Chronicle of Bioresource Management 2025, 9(4): 147-152

Chronicle of Bioresource Management
An International E-magazine

December, 2025 *Popular Article*

Concept and Role of Plant Ideotypes in Sustainable Agriculture

M. Ramesh Naik[1*], V. Alekhya[2], L. Vidyavathi[2], R. Ravi Teja[1], A. V. Ramanjaneyulu[3] and D. Vijaya Lakshmi[3]

Abstract

Sustainable agriculture is vital for global food security amid climate change, pandemics, and geopolitical challenges. The ideotype concept, introduced by Donald (1968), promotes breeding of crop varieties that are high-yielding, resource-efficient, and resilient. An ideotype refers to a model plant with specific traits suited to a particular environment or farming system. Over time, this concept has expanded to include ideotypes tailored to isolation, stress, market, climate, competition, and edaphic conditions. Ideal ideotypes exhibit traits like high photosynthetic efficiency, optimal architecture, synchronized maturity, and tolerance to biotic and abiotic stresses. Their development involves a blend of conventional breeding and modern tools such as marker-assisted selection, genetic engineering, functional genomics, crop modeling, and high-throughput phenotyping. Ideotype-based breeding enhances yield stability, reduces input use, and minimizes environmental impact. While challenges remain, ideotypes offer a strategic path toward resilient and sustainable agricultural systems for future food security.

Open Access

Corresponding Author

M. Ramesh Naik

e-mail: ramesh.naik@naarm.org.in

Citation: Naik et al., 2025. Concept and Role of Plant Ideotypes in Sustainable Agriculture. Chronicle of Bioresource Management 9(4), 147-152.

Data Availability Statement: Legal restrictions are imposed on the public sharing of raw data. However, authors have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

Conflict of interests: The authors have declared that no conflict of interest exists.

Keywords:

Climate resilience, crop breeding, genetic engineering, plant ideotypes, sustainable agriculture

Article History

Article ID: CBM6780

Received on 24th October 2025

Received in revised form on 20th November 2025

Accepted in final form on 03rd November 2025

1. Introduction

Sustainable production and food security is considered to be major concern for a humankind in this current era. The negative impacts of climate change, effect of pandemic and wars among states, which have pushed food production instable. To address these challenges there is a need to shift our goal from green revolution to evergreen revolution. For achieving this, implementation of sustainable farming systems is necessary. Here comes the concept of ideotype which was given by Donald (1968) plays a powerful role in increasing agricultural production not at the cost of harming environment. In sustainable agriculture, approach of crop ideotype is helpful to improve yield stability, efficient use of resources and reduced environmental impact. A crop ideotype refers to an idealized plant model that integrates key morphological and physiological characteristics, specifically designed to optimize yield and quality in a particular environment (Donald, 1968). The

Author's Address

[1]ICAR-National Academy of Agricultural Research Management, Rajendranagar, Hyderabad, Telangana, India

[2]IARI Mega University Hyderabad Hub, ICAR-CRIDA, Hyderabad, Telangana, India

[3]Professor Jayashankar Telangana Agricultural University, Rajendranagar, Hyderabad, India

Journal Home: *https://ojs.pphouse.org/index.php/CBM*

success of ideotype results with the integration of both agronomic management and breeding. It facilitates crops to environmentally adapted, resource-efficient, and high-performing crops. Its integration into sustainable agriculture supports the triple bottom line: ecological health, economic viability, and social equity.

2. Theoretical Framework of Plant Ideotype

Theoretical framework of plant ideotype refers to the conceptual model or set of principles that guides the design and development of ideal plant types for specific agricultural objectives and it act as a blueprint that helps plant breeders define what traits an ideal plant should have in order to achieve high productivity, Sustainability and resilience in a specific agroecosystem. Some of the key elements of the theoretical framework of plant ideotype was discussed below Table 1.

3. Major Types of Plant Ideotypes

❖ ***Isolation ideotype:*** When a cultivar is established, it is the biological model that is anticipated to provide a larger amount or quality of grain, oil, or other useful product. When the plants are space-planted, this particular plant variety works at its best. For instance, loose unrestricted tillering in cereals.

❖ ***Competition ideotype:*** In genetically diverse populations, the ideotype concept is particularly effective. For cereals, this ideotype typically features a tall, leafy, and freely tillering structure capable of shading less competitive neighbors. In annual seed crops, desirable traits include annual growth habit, plant height, a dense leafy canopy, prolific tillering or branching, seed size, rapid germination, and root architecture all of which vary among genotypes (Rahangdale et al., 2023).

❖ ***Crop ideotype:*** Due to the fact that individual plants in this ideotype are weak competitors, this ideotype operates best at commercial crop densities. A crop ideotype for cereal is an upright plant with short, erect leaves that is sparsely tilled.

Table 1: Key traits of an ideal plant and their importance in maximizing yield and sustainability

Traits of an ideal plant	Importance	Examples
Morphological traits	It refers to the physical structure of plant and this design directly influence the plant's ability to utilize resources efficiently and maximize yield	Erect leaves – optimise light interception Short strong stem – Lodging resistance Deep root system – Better nutrient and water uptake
Physiological traits	These traits govern how the plant functions internally, impacting growth, yield, and stress adaptation.	Increased photosynthetic productivity, maximised spike fertility, and lodging resistance
Environmental adaptation	To develop resilience against droughts, high temperatures and increased levels of carbon dioxide.	Drought resistance, salinity tolerant and thermo-insensitive varieties
Economic and Agronomic factors	These factors to be considered for utilization of inputs efficiently and economically.	Disease resistance, Early maturity and Uniform growth
Sustainability	The ultimate goal of agriculture is to increase productivity for present and future generations without deterioration of environmental health.	High nutrient use efficient, Hight water use efficient

❖ ***Market ideotype:*** These ideotypes are specifically developed to align with market demands and consumer preferences, incorporating traits such as seed color, seed size, and qualities relevant to cooking and baking.

❖ ***Climate ideotype:*** Climate change affects both grain quality and yield. In this context, an ideotype for climate resilience is defined as a combination of genetic traits that enables a crop to adapt effectively to climate variability and extreme weather events within a specific environment and cropping system. Key characteristics of such ideotypes include heat and cold tolerance, drought resistance, and an appropriate maturity duration for the evolving climate conditions.

❖ ***Stress ideotype:*** Stress refers to any condition that adversely affects crop growth and leads to reduced yields, encompassing both biotic (e.g., pests, diseases) and abiotic (e.g., drought, salinity) factors. Stress-resilient ideotypes are specifically developed to withstand these challenges, exhibiting resistance and resilience to a wide range of biotic and abiotic stressors.

❖ *Edaphic ideotype:* Edaphic relates to soil, impacted by soil-specific factors as opposed to climatic influences. These ideotypes are created to address edaphic factors. It involves tolerance for salt, mineral toxicity and deficiency, among other things.

4. Key Traits of an Ideal Ideotype

The traits of an ideotype are specific and it depends on several factors like plant type, agroclimatic region etc., Some of the features of crop ideotypes (Figure 1) were discussed briefly.

❖ *High photosynthetic efficiency:* An ideotype with erect, dark green leaves and an optimal leaf area index (LAI) features a well-organized canopy structure that remains photosynthetically active for a longer period after flowering. This enhances sunlight interception, leading to greater dry matter accumulation. Such traits play a crucial role in supporting grain formation, resulting in a higher number of fertile grains per ear head. Erect leaves, in particular, increase the effective leaf surface area, maximizing light capture and carbon assimilation.

❖ *Efficient nutrient uptake and use:* Deep and extensive network of root system have the ability to extract nutrients and water from the soil effectively. This contributes to depend less on fertilizers and increases nutrient efficiency. Advancements in identifying specific root traits that improve nutrient uptake have significantly influenced the breeding of bean and soybean genotypes with enhanced growth performance in phosphorus-deficient soils (Lynch, 2007).

❖ *Water use efficiency (WUE):* The traits responsible to increase water use efficiency are deep rooting system, stomatal regulation and osmotic adjustment helps to maintain productivity under limited water supply. Therefore Water use efficiency of crop ideotype improves.

❖ *Resistance to biotic and abiotic stresses:* Yield reduction due to infestation of pests and diseases is a major problem in agriculture. In addition to this, impacts of climate change increases the occurrence of heat and drought stress which affects the yields. Disease and pest resistance genes, drought tolerant ideotypes maintains stability of yield under variable weather conditions. Under drought stress conditions, "water spender" genotypes characterized by a strategic combination of root and shoot traits have demonstrated superior performance (Polania et al., 2017).

❖ *Optimal plant architecture:* Dwarf varieties typically exhibit a compact growth habit with strong, stiff stems, which provide significant resistance to lodging. In contrast, taller varieties are more prone to lodging under heavy fertilizer applications, leading to a substantial decrease in yield. By incorporating dwarfing genes into ideotypes, these plants maintain high responsiveness to fertilizer applications while preventing lodging, thus improving resource allocation and enhancing yield potential.

❖ *Short and synchronized maturity:* The growth and development of ideotypes follow a rhythmic pattern, characterized by high germination rates, the simultaneous formation of all tillers, and synchronized maturity across these tillers. As a result, the grains on different ears of the plant mature at the same time, resulting in a high degree of synchronization. This synchronization facilitates mechanized harvesting and makes the ideotype well-suited for integration into multiple cropping systems.

❖ *High harvest index:* Ideotypes possess a greater capacity to absorb and assimilate nutrients from the soil throughout their growth cycle. Combined with enhanced photosynthetic activity, this enables higher dry matter production. The efficient plant mechanisms in ideotypes, along with reduced respiration by non-reproductive organs at the flowering stage, optimize respiration for growth and grain production. After flowering, this results in the effective translocation of stored nutrients from the straw to the grains. As a result, the efficient movement of assimilates to the reproductive organs increases the ratio of economic yield to biological yield.

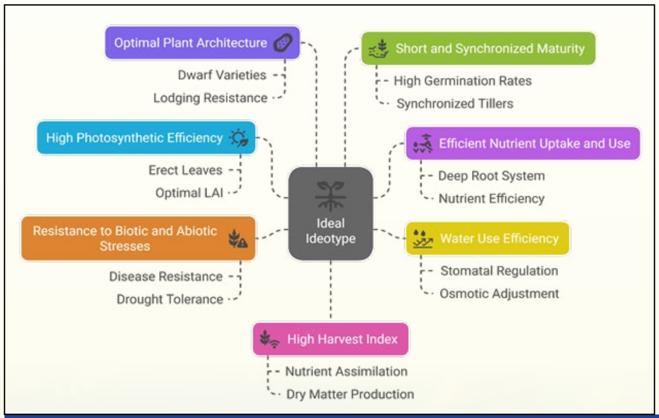

Figure 1: Key traits of an ideal ideotype

Example of wheat ideotype (Figure 2)

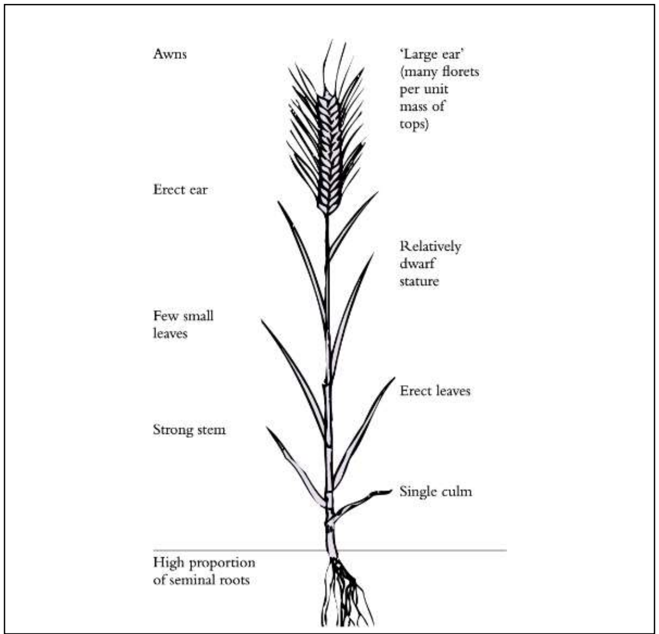

Figure 2: Wheat Ideotype

The first wheat ideotype was proposed by Donald (1968) and is characterized by the following key features:

1. A short, strong stem to prevent lodging.
2. Few, small, erect leaves that allow sunlight to penetrate the canopy.
3. A large, erect ear for better grain formation.
4. A higher number of fertile florets per unit area, leading to an increased harvest index.
5. The presence of awns, which expand the photosynthetic surface area.
6. A single culm to reduce wasteful vegetative growth.
7. Resistance to insects, pests, and diseases.
8. Effective partitioning and translocation of assimilates to the reproductive organs.

5. Approaches For Developing Plant Ideotypes

A plant ideotype is a model of a perfect plant made to grow well in certain conditions. The main idea is to increase crop yield, use resources better, and handle stress like drought or pests. Scientists use both old and new methods to create these ideal plants.

❖ ***Conventional breeding approaches:*** Conventional breeding methods such as mass selection, pedigree breeding and recurrent selection have long been used to improve crop performance by combining desirable traits through hybridization. These approaches are fundamental in assembling morphological and physiological traits associated with ideotypes (Acquaah, 2012).

❖ ***Molecular breeding and marker-assisted selection (MAS):*** Marker-assisted selection enables breeders to select genotypes based on the presence of the specific DNA markers linked to traits of interest, such as disease resistance or stress tolerance. It accelerates breeding cycles and improves the accuracy of selection (Collard and Mackill, 2008).

❖ ***Genetic engineering and genome editing:*** Biotechnology tools, such as transgenic methods and CRISPR/Cas9, enable precise modifications to genes that control essential plant traits. These technologies play a crucial role in ideotype development, particularly when natural genetic variation is limited (Chen et al., 2019). Model-assisted phenotyping offers a phenotypic fingerprint that links trait correlations to genetic data. By integrating global climate models, these approaches can also predict desirable traits both for current conditions and future environmental scenarios.

❖ ***Functional genomics and systems biology:*** The integration of genomics, proteomics, transcriptomics and metabolomics provides a systems-level understanding of trait development. Functional genomics identifies gene functions that contribute to ideotype traits, helping in the design of more efficient plants.

❖ ***Crop modeling and simulation:*** Crop simulation models such as DSSAT, APSIM predict plant behaviour under various scenarios and help determine the best mix of traits suited to specific environmental conditions. These tools Aid in forming a clear understanding or framework and refine ideotype models before actual breeding begins (Hammer et al., 2006).

❖ ***High-throughput phenotyping (HTP):*** High-throughput phenotyping (HTP) technologies rely on imaging, sensors, and automated systems to quickly and precisely measure plant traits in large groups. this is crucial for measuring ideotype features such as canopy architecture, root traits, and photosynthetic efficiency.

❖ ***Ideotype based breeding:*** Modern ideotype breeding combines physiological and genetic knowledge to assemble ideal trait combinations tailored to specific environments. Simulation models have been extensively used in ideotype design across various crop species. The first model-assisted ideotype design was achieved in irrigated rice, leading to the development of the high-performing hybrid rice variety Lianyoupeijuu. In wheat, Semenov and Stratonovitch (2013) utilized the Sirius simulation model to design high-yielding ideotypes for two contrasting European locations, the UK and Spain, under the 2050 A1B climate scenario. Additionally, three-dimensional (3D) visual modeling provides an innovative approach to model-assisted ideotype breeding, helping to identify both phenotypic features and agronomic practices that contribute to improved yield potential (Wang et al., 2019).

6. Role of Plant Ideotypes in Sustainable Agriculture

Plant ideotypes play a crucial role in sustainable agriculture by helping crops perform better while reducing the environmental impact of farming. They reduce dependency on chemical inputs and water, adapt to climate variability and contribute to ecological balance by improving biodiversity and soil health.

i. Efficient resource use:

Water efficiency: Plants are designed to use less water, making them ideal for drought-prone areas.

Nutrient efficiency: Plants can take up nutrients more effectively, reducing the need for chemical fertilizers.

ii. Resilience to climate change:

Drought and heat tolerance: Plants are bred to survive extreme weather conditions, such as heatwaves or droughts, which are becoming more common due to climate change.

Pest and disease resistance: Plants with built-in resistance reduce the need for chemical pesticides.

iii. Stable yields:

Plant ideotypes are bred for consistent, high yields, ensuring reliable food production, even with climate fluctuations.

iv. Environmental protection:

Soil health: Plants with deep roots improve soil structure and prevent erosion.

Biodiversity: Ideotypes help maintain diverse ecosystems, which are crucial for ecological balance.

v. Lower environmental impact:

Reduced chemical use: Less reliance on fertilizers and pesticides protects ecosystems and human health.

Reduced greenhouse gas emissions: Plants that need fewer chemical inputs produce less pollution, helping to fight climate change.

7. Challenges and Future Directions

Challenges: The concept and role of plant ideotypes in sustainable agriculture are central to improving crop yields while minimizing environmental impacts. However, there are several challenges that need to be addressed. One major issue is the reduction of plant variety, which limits adaptability to diverse climates and soils. Additionally, new pests and diseases pose a continuous threat, and the cost and accessibility of advanced breeding techniques can be prohibitive. There are also concerns surrounding genetic engineering, along with the complexity of integrating traits due to epistasis and the trade-offs that often occur, such as balancing yield with stress resistance.

Future Directions: Looking to the future, there are promising directions for overcoming these challenges. The use of new breeding technologies, such as CRISPR and genomic selection, can help create crops better suited to withstand climate change. Smart farming tools that enable precision agriculture will also play a significant role in enhancing sustainability. Plant ideotypes can be integrated into eco-friendly farming practices, fostering agricultural systems that are both productive and environmentally conscious. Furthermore, involving farmers more directly in the breeding process can help ensure that the crops developed meet the specific needs of local ecosystems and farming practices.

8. Conclusion

The ideotype concept offers a strategic, goal-oriented approach to crop improvement for sustainable agriculture. By integrating breeding and agronomic methods, ideotypes are designed with specific traits to enhance efficiency, climate resilience, and adaptability. They reduce reliance on chemical inputs, ensure stable food production, and lessen environmental impact. Despite challenges like trait trade-offs and climate variability, advances in genetic tools and crop modeling provide effective solutions. Ideotype breeding supports a more productive, resilient, and eco-friendly agricultural future.

9. References

Acquaah, G., 2012. Principles of plant genetics and breeding (2nd Edn.). Wiley-Blackwell.

Chen, K., Wang, Y., Zhang, R., Zhang, H., Gao, C., 2019. CRISPR/Cas genome editing and precision plant breeding in agriculture. Annual Review of Plant Biology 70, 667–697.

Collard, B.C.Y., Mackill, D.J., 2008. Marker-assisted selection: an approach for precision plant breeding in the twenty-first century. Philosophical Transactions of the Royal Society B: Biological Sciences 363(1491), 557–572.

Donald, C.M., 1968. The breeding of crop ideotypes. Euphytica 17(3), 385–403.

Hammer, G.L., Sinclair, T.R., Chapman, S.C., Van Oosterom, E., 2006. On systems thinking, systems biology, and the in-silico plant. Plant Physiology 142(2), 427–431.

Lynch, J.P., 2007. Roots of the second green revolution. Australian Journal of Botany 55(5), 493–512.

Polania, J., Poschenrieder, C., Rao, I., Beebe, S., 2017. Root traits and their potential links to plant ideotypes to improve drought resistance in common bean. Theoretical and Experimental Plant Physiology 29, 143–154.

Rahangdale, S., Lakhani, J.P., Singh, S.K., Barela, A., 2023. Phenotyping and reveal novel traits in mungbean (*Vigna radiata* L.) genotypes. South African Journal of Botany 156, 65–71.

Semenov, M.A., Stratonovitch, P., 2013. Designing high-yielding wheat ideotypes for a changing climate. Food and Energy Security 2(3), 185–196.