Light Degrades Iron-Chelates in Fertilizer Solutions, Affecting Physiology of Iron Acquisition in Marigold (*Tagetes erecta* L.)

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Introduction

In crop production, a grower must consider many factors in fertilization, including formulation and application frequency. Often not considered, however, is the manner that the fertilizer solution is stored, especially if prepared as a concentrated stock. Research has indicated that iron-chelates are affected by light. For example, in tissue culture, plants are typically grown on a translucent, gel-like agar incorporated with nutrients often containing iron-chelates such as iron-EDTA. Recent work has shown that iron-EDTA in the agar degrades when exposed to light (irradiated), resulting in the precipitation of iron. Precipitated iron in the agar is insoluble and unavailable to the plant, and limited soluble iron significantly reduces plant growth and may alter plant physiology.

Many plants respond to iron-deficiency stress by modifying root physiology. These modifications include root induced acidification of the media to increase iron solubility in the root zone, and an enhanced ability to reduce, or chemically convert, ferric iron (Fe^{3+}) to ferrous iron (Fe^{2+}), the form of iron that plants take up. These physiological reactions are collectively referred to as iron-efficiency.

A metal-chelate complex (i.e., iron-EDTA and iron-DTPA) is the result of a special form of complexation in which the chelating agent (i.e., EDTA and DTPA) is capable of forming multiple bonds with the metal ion (i.e., iron). These bonds occur in a ring structure around the metal ion. Chelates are capable of maintaining iron in a soluble form in chemical environments where iron would otherwise precipitate. Therefore, chelates like EDTA and DTPA are commonly added to fertilizer. These chelates have a high affinity for Iron and generally form stable complexes with the metal across a pH range from 4 to 7.

A conceptual model of chelate function can be demonstrated with one's hand and a tennis ball. Consider the hand as the chelating agent and the ball as iron. With all five fingers wrapped around the tennis ball, the ball can be kept from falling to the ground. Consider the force of gravity as pH, and the function of chelates is understood (i.e., gravity pulls a tennis ball down just as pH causes Iron to precipitate).

Although research has demonstrated that iron-chelate degradation by light is a problem in tissue culture, the significance of this phenomenon to the ornamental horticulture industry is unknown. Therefore, studies were initiated to determine if (1) iron-chelates incorporated into commercial fertilizers degrade in light, and (2) to determine if the use of such fertilizers exposed to light affect plant physiology associated with iron acquisition.

Materials and Methods

Commercially produced soluble 20-10-20 (N-P-K) fertilizers that contain iron-EDTA were prepared as 100X stocks based on a 100 ppm nitrogen (N) (1X) concentration. Samples of the fertilizer solutions were then kept dark (1.1 qt. containers covered with aluminum foil) or irradiated with 500 $\mu mol \cdot m^{-2} \cdot s^{-1}$ (approximately 3,500 foot candles) from fluorescent and incandescent light sources for 10 days at 70˚F. Also, 200 ppm nitrogen solutions containing iron-DTPA were prepared as 10X stocks and treated with a combination of light intensity (250 μmol•m^{-2}•s^{-1} or 500 μmol•m^{-2}•s^{-1}) and temperature [68˚F (20˚C) or 104˚F (40˚C)]. Chelated iron was separated from unchelated iron in samples taken daily by centrifugation (spinning).

To determine the effects of fertilizer treatment on plant physiology, 24 day old 'First Lady' marigold (*Tagetes erecta* L.) plants were grown hydroponically in 1X concentrations (100 ppm nitrogen) of the fertilizer solutions treated as described in the previous study, consisting of both irradiated and dark-kept solutions of brand 1 and brand 2 fertilizers. At the end of 8 days, the ability of the plants to cause root zone acidification and to reduce ferric iron to ferrous iron (ferric reductase activity) was determined; giving an indication as to whether plants grown in the irradiated fertilizer solutions were under iron deficiency stress.

Results and Discussion

Soluble iron decreases with light exposure. Soluble iron in the irradiated commercial fertilizer solutions decreased 85% in 10 days (Fig. 1). In conjunction with the decrease in soluble iron in the irradiated fertilizer solutions was the formation of a tan precipitate. Analysis of the precipitate revealed that it was composed of iron in an amount that was equivalent to 90% of the soluble iron lost by irradiation. There was no loss in soluble iron in treatments kept dark (Fig. 1). These findings indicate that light levels in the greenhouse are sufficient to degrade iron-chelates in commercially produced fertilizers, rendering iron unchelated and readily unavailable to the plant.

Light intensity and temperature affect iron chelate degradation. Work with the lab prepared nutrient solutions indicated that both light intensity (photon flux density) and temperature affects the rate of iron-chelate degradation. Doubling the photon flux density from 250 μmol•m^{-2}•s^{-1} to 500 μmol•m^{-2}•s^{-1} (at a constant temperature) doubled the rate of iron-chelate degradation in a nutrient solution (Fig. 2). Also, increasing the temperature from 68˚F (20˚C) to 104˚F (40˚C) (at a constant photon flux density) resulted in a 2.6-times greater rate of iron-chelate degradation in the first 24 hours of irradiation (Fig. 2). These findings indicate that growers should maintain fertilizer stock solutions in an opaque container and in a cool location (i.e., out of direct sunlight).

Light exposed fertilizers affect plant physiology. Roots of marigold grown hydroponically in the irradiated fertilizer solutions had 3.5-times greater ferric iron-DTPA reductase activity than roots of plants grown in fertilizer solutions kept dark (Fig. 3). Plants grown in irradiated fertilizer solutions acidified the root zone more than plants grown in fertilizer solutions kept dark. The increase in iron reductase activity and root zone acidification are iron-efficiency reactions of marigold responding to the degradation of iron-chelates by light and subsequent decrease in soluble Fe in the commercial fertilizer solutions. These findings indicate that the use of irradiated commercial fertilizers containing iron-chelates can affect plant physiology associated with iron acquisition.

Conclusions

Significance to Industry. Iron-chelates in commercially produced soluble fertilizers are vulnerable to light degradation. Therefore, a grower not only has to consider fertilizer formulation and application frequency in crop production, but also must consider how the fertilizer stock solution is stored. Our research findings indicate that using an irradiated iron-chelate containing fertilizer solution in plant production can result in modifications in root physiology typically associated with iron deficiency stress, i.e. iron-efficiency. Through proper storage of fertilizer stock solutions in opaque containers, degradation of iron-chelates by light can be avoided. *Solid forms of the fertilizer are not vulnerable to iron-chelate photodegradation*.

Acknowledgments

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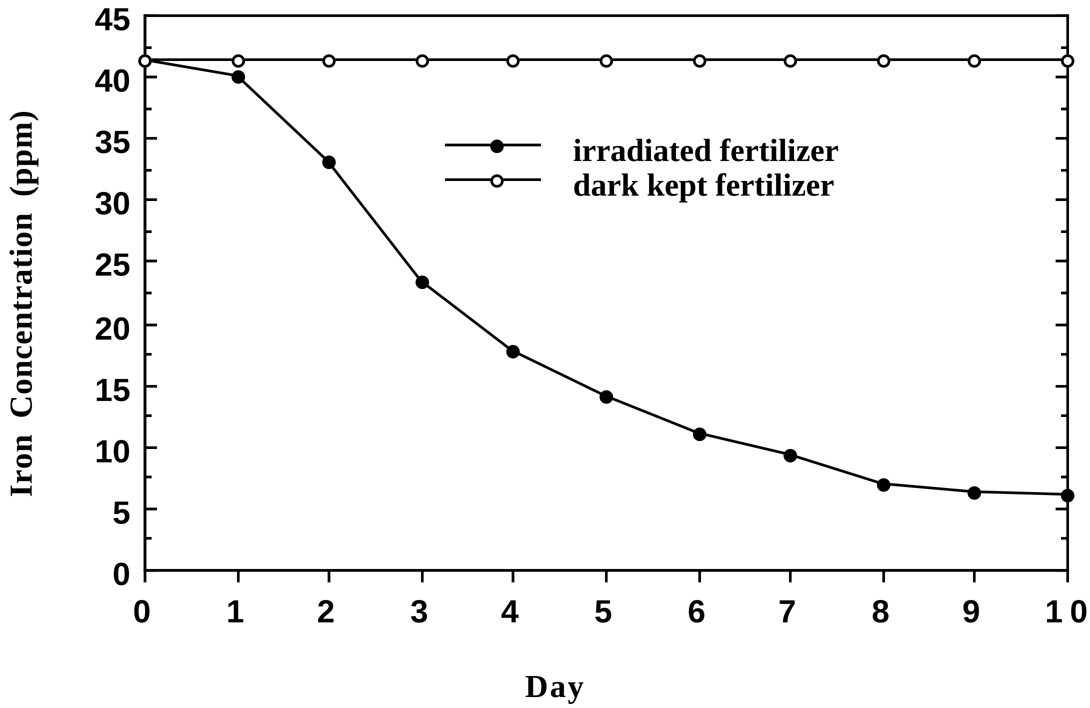

Figure 1. Soluble iron in a commercially produced (iron-EDTA)-containing 20-10-20 fertilizer prepared as a 100X stock based on 200 ppm nitrogen (N) decreased 85% in days 10 days of irradiation at 500 $\mu mol \bullet m^{-2} \bullet s^{-1}$.

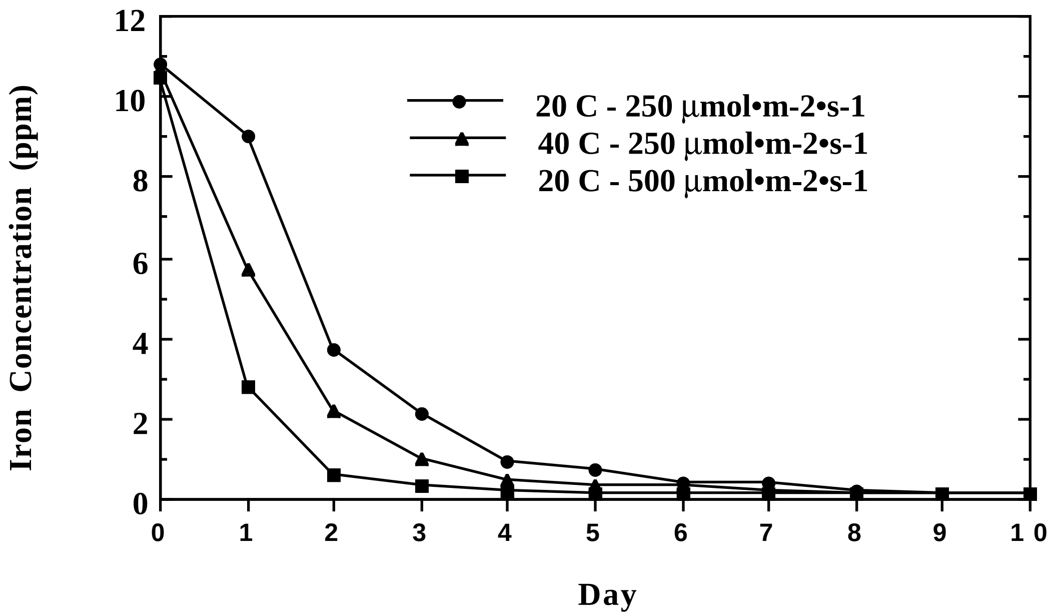

Figure 2. Soluble iron in lab prepared nutrient solutions containing iron-DTPA prepared as a 10X stocks based on 200 ppm nitrogen (N), were affected by both light intensity and temperature. An increase in either light intensity or temperature, resulted in an increased rate of iron-chelate breakdown.

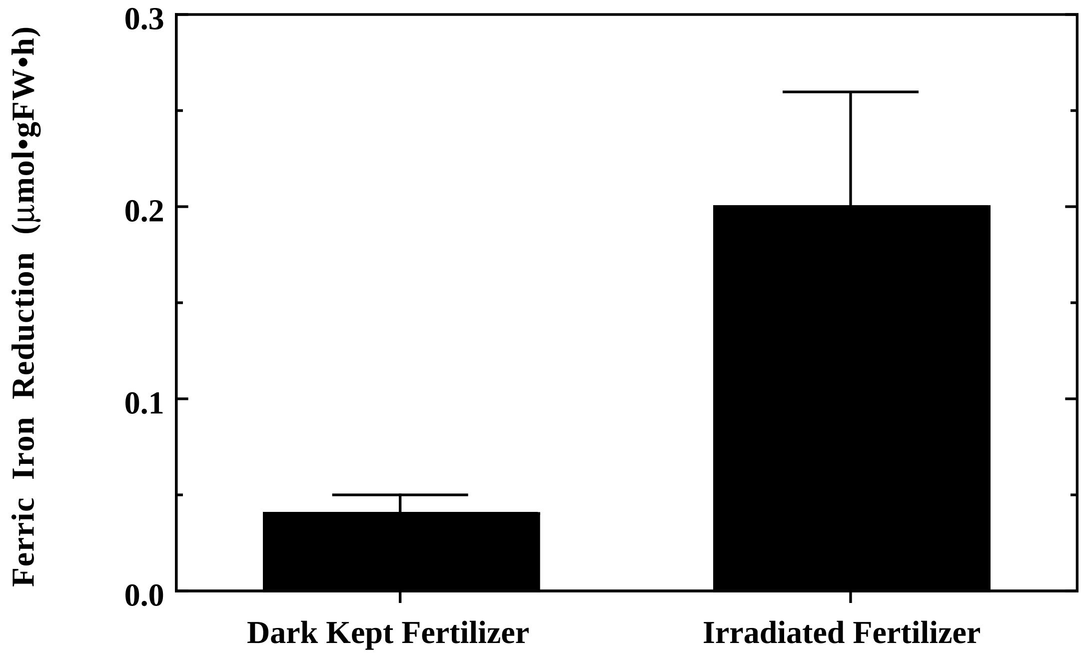

Figure 3. Roots of marigold grown hydroponically in the irradiated fertilizer solutions had ferric iron-DTPA reductase activity, on average, 3.5-times greater than roots of plants grown in fertilizer solutions kept dark.