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Understanding crop-weed-fertilizer-water interactions and their implications for weed management in agricultural systems

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A B S T R A C T

Crops and weeds share the same aboveground/aerial (sunlight, space, atmospheric gases, etc.) and underground/soil (water and nutrients) resources. Competition is a predictable response of organisms living in communities, and is a struggle between two organisms for a limited resource that is essential for their growth. Crop-weed competition causes an alteration in the utilization of various resources and also affects complex interactions between plants and environmental factors. Water, nutrients, light, and space are the major factors for which organisms compete. Light and space are the main aboveground resources, and the effects of competition for these resources can be visually observed. This article focusses on crop-weed interactions for underground resources - nutrients and water. Weeds, being more aggressive, adaptive and persistent than crops, pose a serious threat to crop production as they have the ability to survive under adverse conditions and extract more water and nutrients from the soil; thereby, reducing crop yields. Fertilizer application and inherent soil fertility have a definite influence on weed diversity, emergence, growth, dormancy, persistence, and crop-weed competition. Weed suppression with balanced fertilization through increased competition for light has been regarded as one of the most important determinants of the yield advantage of a crop, and the effect on yield depends upon the interaction of crop and weed flora. The elimination of weeds from crops is the most efficient and practical means of reducing transpiration and thus saving water for crop use. Additional fertilizer and water amounts cannot compensate fully for yield losses due to weed competition, but appropriate fertilizer and water management could be used as an important tool in integrated weed management systems, which may prove helpful for achieving higher net returns.

Contents

1. Introduction 66
2. Weed-fertilizer interactions 66
   2.1. N fertilization and weeds 67
   2.2. P fertilization and weeds 68
   2.3. Bulky organic manure and weeds 68
   2.4. Fertilizer and weed control 68
      2.4.1. Time of fertilizer application 68
      2.4.2. Method of fertilizer application 68
   2.5. Weeds as a source of nutrients 69
   2.6. Fertilizer and herbicide efficacy 69
3. Weed-water interactions 69
4. Weed-fertilizer-water interactions 70

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5. Conclusions and future research directions 70
References 70

1. Introduction

Weeds are unwanted plants that interfere with the utilization of land and thus adversely affect crop production. The developing world is facing the ramifications of four inter-related problems viz; the energy crisis, food shortages, poverty, and under-employment as a consequence of population explosion. To meet the rise in food demand, global food production needs to be increased by over 40% by 2030 (FAO, 2009). The dynamic nature of weed problems requires continuous development of novel weed management technologies which can be mechanical/physical, chemical, cultural/agronomic, biological and integrated ones (Clements et al., 2014). Chemical weed management measures have wider acceptance amongst growers due to the ease of application, low prices, timeliness and efficiency. However, an acute rise in cases of herbicide resistance in weeds and emerging concerns about environmental pollution due to indiscriminate use of herbicides have necessitated a shift and/or focus on other control measures and integrated weed management (Chauhan et al., 2017). The key principle of integrated weed management is to manage the crop habitat in such a way as to exploit biological differences between crops and weeds (Chauhan, 2012). The objective of integrated weed management is to maintain weed densities at manageable levels and to place the crops at a competitive advantage over the weeds (Zimdahl, 2017). Weeds, being well adopted, highly competitive, persistent and hardy as compared to cultivated crops, interfere with agricultural operations and reduce resource-use efficiency. This imbalance of nature can be manipulated in favour of crops by suitably modifying soil and cropping conditions, leading to selective stimulation of crop growth. Vigorous crop plants compete better with weeds and cover the ground more quickly. This can be achieved by timely and judicious use of various external applied inputs like water and nutrients (Walia, 2010). A comprehensive understanding of interactions between crops and associated weeds for these resources is a must for the development of a sound framework for combating weed problems.

Various positive and negative interactions between two species sharing the same niche are observed in a mixed agroecosystem. Interactions between crops and weeds are mainly for nutrients, soil moisture, light, and space (carbon dioxide). Luca et al. (2014) summarized different interferences and divided them into two types, positive and negative. Positive interferences are mutualism (both organisms benefit) and commensalism (one is neutral and the other benefits). Negative interferences are competition (one benefits, while the other is harmed) and amensalism (one is neutral, and the other is harmed). Allelopathy is also considered a negative form of interference. Competition is the most important interaction for determining crop productivity. It is the mutual adverse effect of two organisms utilizing common resources, which are essential for their growth and development, and are in short supply. Inter- and intraspecific competition starts when any of the resources become limiting and affect plant growth and biomass production, and the plant cannot effectively utilize other available resources. The principle of plant competition is that the plants which are first to occupy any area of soil, small or large, tend to exclude others. This article focuses on the various interactions for underground resources observed in the crop-weed complex, and the implications for weed management.

Soil resources or agricultural inputs, nutrients/fertilizers and water, are vital for crop production and involve a huge investment by farmers. Soil, water and nutrients play a decisive role in crop-weed interactions. Weeds have high photosynthetic rates and relative growth rates, and the capacity for rapid phenotypic adjustment under stress conditions (Radosevich et al., 1997). The nutrient and water extraction ability of any plant depends upon the depth and density of its root system, and inherent growth characteristics of the roots. Micronutrients and macro-nutrients, like nitrogen (N), phosphorus (P) and potassium (K), are essential for production of crops used for food, animal feed, fibre, and fuel. Most of these nutrients are absorbed by the crop, but the absorption pattern differs when applied in the presence of weeds. Before the advent of mineral fertilizers in the 19th century, soil fertility was maintained by the use of bulky organic manures and inclusion of N-fixing crops in crop rotation. It has been estimated that animal manure provides about 11% of the total N required for global food production (Smil, 1999). Over the past 50 years, approximately 40% of the world's dietary protein has been contributed through applying N fertilizers to increase per-capita food production (Smil, 2002). Water is a scarce, exhaustible and expensive resource, and the renewable quantity of water is finite; thus, necessitating its use in the most efficient way. Global water projections made by several researchers have indicated major shortfalls in the future. In Asia, it has been estimated that 17 million ha of irrigated rice may experience “physical water scarcity” and 22 million ha may have “economic water scarcity” by 2025 (Bouman et al., 2002). Ground water in the major rice growing areas of North-West India is declining at a rate of 0.1–1.0 m $year^{-1}$ (Hira et al., 2004). Water is an essential factor in agricultural production, and strongly affects various plant physiological processes like photosynthesis, respiration, absorption, translocation, utilization of mineral nutrients, and cell division.

Nutrient and water management plays a significant role in weed management, as crop and weed species require sufficient soil moisture for their germination, growth, and establishment (Baltazar and De Datta, 1992). A greater understanding of weed-fertilizer-water interactions would facilitate the development of effective cultural management practices in field crops, which favour the growth of crops while inhibiting weed germination and growth.

2. Weed-fertilizer interactions

Application of fertilizer may benefit weeds to a greater extent than crops, because nutrient absorption is faster and higher in weeds than in crop plants (Balasubramanian and Palaniappan, 2004). For each kilogram of dry matter production by wheat (*Triticum aestivum* L.), 5.5 kg N and 1.2 kg P are required; while *Chenopodium album* L. required 7.6 kg N and 1.6 kg P (Balasubramanian and Palaniappan, 2004). For every gram of dry matter produced by weeds, there is a corresponding loss of yield by the crop. Weeds in the first three weeks of growth take one-third of fertilizer nutrients applied to crops, and weeds can deprive a rice crop of 47% N, 42% P, 50% K, 39% calcium, and 24% magnesium. Some weeds consume more nutrients than they need for their growth, and may accumulate higher mineral nutrient concentrations (1.0–3.8% N, 0.5% P and 1.0–5.0% K) than crop plants (Alkamper, 1976). Such ‘luxury