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MODERN APPROACHES TO INCREASING YIELD STABILITY IN CORN (*ZEA MAYS L.*)

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Abstract

Efficient resource management is essential for achieving high yield potential and environmental sustainability in maize (*Zea mays L*.) production. This study highlights the role of drones in improving water, fertilizer, and pesticide management in the cultivation of two high-yielding corn hybrids. Drones equipped with multispectral and thermal sensors enable real-time monitoring of crop water stress, allowing for precise irrigation scheduling and improved water-use efficiency. Similarly, NDVI and chlorophyll mapping from aerial imagery provide accurate assessments of nutrient status, facilitating targeted fertilizer application and minimizing nutrient losses. In pest control, drone-assisted spraying systems deliver pesticides more evenly and effectively while reducing chemical use, soil compaction, and operator exposure. These technologies collectively improve input efficiency, crop health, and yield stability, particularly under variable environmental conditions. By integrating drone-based monitoring and application systems, corn producers can optimize their production costs and ensure that hybrids like P9903 and P9241 reach their full genetic potential, while conserving resources and protecting the environment.

Keywords: maize (*Zea mays L*.), yield stability, effective use of drones, environmental protection

INTRODUCTION

Maize (*Zea mays L.)* is one of the most important members of the grass family (*Poaceae*), valued both for its rich nutritional content and its strong biological adaptability. It is the second most widely grown cereal crop in the world, coming right after wheat. In South Africa, maize plays a central role in both food security and the national economy. During the 2024/2025 growing season, farmers planted around 2.65 million hectares of commercial maize. Of this, roughly 1.6 million hectares were devoted to white maize, while just over one million hectares were used for yellow maize. On average, the commercial maize area in the country ranges between 2.5 and 2.75 million hectares each year, with an additional

350,000 to 500,000 hectares cultivated by small-scale farmers who often use traditional or open-pollinated varieties. In Bulgaria, maize is also an essential crop for both feed and grain production. For the 2024/2025 season, the total maize-growing area was estimated at about 484,000 hectares.

Maize yields around the world are affected by many challenges, mainly abiotic and biotic stresses. Among the abiotic factors, drought and soil salinity are the most damaging, often leading to serious drops in production. How much yield is lost usually depends on how long the stress lasts, the stage of crop growth, how intense it is, and how sensitive the specific hybrid is to different soil conditions (Tollenaar et al., 2011).

Because of this, developing drought-tolerant maize hybrids has become one of the main goals in breeding programs. As noted by Chaves et al., 2009, breeders should focus on selecting maize varieties that can produce high yields not only under normal growing conditions but also when faced with drought, ensuring the crop remains productive even in challenging environments.

MATERIALS AND METHODS

Plant material - general description of Maize Hybrids

Over the years, plant breeders have developed a wide range of maize (*Zea mays L.*) hybrids to improve yield, adaptability, and resistance to environmental stresses. The following are summaries of several well-known hybrids, taken from research papers and seed company catalogues. Although not all of them are identical to those used in this study, they share similar maturity classes (FAO ratings) and agronomic traits, especially within the Optimum® AQUAmax® family of drought-tolerant hybrids.

- P 9903 (Optimum® AQUAmax®) A medium- early hybrid (FAO 430) bred mainly for grain production under hot and dry conditions. Field trials show it performs well across different planting densities and irrigation levels, maintaining good yield even during stress according to research gate. Suitable for growing in areas with severe water deficit during grain filling.
- P 9241 mid-early Optimum® AQUAmax® hybrid, FAO 370. Proven and preferred by many manufacturers in Bulgaria. This hybrid demonstrates high and stable yield potential, including under limited moisture stress conditions. Suitable for cultivation with No Till technology.

Figure 1. General view of Corteva corn hybrids

Main Traits Used to Describe Maize Hybrids

When evaluating maize (*Zea mays L.*) hybrids, several key characteristics are considered to understand how each genotype performs and adapts to different environments. These traits help farmers, breeders, and researchers identify which hybrid is best suited for specific growing conditions.

- **Maturity** (FAO Group) this shows how long a hybrid needs to reach full maturity. It's usually measured in days or FAO units. Early-maturing hybrids grow faster and are ideal for regions with short seasons or cooler climates, while later-maturing hybrids need more time and warmth but often produce higher yields
- **End Use** (Grain or Silage) some hybrids are bred mainly for grain production, others for silage, and some can be used for both. Grain hybrids focus on kernel yield and drying ability, while silage types aim for high biomass, good digestibility, and feed quality.
- **Yield Performance.** Yield potential is one of the most important factors. It's assessed under:
    - Favorable conditions, where the plant receives enough water and nutrients.
    - Stress conditions, such as drought or heat, to see how well it copes with tough environments.
    - Different planting densities or soil types, to evaluate adaptability.
    - Agronomic Characteristics -These include plant and ear height, ear size and length, kernel type (dent, flint, or semi-flint), husk cover, and how quickly the grain dries at harvest. These traits affect how easy it is to harvest and how good the grain quality will be.
- **Tolerance and Stress Resistance.** This covers how well the hybrid can handle drought, heat, or disease pressure. Important traits include stay-green (keeping leaves healthy during grain filling), strong roots, and resistance to common diseases like stalk rot or leaf blight.
- **Stability and Environmental Adaptation (G×E).** Good hybrids produce consistent yields even when the weather or soil changes. This is measured through multi-location trials, which show how the hybrid performs in different regions and years.
- **Nutritional and Quality Traits.** These focus on starch and protein content, moisture at harvest, grain weight, and texture. They help determine how suitable the hybrid is for food, feed, or industrial use.
- **Recommended Management Practices**. Each hybrid performs best under specific planting densities, fertilization plans, and irrigation levels. Following these recommendations allows farmers to get the most out of the hybrid's genetic potential.

High-yielding maize cultivars don't always perform well under drought conditions, and the opposite is also true, drought-tolerant varieties may not always produce the highest yields (Anjum et al., 2011). Hoffmann et al. (2016) pointed out that using selection indices is often a better approach than focusing only on grain yield when choosing promising hybrids. Many scientists agree that combining statistical analyses with drought tolerance indices, which consider performance under both normal and water-stressed conditions, provides a more reliable way to identify resilient genotypes. This approach is particularly valuable in areas without irrigation, where rainfall patterns and drought severity can vary greatly from year to year (Farooq et al., 2009).

RESULTS AND DISCUSSION

Effects of Poor Water Management on Maize Hybrid P9903

Inadequate water management has a significant effect on the growth, physiology, and productivity of maize hybrids such as P9903. Limited water availability during critical growth stages, particularly flowering and grain filling, restricts vegetative development, reduces biomass accumulation, and ultimately results in considerable yield losses (Virág et al., 2020; Zwart & Bastiaanssen, 2004).

Water stress also negatively influences grain quality, leading to reductions in starch and protein content, which diminish both the nutritional and economic value of the crop (Farooq et al., 2009; Cakir, 2004). These declines are closely linked to impaired nutrient uptake and reduced enzymatic activity under drought conditions (Çakir, 2004; Anjum et al., 2011).

At the physiological level, inadequate water supply disrupts the plant's normal functioning by damaging photosynthetic membranes, lowering chlorophyll content, and reducing the efficiency of carbon assimilation (Chaves et al., 2009; Anjum et al., 2011). Such physiological disruptions often result in premature leaf senescence and reduced photosynthetic capacity, further limiting grain filling and yield. Moreover, under poor water management, especially at high planting densities, hybrid P9903 tends to show increased sensitivity to drought stress. Competition for limited soil moisture intensifies under these conditions, amplifying the negative impacts on yield stability and overall crop performance (Virág et al., 2020; Tollenaar & Lee, 2011).

Effects of Poor Fertilizer and Pest Management on Maize Hybrid P9903 and P9241

Poor fertilizer use and ineffective pest control can seriously reduce the performance of maize hybrids such as P9903 and P9241. Maize is a crop with high nutrient demands, especially for nitrogen (N), phosphorus (P), and potassium (K). When these nutrients are not supplied in the right amounts or at the right growth stages, the plant's photosynthesis and biomass production decline, leading to smaller plants and lower yields (Worku et al., 2012; Ciampitti & Vyn, 2014). Particularly limited nitrogen (N) and zinc (Zn) availability, negatively affected the performance of both maize hybrids. Across multiple environments, reduced nutrient supply was associated with lower starch accumulation and changes in grain protein and lipid proportions. In forage trials conducted under low baseline fertility, zinc application improved biomass yield, with the strongest responses observed at higher planting densities (69,000 plants ha^{-1}), where nutrient stress increased lodging incidence. Nitrogen limitation further intensified the effects of water stress, contributing to reduced kernel weight. These observations align with established roles of nitrogen and zinc in maize growth and grain development. Nutrient deficiencies make the crop weaker and less productive. For instance, a lack of nitrogen causes pale leaves and poor kernel development, while low phosphorus levels restrict root growth and energy transfer within the plant (Hawkesford, 2012). Under such conditions, P9903 often produces smaller ears with fewer kernels and reduced grain weight.

In addition to nutrient stress, pest infestations can further reduce productivity. Common maize pests such as the fall armyworm (*Spodoptera frugiperda*), stem borers *(Busseola fusca*, *Chilo partellus*), and maize weevils can cause significant damage to leaves, stems, and kernels. Without proper integrated pest management (IPM), which combines resistant hybrids, crop rotation, biological control, and timely pesticide use, these pests can dramatically lower both yield and grain quality (Kumela et al., 2018; Goergen et al., 2016).

Poor fertilizer and pest management often work together in a negative way. Crops that are nutrient-deficient become more vulnerable to pest attacks, while pest damage makes it even harder for plants to absorb nutrients and perform photosynthesis effectively (Prasanna et al., 2018). For hybrids like P9903 and P9241, which are bred to perform well under both favourable and moderately stressful conditions, this kind of mismanagement can greatly reduce yield potential and crop stability from season to season.

The Use of Drones in Water, Fertilizer, and Pesticide Management for Maize Hybrids P9903 and P9241

The adoption of drone technology has become an essential part of precision agriculture, offering farmers a more efficient and sustainable way to manage inputs such as water, fertilizers, and pesticides. For high-performing hybrids like P9903 and P9241, which are sensitive to both under- and over-application of resources, drones provide the ability to optimize field management, reduce waste, and improve overall yield stability

Figure 2. Application of drones in corn cultivation

UAV flights can be conducted at regular intervals (weekly or biweekly), at critical growth stages (V6, VT, R1), and across multiple locations, generating large and consistent datasets. Compared with manual scoring, UAV-based assessments are faster, more repeatable, and more cost-effective than dense ground-based sensor networks. This scalability represents a significant innovation for commercial hybrid evaluation, including P9241 and P9903 (Zhang and Kovacs, 2012).

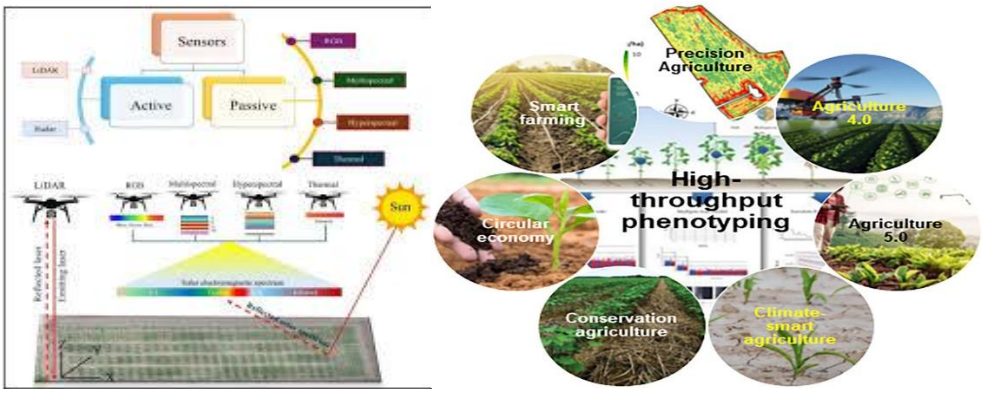

Figure 3. Possibility to track the phenological development of plants in critical phases using UAV-based assessments (according to data from Zhang and Kovacs, 2012)

1. Water Management

Drones equipped with multispectral and thermal sensors can monitor crop water stress by capturing high-resolution images that detect variations in leaf temperature and canopy colour (Bendig et al., 2015). This allows farmers to identify areas suffering from drought stress or irrigation leaks and apply water only where needed, improving irrigation efficiency and reducing water waste (Hoffmann et al., 2016). For maize hybrid P9903, which performs best under moderate soil moisture, drone-assisted irrigation scheduling can help maintain optimal water levels, especially during critical growth stages such as flowering and grain filling.

2. Fertilizer Management

Nutrient application efficiency can be greatly improved through drone-based monitoring. Using NDVI (Normalized Difference Vegetation Index) and chlorophyll mapping, drones help detect nitrogen and phosphorus deficiencies across the field (Tripicchio et al., 2015). By integrating this data with variable-rate fertilizer spreaders, farmers can apply nutrients precisely where they are needed, reducing costs and preventing nutrient runoff. For P9903, which requires balanced nitrogen for high yield performance, drones support more targeted fertilization, improving both plant vigour and kernel quality (Mulla, 2013).

3. Pesticide Application

Drones are also increasingly used for targeted pesticide spraying, providing better coverage with smaller quantities of chemicals. They can fly at low altitudes and deliver uniform droplets, reaching parts of the plant that ground sprayers might miss (Zhang et al., 2018). This precision helps control pests such as the fall armyworm (*Spodoptera frugiperda*) and stem borers, which commonly affect maize hybrids like P9903. In addition, drone spraying minimizes operator exposure to harmful chemicals and reduces soil compaction from heavy machinery (Huang et al., 2020).

Weed competition in unmanaged plots significantly reduced the yield performance of maize hybrid P9241. Field trials conducted in Bulgaria between

2020 and 2021 demonstrated that the use of pre-emergence herbicides was effective in preserving yield potential by minimizing early-season competition (Mitkov et al., 2021). Elevated anthocyanin accumulation in stressed plants indicated physiological responses associated with combined herbicide and pest pressure. In addition, non-Bt P9241 exhibited increased vulnerability to stem borer infestation, resulting in plant stand gaps of approximately 20–30%, whereas related Bt hybrids maintained greater stand integrity. These findings highlight the importance of integrated weed and pest management strategies to sustain productivity under high-pressure conditions (Yancheva et al., 2016).

CONCLUSIONS

An important point in modern and precision agriculture is the correct selection of a suitable genotype (hybrid corn) for specific soil and climatic growing conditions. From the conducted literature study, we can conclude that the combination of high-quality corn hybrids from Corteva Agriscience, such as P9903 and P9241, with the correct use of unmanned aerial vehicles (UAV-based assessments) will increase the productive potential of the hybrids, will refine the amount of water, nutrients and the amount of pesticides in plant cultivation. All this will contribute to a more gentle approach to environmental protection.

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