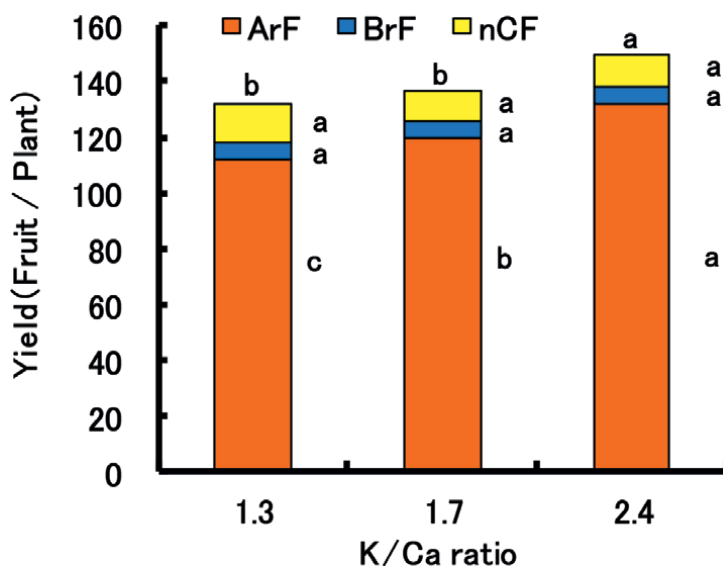


Figure 19. Effect of K/Ca ratio on the cucumber fruits yield. ArF: A-rank fruits, BrF: B-rank fruits, nCF: non-commodity fruits. Different letters above the column indicate significant differences at $P < 0.05$ by Tukey's test.

the above, a nutrient solution K/Ca ratio of about 1.7 is suitable for obtaining high yields without causing physiological disorders in cucumber cycle-type nutrient solution cultivation.

7. Comparison between soil culture and hydroponics in cucumber cultivation

In the same greenhouse, ‘All Star Ikki’ was used as a rootstock, ‘Fresco Dash’ as a scion for semi-forcing culture (planted on February 8 and harvested on July 9), and ‘Cho Saiki’ for suppressed production (planted on August 3 and harvested on December 20), and soil culture and hydroponics were compared. The training method was ‘pinching’ in soil culture and ‘hanging’ in hydroponics. Chip charcoal was used as the medium, and nutrient solution management was a recirculating quantity control, adding nutrients equivalent to 144–403 mg/plant/day of N in the semi-forcing culture and 65–260 mg/plant/day in the delayed-start culture.

Commercial fruit yield was 81.0 fruits/plant in semi-forcing culture, 43.3 fruits/plant in delayed-start culture in soil culture, 147 fruits/plant in semi-forcing culture, and 55.4 fruits/plant in delayed-start culture in hydroponics, which was about 80% higher in semi-forcing culture, about 30% higher in delayed-start culture, and about 60% higher annually compared to soil cultivation (Figure 20). The soil culture resulted in a drop in yield in the later stages of cultivation, while high yields were maintained until the late stages of cultivation in hydroponics. Compared to soil culture, the time spent after planting in hydroponics was about 20% more for training and about 10% more for total work, but the time spent per commercial fruit was about 30% less than in soil culture (Figure 21).

The above results show that hydroponics in cucumber (Figure 22) not only significantly increased fruit yields compared to soil culture but also reduced labor time.

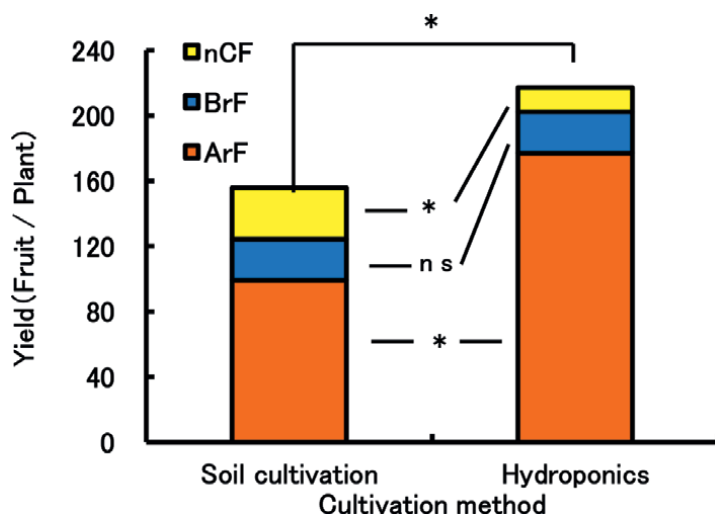


Figure 20.

Comparison of cultivation methods, soil cultivation, and hydroponics on cucumber fruits yield and quality. Total yield of semi-forcing culture and delayed-start culture. ArF: A-rank fruits, BrF: B-rank fruits, nCF: non-commodity fruits. n s: no significant differences at $P < 0.05$ by Student's *t*-test. *: significant differences at $P < 0.05$ by Student's *t*-test.

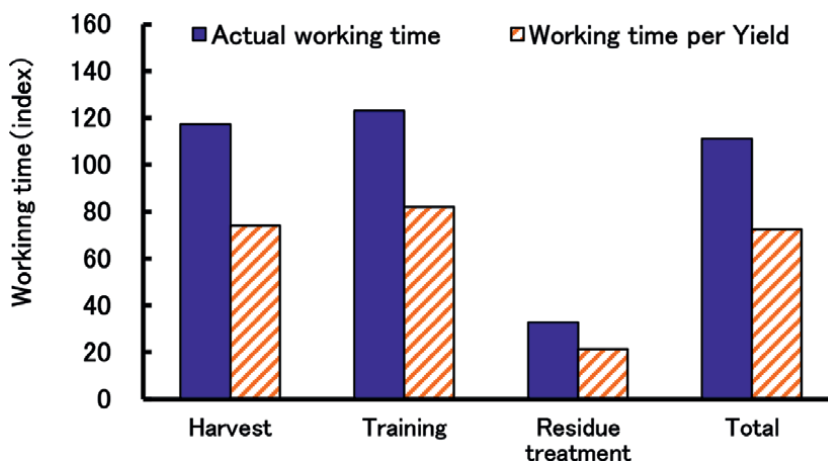


Figure 21. Comparison of working time in hydroponic cultivation with soil cultivation. Total of semi-forcing culture and delayed-start culture. Index value with soil cultivation as 100.



Figure 22. Photograph of hydroponic cultivation of cucumber plants.

Because cultivation management and nutrient and moisture management can be manualized with hydroponics, it is possible to expand the scale of cucumber cultivation using hired labor, and it is possible to shift Japanese cucumber cultivation from being primarily a family business to a corporate business.

8. Conclusions

Compared to soil cultivation, cucumber hydroponic cultivation has an extremely narrow root zone, and the number of 3rd and 4th order lateral branches is clearly lower. In cucumber hydroponics, although more labor is required to lower branches,

hanging training is the most suitable branching method because of its superior yield and quality. Chipped woody charcoal (chip charcoal), made from thinned wood and driftwood washed downstream from hydroelectric dams, was suitable as a medium for cucumber hydroponics, and could be grown continuously for more than 10 consecutive cultivation cycles. In the open system, the nutrient solution concentration should be 1.5 dS/m from planting to the end of harvest in the suppression type, and 2.0 dS/m after planting and 1.5 dS/m when the effluent EC tends to increase in the semi-accelerated type. A new circulation hydroponic system was developed, in which nutrient solution in a storage tank dripped into the culture medium from a tank and the wastewater discharged from the medium was recycled in the storage tank. The nutrient solution did not change through the cultivation period, and the total amounts of nutrients were reduced by about 50 to 75% compared to open system. A nutrient solution K/Ca ratio of about 1.7 is suitable to obtain high yields without causing physiological disorders in cucumber cycle-type nutrient solution cultivation. Compared to soil cultivation, the hydroponic cultivation resulted in 60% higher yields and 30% shorter post-planting labor hours per commercial fruit yield.

Conflict of interest

The authors declare no conflict of interest.

Author details

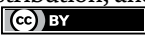
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