CORPUS PUBLISHERS

Archives of Agriculture Research and Technology (AART)

ISSN: 2832-8639

Volume 4 Issue 3, 2023

Article Information

Received date : June 23, 2023

Published date: July 31, 2023

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DOI: 10.54026/AART/1054

Keywords

Sorghum; Millet; Nitrogen fertilizers; Legumes

Mini Review

Crops Nutrient use Efficiency

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Abstract

During the post-war "green revolution," the paradigm for obtaining high yield was based on the response of plants to the use of energy and fertilizers (considered at the time as limitless sources) and intense mechanization, with the consequent development of high-yield varieties (HYVs), which brought a significant increase in agricultural productivity. However, with the oil crisis in the 1970s, the era where the environment was modified (irrigation, heavy fertilization, mechanization, and other practices) to adapt it to the needs of the crops came to be outdated. Thus, the new emerging era in agriculture needs to be based on the adaptation of the plant to the environment, developing sustainable agricultural production systems (no-tillage, green manure, agroforestry, and other agrosystems), with production stability and advanced technologies, but with low-cost, as the biological nitrogen fixation (BNF) or the use of microorganisms growth promoters. In addition, areas once considered marginal to agriculture, under abiotic stresses and poor soils, such as the Brazilian Savannah "Cerrado," are now exploited for agricultural production to sustain the world's growing population. Therefore, the key to the agriculture of the future, especially in these marginal areas, so common in the tropical region, is the selection and cultivation of plants with greater efficiency in the use of nutrients, the so-called low input varieties (LIVs), associated with the diffusion of sustainable agricultural practices.

Introduction

Agriculture needs to feed an increasing human population, especially under future climate change, which will increase drought frequency and air temperatures [1]. These effects are important in marginal areas for agriculture, which are submitted to environmental stresses and soils with low nutrient contents, but it is where population growth is higher [1]. The green revolution created a whole new set of technological, economic, and social problems; for example, with HYVs, there was a need for costly inputs such as fertilizers, pesticides, irrigation facilities, and machines, all of which only wealthy farmers could afford. However, traditional staples from marginal areas such as sorghum, millet, chickpea, pigeon pea, cowpea, and groundnut, among others, can be considered as LIVs, because they yield without a costly input as required for HYVs, had generally been neglected by experts (Table 1). The key to this effort will be to select plants with improved nutrient uptake and utilization efficiency [2] and stress tolerance (Table 2). In Brazil, for example, there are two native LIVs species, *Spondias tuberosa*, and *Caryocar brasiliense*, that produce a large number of fruits in marginal areas of Brazilian semiarid Northeast and Savannah, without any input, which are very important for the economy of small farmers [3].

Table 1: Nutrient use by varieties from marginal agro-environments or LIVs and modern HYVs selected for high-input agriculture.

Agro-Environment	Wild Varieties	Modern Varieties
Low nutrient availability	“Normal” growth	Nutrient deficiencies
High nutrient availability	Nutrient toxicities	“Normal” growth

LIVs: low input varieties; HYVs: high yield varieties.

Table 2: Traits for genotypic variation for plant nutrient use efficiency.

A. Acquisition from the Environment
Shoot attributes:
1) Reduced foliage (smaller or fewer thicker leaves);
2) Stiff, vertically-oriented leaves;
3) High daily net rate of leaf CO_2 uptake per unit of leaf area (A): high daily A with lower photorespiration and manutention respiration rate;
4) High photosynthetic nitrogen use efficiency (PNUE): high rate of CO_2 uptake per unit of leaf nitrogen content;
5) High water use efficiency (WUE): high A with lower transpiration or stomatal conductance (High Rubisco activity with lower CO_2 Km and specificity);
6) Efficiency in photoassimilates transport and distribution to sinks;
7) Leaf duration (especially for the source leaves, as flag leaf for panicle crops, or leaf at the same node of ears and legumes, etc.) and sink strength (number and duration of harvestable sinks);
Root attributes:
8) High root/shoot ratio, especially under nutrient deficiency (perennial plants);
9) Greater lateral and vertical spread of roots, with a vigorous, highly branched root system with a large number of apices;
10) High root density or absorbing surface in the top and deeper soil layers, with more root hairs in top soil layers;
11) Ability of the roots to modify rhizosphere: generation and secretion of organic acids (especially citrate and malate, but also piscidic acid), sugars and amino acids, protons or hydroxyls, and acid phosphatases (P solubilization);
12) Capacity for "extension" of the root system by association with mycorrhiza;
13) Capacity for Symbiotic nitrogen fixation (SNF) with soil microorganisms;
14) Physiological efficiency of ion uptake per unit of root surface (lower nutrient root Km);
15) Capacity for storage (carbohydrates and water) in belowground organs;
16) Longevity and activity of roots;
B. Nutrient Distribution and Assimilation within Plants
17) Rapid root radial and xylem transport;
18) Efficiency of NO_3^- (higher Nitrate Reductase activity with lower Km) and NH_4^+ assimilation (higher Glutamine Synthetase [GS]/ Glutamate Synthase [GOGAT] system activity with lower Km);
19) Efficiency of reutilization under nutrient stress; rates of senescence and organic P and N hydrolyses (especially for old leaves);
20) Capacity for rapid uptake when the nutrient is available, for accumulation in vacuoles and storage tissues, and posterior use during nutrient stress;
21) Capacity to maintain "normal" metabolism under nutrient deficiency (wild plants in marginal environments, such as *Spondias tuberosa* and *Caryocar brasiliense*;
22) Improved environmental stress tolerance.

Adapted from Duncan & Baligar [2].

Sustainable Agronomic Practices

The first approach to management strategies for nutrient stress is fertilizer use and organic matter management. Adequate fertilizer application as a band is preferred to broadcast application because it will reduce the amount of fertilizers applied and improve the acquisition by roots [2]. In addition, the simultaneous use of organic materials and nitrogen fertilizers can increase nitrogen availability for plants more than any of these practices alone [2]. However, a fundamental high technology with a low input that needs to be improved is the use of microorganisms' promoters of plant growth, producing or inducing the formation of phytohormones by plants, inoculation of legume seeds with Rhizobium bacteria to do BNF, and mycorrhiza-plant associations, for nitrogen, phosphorus, and water acquisition by crops [3]. BNF is an essential source of plant nitrogen obtained from N_2 in the air and is a process that should be done by inoculation of seeds of legumes doing symbiosis, intercropping grasses with legumes, and using leguminous green manures [3]. This process must be better studied to improve its efficiency in supplying all nitrogen required by the crop or the green manure, improving nitrogen input in the agro-environment, especially in marginal areas for agriculture. The enhancement of BNF can be achieved by better understanding the plant genes and messengers involved in the process and selecting efficient plants and bacterial strains.

In addition, management strategies for soil organic matter conservation and addition to soils are essential for global changes because of carbon sequestration and the increase in soil nitrogen content. Cultivation of soils results in the disruption of soil aggregates and the loss of soil organic matter compared to native soils. In no-tillage management, the soil is not plowed and is cultivated firstly with a dry matter producers crop, such as pearl millet, before the principal crop, and thus, crop residues accumulate on the soil surface as mulch, improving soil aggregation and reducing losses of soil organic matter that result from plowing [3]. The introduction of minimal tillering systems in Brazilian Savannah "Cerrado" agriculture increased the cultivation of pearl millet in the 1990s. Pearl millet is now used for biomass production to cover the soil in the minimal tillering system or for rotation during the low rainfall winter, recycling nutrients leached from the principal crop used in the rainy season [3].

The return of crop residues can increase soil organic matter content, the introduction of green manure cultivation during rotation, and the application of farmyard manure and other materials containing organic substances in the farm too [2]. In sub-humid Benin, for example, *Mucuna pruriens* (velvet bean) is used as green manure mulch and has become an accepted method to counter soil fertility decline. In semiarid Kenya, farmers choose "trash lines" (bands of uprooted weeds and crop residues) to intercept sediments and runoff. China has a 3000-year history of using green manuring to increase yields of cereal crops and to maintain and increase soil fertility. Some green manure used around the world is *Mucuna spp., Crotalaria spp., Canavalia spp., Vigna spp., Cajanus cajans, Pueraria phaseoloides*, and *Cymopsis tetragonoloba*, among others [3].

Other agronomic practices for improving soil nutrient supply are crop rotation, intercropping, and agroforestry systems. Crop rotation can reduce mineral depletion, changes in soil structure, accumulation of toxic substances, and increase soil pathogen populations, frequently associated with continued monoculture, which requires large amounts of fertilizers, pesticides, and machinery [3]. Crop rotation increases yield and profitability via diversification, reducing environmental risks and the need for chemical inputs. Intercropping, especially of grass with a legume such as pearl millet and cowpea, two water stress-tolerant crops, improved the pearl millet grain yield by 15 to 103% in semiarid West Africa. In addition, higher plant density planting systems, and thus, the cover of the area, diminish the evapotranspiration because of soil cover and lead to a higher yield. Increasing the pearl millet density, from 5000 to 20,000 "hills" per ha, increases yield and evapotranspiration efficiency in West Africa [3]. Agroforestry, especially using leguminous trees native to marginal environments such as *Acacias* spp., *Prosopis* spp., and *Faidherbia albida*, among others, which can be used for animal feeding, and can improve nitrogen addition in the soil by BNF, and reduces water and wind erosion, improving nitrogen supply for the intercropped culture. The yield of pearl millet and other crops increases when intercropped with *Faidherbia albida* trees due to improved nutrient availability, reduced solar irradiance and photoinhibition, and lower soil and air temperature, reducing crop transpiration [3].

Nutrient use Efficiency in Marginal Agro Environments

Nutrient use efficiency (NUE) represents different things to different people and has little meaning unless specifically defined. The broad definition of efficiency is output divided by input. Thus, the NUE would refer to the ratio of the increase in plant biomass to the plant nutrients applied in an agronomic view [2]. The primary process that governs dry matter accumulation is the net rate of leaf CO_2 uptake per unit of leaf area (A), and especially for nitrogen use efficiency, the photosynthetic nitrogen use efficiency (PNUE) can also be viewed as a plant physiology's approach for increasing yield potential [3]. Accordingly, the metabolism of nutrients such as nitrogen or phosphorus cannot be seen alone without its interaction with carbon metabolism and water available, mainly if the studies aim to evaluate crop metabolism in the marginal agro environment, where water and nutrient are limiting carbon assimilation and dry matter accumulation and ultimately, yield [1]. After CO_2 and H_2O acquisition and economy, which are obtained from the air and soil, when water availability allows plant growth, organic nitrogen and phosphorus content in plants controls dry matter accumulation and yield of crops, especially in marginal agro environments [3].

Therefore, landraces of plants native to marginal environments with nutrient scarcity need to be used to improve yield in other marginal agro environments, and they can be used as progenitors to generate new LIVs genotypes [1]. These plants evolved in marginal environments for thousands of years and must possess some distinct attributes to tolerate these stresses, which may not be present in species from humid and nutrient-rich regions. In every marginal environment in the world, the local farmers use and maintain these adapted genotypes (LIVs), using particular crop managements, for household agriculture, and these technologies need to be diffused for other marginal regions [3].

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