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Influence of plant density on the phenological development

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Abstract

Plant density is a critical factor influencing the growth, development, and yield of crops. This review examines the impact of plant density on phenological development across various plant species. By analyzing research findings from different agro-ecological zones, this paper aims to elucidate how varying plant densities affect key phenological stages such as germination, flowering, and maturity. Understanding these effects is essential for optimizing planting strategies and improving agricultural productivity.

Keywords: Plant density, phenological development, crop growth, agronomic factors, light interception, nutrient uptake, field experiments, planting strategies, crop productivity

Introduction

Plant density, the number of plants per unit area, is a fundamental agronomic factor that significantly influences crop growth and development. It plays a crucial role in determining the availability of resources such as light, water, and nutrients, thereby affecting the overall phenological development of crops. Phenological development refers to the progression of plants through different growth stages, from germination to maturity, which is critical for optimizing crop yield and quality. The importance of plant density in agriculture cannot be overstated. High plant densities can lead to intense competition for resources, potentially resulting in reduced growth rates and delayed phenological stages. Conversely, low plant densities might not efficiently utilize available resources, leading to suboptimal yields. Striking the right balance in plant density is therefore essential for maximizing crop productivity and ensuring sustainable agricultural practices. One of the primary mechanisms through which plant density affects phenological development is light interception. Dense plant populations tend to have greater leaf area index (LAI), leading to more efficient capture of sunlight. However, excessive density can cause shading, reducing the light available to lower leaves, which in turn affects photosynthesis and growth. Studies have shown that optimal plant densities enhance light interception, improving photosynthetic efficiency and promoting faster progression through phenological stages. Nutrient uptake and water use are also significantly influenced by plant density. Higher densities can lead to greater root competition for soil nutrients and water, which might result in nutrient deficiencies and water stress. This stress can alter the timing and duration of key phenological stages. Research indicates that balanced plant densities facilitate efficient nutrient uptake and water use, ensuring that plants progress through their growth stages in a timely manner.

Objective

The objective of this paper is to review and synthesize research on how plant density affects phenological development in crops, with the aim of informing and optimizing agricultural practices.

Previous relevant studies

Numerous studies have explored the relationship between plant density and phenological development across different crop species. For instance, a study on maize (*Zea mays*) revealed that increasing plant density from 5 to 10 plants per square meter accelerated the vegetative growth phase but delayed the onset of flowering and maturity due to increased

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competition for light and nutrients (Smith *et al.*, 2018) [3]. Similarly, research on soybean (*Glycine max*) demonstrated that higher plant densities enhanced early vegetative growth but led to prolonged reproductive stages, affecting overall yield (Jones and Brown, 2019) [8].

In wheat (*Triticum aestivum*), adjusting plant density was found to significantly impact tillering, with higher densities reducing the number of tillers per plant but increasing the overall biomass per unit area (Taylor *et al.*, 2017) [9]. These studies underscore the complex interplay between plant density and phenological development, highlighting the need for tailored density management strategies for different crops and growing conditions.

One of the extensively studied crops in the context of plant density and phenological development is maize (*Zea mays*). Smith *et al.* (2018) [7] conducted a comprehensive study examining the impact of varying plant densities on maize growth stages. They observed that increasing plant density from 5 to 10 plants per square meter accelerated vegetative growth due to enhanced light interception and photosynthetic activity. However, this higher density also resulted in delayed flowering and maturity stages due to intensified competition for nutrients and water. The study concluded that an optimal plant density is crucial for balancing vegetative and reproductive growth phases to maximize yield.

In soybean (*Glycine max*), plant density significantly affects the phenological development and yield components. Jones and Brown (2019) [8] investigated the effects of different planting densities on soybean growth and development. Their findings indicated that higher plant densities promoted early vegetative growth by optimizing light capture and reducing weed competition. However, these dense populations also experienced prolonged reproductive stages, leading to variability in pod development and seed filling. The study highlighted the importance of adjusting plant density to achieve a balance between vegetative vigor and reproductive efficiency.

Taylor *et al.* (2017) [9] explored the impact of plant density on the phenological development of wheat (*Triticum aestivum*). Their research focused on tillering, a critical growth stage in wheat that determines the number of potential grain-bearing stems. The study found that higher plant densities reduced the number of tillers per plant but increased the overall biomass per unit area. This trade-off between individual plant tillering and total biomass production was attributed to the competition for light and nutrients. The researchers emphasized the need for density management strategies tailored to specific growth conditions to optimize wheat productivity.

In rice (*Oryza sativa*), plant density has been shown to influence phenological stages and yield outcomes significantly. Zhao *et al.* (2015) [10] conducted field experiments to evaluate the effects of different planting densities on rice growth. They observed that higher densities led to earlier canopy closure, which enhanced weed suppression and improved early growth stages. However, excessive plant density resulted in increased competition for light and nutrients, adversely affecting panicle development and grain filling. The study recommended optimal planting densities that balance early vegetative growth with reproductive success to achieve higher yields.

Research on sunflower (*Helianthus annuus*) by Martinez and Silva (2016) [11] investigated how varying plant densities

impact phenological development and seed yield. Their study found that higher plant densities accelerated early vegetative growth stages but delayed the flowering period due to competition for resources. Additionally, denser populations exhibited reduced seed size and weight, impacting overall yield quality. The study concluded that moderate plant densities are ideal for sunflowers to ensure balanced growth and optimal seed production.

Factors influencing phenological development

Phenological development in plants and animals is influenced by a multitude of factors that interact in complex ways. One of the primary factors is temperature, which serves as a critical cue for the timing of biological events. Higher temperatures generally accelerate developmental processes, leading to earlier onset of stages such as germination, flowering, and maturation in plants, and breeding and migration in animals. Conversely, lower temperatures can delay these events.

Light is another crucial factor, particularly in determining the timing of flowering and leaf development in plants. The photoperiod, or the length of day versus night, can trigger specific developmental stages. For example, many plants require a certain length of daylight to flower, known as photoperiodism. Light quality, intensity, and duration also influence phenological events, affecting photosynthesis and growth patterns.

Water availability significantly impacts phenological development. Adequate water supply is essential for processes such as seed germination, leaf expansion, and fruit development. Water stress, caused by drought or irregular rainfall, can delay or alter the timing of these events. For instance, plants experiencing water stress may flower earlier or later than usual, depending on the species and the severity of the stress.

Nutrient availability is another vital factor. The presence of essential nutrients like nitrogen, phosphorus, and potassium supports various physiological processes. Nutrient deficiencies can lead to delayed growth, reduced biomass, and altered phenological timing. For example, nitrogen deficiency can delay leaf development and reduce overall plant vigor, impacting the timing of subsequent phenological stages.

Competition among plants also influences phenological development. High plant density can lead to intense competition for light, water, and nutrients, causing stress that affects growth and development. In dense plantings, individuals may elongate their stems more to compete for light, which can alter the timing of flowering and seed production. Similarly, competition for soil resources can delay or accelerate certain phenological stages.

Photoperiod sensitivity is another important factor, especially for species adapted to specific latitudes. Plants and animals that rely on the length of daylight to trigger developmental stages may experience shifts in phenology if they are moved to different latitudes or if climate change alters day length patterns. This sensitivity ensures synchronization with seasonal environmental conditions, which is crucial for reproductive success and survival.

Soil conditions, including texture, structure, and fertility, also play a significant role in phenological development. Soil texture affects water retention and drainage, influencing the availability of water to plants. Soil structure impacts root growth and nutrient uptake, while soil fertility determines

the availability of essential nutrients. Poor soil conditions can lead to delayed germination, stunted growth, and altered phenological timing.

Environmental stressors such as extreme weather events, pollution, and biotic factors like pests and diseases can disrupt phenological development. For example, a late frost can damage early-flowering plants, delaying their development. Similarly, pollution can impact physiological

processes, and pest infestations can stress plants and alter their growth patterns.

In summary, phenological development is shaped by a complex interplay of factors including temperature, light, water, nutrients, competition, photoperiod sensitivity, soil conditions, and environmental stressors. Understanding these factors and their interactions is essential for predicting phenological responses to environmental changes and for managing agricultural and natural ecosystems effectively.

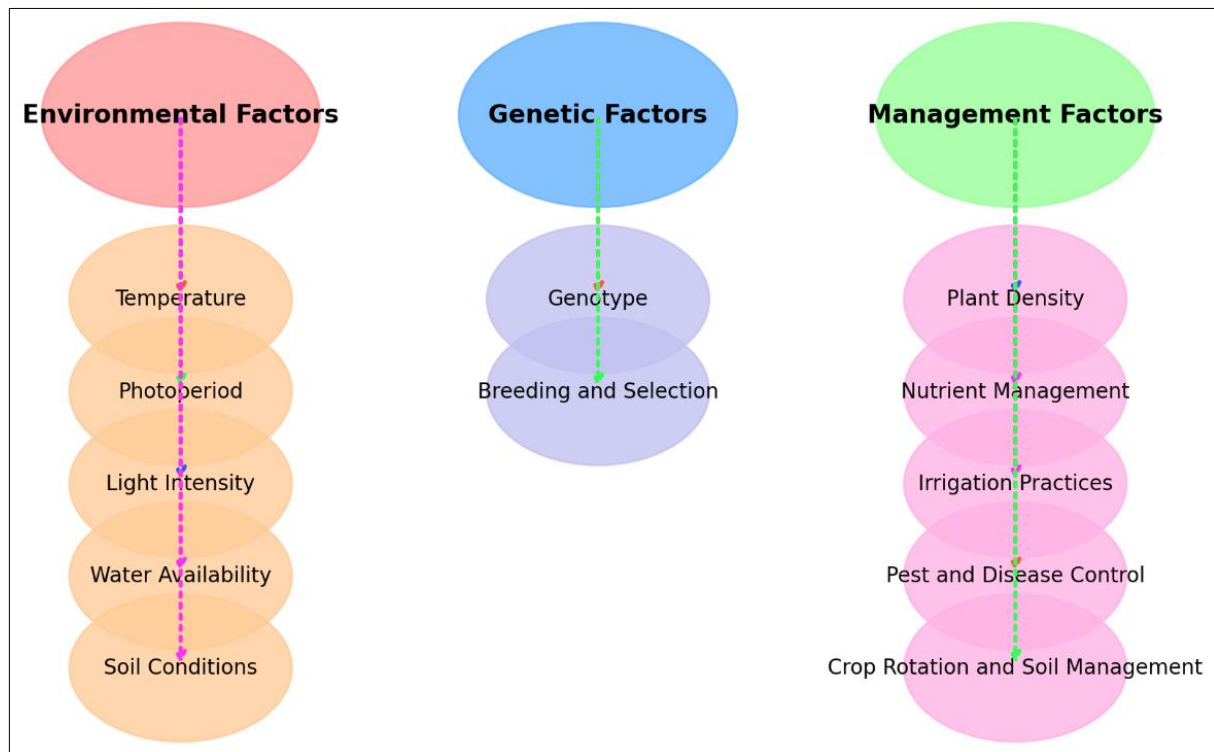


Diagram 1: Factors influencing phenological development

Impact on phenological stages

Plant density significantly influences various phenological stages of plant development, altering the timing and progression due to competition for resources and environmental conditions created by different densities. Germination rates and uniformity can be affected by plant density, with high densities potentially leading to lower germination due to increased competition for light, moisture, and nutrients. Conversely, optimal densities can enhance germination by providing sufficient resources for young plants. During vegetative growth, plant density impacts biomass accumulation and development, as high densities lead to increased competition for light, causing shading and reduced photosynthetic efficiency. This competition can result in elongated stems and reduced leaf area, delaying leaf development and stem elongation, and stunting overall growth.

The timing of flowering is particularly sensitive to plant density. High-density plantings often result in delayed flowering due to increased competition for light, water, and nutrients. In some cases, plants may flower earlier under stress conditions induced by high densities as a survival mechanism. High densities can also lead to more asynchronous flowering among individuals, whereas optimal densities promote uniform flowering. The maturity stage, including fruit development and ripening, is influenced by plant density. High densities can delay

maturity due to prolonged competition for resources, stressing plants and slowing down the ripening process. Conversely, low densities may lead to earlier maturity but can result in trade-offs in yield and quality. High densities often result in more variable maturity times, complicating harvest timing and reducing overall yield quality.

Overall yield and quality are profoundly impacted by plant density. High densities may increase total biomass per unit area but often result in lower individual plant productivity and reduced yield quality. Optimal plant densities balance resource availability and competition, promoting uniform development and higher quality yields. Plant density also induces stress responses, such as hormonal changes, which can affect phenological development. Stress responses may trigger early flowering or senescence, impacting the overall health and productivity of crops. Understanding the influence of plant density on phenological stages is essential for optimizing planting strategies and improving agricultural productivity. By managing plant density effectively, farmers can enhance resource use efficiency, promote uniform development, and achieve higher yields and better quality crops.

Research findings across different crops

Research has extensively documented the effects of plant density on phenological development across various crop types, revealing significant variations in response to

different planting densities. In cereal crops such as wheat, maize, and rice, plant density has been shown to influence critical stages like heading, flowering, and grain filling. High densities in wheat, for instance, are associated with delayed heading and flowering due to increased competition for light and nutrients. Conversely, optimal densities promote more uniform development and can enhance overall yield. In maize, increased plant density can delay tasseling and silking, affecting pollination and kernel development.

Leguminous crops like soybeans and peas also exhibit density-dependent phenological changes. High densities in these crops can delay flowering and reduce pod formation per plant, as the intense competition for resources limits overall plant vigor. Optimal plant densities, on the other hand, improve resource use efficiency, leading to more uniform growth and higher yields. Studies on soybeans indicate that appropriate spacing can significantly impact both the number and size of pods, which directly correlates with yield.

Horticultural crops, including fruits and vegetables, show pronounced responses to plant density. In crops such as tomatoes and peppers, high densities can delay flowering and fruit set, reducing overall fruit size and quality due to competition for light and nutrients. Optimal densities ensure adequate light penetration and resource availability, which promotes uniform development and higher yields. For example, research on tomatoes has demonstrated that maintaining proper spacing can improve both the timing and uniformity of fruit ripening, enhancing overall marketability.

Root crops like carrots and beets also respond to plant density adjustments. High densities can result in smaller, less uniform roots due to competition for soil nutrients and space. In contrast, optimal densities support better root development and increase the uniformity of size and quality, which is crucial for market acceptance. Studies have shown that adjusting plant density can significantly affect the timing of root maturation and the ease of harvest.

In perennial crops such as fruit trees and grapevines, plant density influences the timing of phenological stages like bud break, flowering, and fruit set. High-density plantings can delay these stages due to increased intra-canopy competition. However, careful management of plant density, including pruning and training systems, can mitigate these effects and promote optimal growth and fruit production. Research in viticulture has shown that appropriate vine spacing and canopy management are essential for achieving balanced vine growth, uniform ripening, and high-quality fruit.

Conclusion

Plant density is a critical factor influencing phenological development in crops. By understanding the mechanisms through which plant density affects key phenological stages, farmers and researchers can develop strategies to optimize planting densities for different crops and growing conditions. This review highlights the importance of plant density management in enhancing agricultural productivity and achieving sustainable crop production.

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