Fertilizers: Interactions and Overwintering—A Review

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INTRODUCTION

Plant nutrition plays a critical role in the rooting of cuttings. Research (Andersen, 1986) has shown that essential nutrients are calcium, nitrogen (in very limited amounts), potassium, and phosphorus. Important trace elements are zinc and boron but it is difficult to ascertain what the exact requirements are. Nitrogen is by far the most complex and difficult to use and prescribe. While it is apparent that it is essential for such things as cell division and new root development, nitrogen can also place many demands upon the plant energy systems. The supply of nitrogen is complicated by simultaneously trying to meet but not exceed what is required.

EFFECTS OF NITROGEN ON ROOT DEVELOPMENT

The rooting of many plants has been shown to be sensitive to nitrogen. Investigators have found that a lowering of nitrogen increases rooting potential and a lowering of calcium decreases rooting potential. Others have found the rooting of cuttings could be increased by applying phosphorus and potassium while simultaneously lowering nitrogen (Haissig, 1986).

TEMPERATURE

Another factor in root development is temperature. While higher temperatures promote rooting they also cause a reduction of carbohydrate accumulation.

A review by Haissig (1986) noted that starch buildup in cuttings occurs at 15C but not at 25C. Most cutting however root best at 25C. In *Camellia,* rooting is directly related to temperature with more rooting occurring at higher temperatures.

One suggestion to increasing overwintering survival of cutting is to root them as early in the season as possible at the higher temperature, and then move them to a lower temperature regime to allow for more carbohydrate accumulation.

ENERGY CONSUMPTION DUE TO NITROGEN

Nitrogen plays an important part in the nutrition of a plant but it has another role affecting carbohydrate assimilation (Barker and Mills, 1980). The nitrogen requirements for root growth is insufficient for shoot growth. In some instances there is direct competition between the rooting and the subsequent growth of the cutting for the same nutrient. This can lead to an energy deficit in the whole plant (Bryan, 1976). It should be remembered that the roots must expend energy in order to facilitate the incoming nitrogen. Waxman (1965) suggests that for some plants overwintering difficulties are possibly due to low carbohydrate level and/or an inability to harden tissue. Both of these factors appear to have a relationship to nitrogen balance.

In plants, introduced nitrogen (from fertilizer) has to be metabolized in a very highly specific process. Once nitrogen is introduced into the cellular system, it is normally metabolized by conversion to amines and amino acids. In order to do this conversion the plant must provide the necessary carbon skeletons to form the compounds. The plant uses the same enzyme systems and sources of energy to form amines as it does carbohydrates (Barker and MIlls, 1980; Bryan, 1976). Ammonium ion is known to curtail sucrose formation in *Chlorella* (algae) (Bryan, 1976), inhibit photosynthesis, and damage chloroplasts. The relative toxicity of nitrogen, either as ammonium ion (NH_4^+) or nitrate(NO_3^-), to plant cells calls for rapid detoxification at the expense of carbohydrate (Bryan, 1976). The higher the nitrogen input the lower the reduction of carbon dioxide and consequently the lower the production of carbohydrate (Salisbury and Ross, 1978).

Another aspect of nitrogen metabolism is temperature related. When roots are cold, nitrate (NO_3^-) will be transported directly to the leaves and stems and will not be metabolized. It will accumulate until sufficient warmth is attained and then it is rapidly converted to amine (Salisbury and Ross, 1978). This is a third energy drain upon a plant system at a time when energy reserves are already low, i.e., late winter or early spring.

Light appears to be a factor in nitrogen metabolism and ammonium ion may accumulate during darkness when the necessary carbon sources are not available (Stimart and Michael, 1985).

The conversion of nitrogen into nitrogenous metabolites is a two-step process and requires carbon sources at both steps (Bryan, 1976; Stimart and Michael, 1985).

$$\underset{\text{nitrogen}}{NH_4^+} \quad + \quad \text{light} \quad + \quad \underset{\substack{\text{carbon}\\\text{dioxide}}}{CO_2} \quad = \quad \underset{\text{amino acid}}{CH_xNH_2COOH}$$

$$\underset{\text{amino acid}}{CH_xNH_2COOH} \quad + \quad \underset{\text{nitrogen}}{NH_4^+} \quad + \quad \underset{\text{energy}}{\text{energy}} \quad = \quad \underset{\text{more complex amino acid}}{XCH_x(NH_2)_xCOOH}$$

In the above sequence more and more energy is consumed to make use of and to detoxify the ammonium cations. Ammonium is also released during the senescence of leaves (Salisbury and Ross, 1978) where it again requires the use of ATP (energy) to be converted into the amino acid, asparagine. Trees are known to convert this resultant amino acid to storage proteins found in stem tissue. The metabolism of sulfur also results in the formation of ammonium and, as indicated, before results in an energy consumptive process (Salisbury and Ross, 1978).

AMMONIUM TOXICITY

Most modern day fertilizers contain two forms of nitrogen, nitrate (NO_3^-) and ammonium (NH_4^+). Plants evolved with the predominate form of nitrogen being nitrate. They did not have ammonium ion as a common source for nutrition. While many plants can utilize ammonium cation they cannot tolerate its accumulation and its transport within the cellular system is harmful (Bryan, 1976).

Joiner (1983) states that the use of ammonia-based fertilizer can lead to the pathological condition known as ammonia toxicity. Salisbury and Ross (1978) suggest that ammonium ion is directly toxic because it interferes with the production of ATP (energy) in mitochondria and with the photosynthetic electron transport system. Ammonia toxicity manifests itself as restricted root growth, chlorosis and necrosis of leaves, stem lesions, and epinasty (Bryan, 1976). Ammonium ion appears to present itself in ways which are not directly toxic but do much to alter the plant's nutritional balance. Deterioration and loss of leaves is one of the more dramatic aspects of ammonium toxicity (Bryan, 1976). Another symptom of nitrogen toxicity is the delay in the maturation process of fruits and nuts (Shear and Faust, 1980). Poinsettia grown on ammonium fertilizers as opposed to nitrate are stunted, chlorotic, and exhibit leaf abscission (Joiner, 1983). Ammonium sulfate has been shown to be toxic to potatoes on acidic soils and the use of urea and ammonium fertilizer on acidic soils has had deleterious affects on citrus and leather leaf fern. Ammonium toxicity is pH dependant, the more acidic the soil the more pronounced the symptoms. Alternatively, alkaline soils exhibit little or no ammonium toxicity problems (Bryan, 1976).

The adverse affects of ammonium occur after absorption into the plant. One of the most dramatic affects of ammonium intake is through the displacement of potassium (K^+) in the plant. Roots will selectively admit ammonium ion into the plant at the expense of potassium and the situation can become advanced enough to lead to potassium deficiency (Bryan, 1976). Tomatoes have such a preference for ammonium ion that they will absorb it to the point of direct toxicity (Korcak, 1988). Roses are particularly affected by ammonium ion, especially when potassium is limited (Joiner, 1983). Low levels of potassium can in turn lead to phosphorus toxicity (Wright and Nierniera, 1987). Ammonium will eventually reach a level in plants that will decrease root and total plant growth. This can be reduced by the presence of nitrate in the fertilizer, but others (Titus and Seong-Mo, 1982) have indicated that ammonium ion will inactivate nitrate reductase enzyme which leads to a reduction in nitrate metabolism.

In addition to the reduction in the uptake of potassium and nitrate, ammonium ion also reduces the absorption of calcium and magnesium (Bryan, 1976). The reduction of these two ions is proportionally greater than that of potassium; every ion of ammonium absorbed will eliminate two ions of calcium or magnesium. A particular dramatic impact of the exclusion of calcium is that calcium is essential as a co-factor for the metabolism of iron and calcium also plays a very important part in the exclusion of sodium (Salisbury and Ross, 1978). Haissig (1986) asserts that calcium has multiple roles in the rooting process including that of an important role in nitrate reductase enzyme. It is apparent that a reduction or limitation of calcium due to ammonium ion can have serious consequences for plant development.

OVERWINTERING

One of the most significant influences of fertilizer use is in respect to overwintering survival. Stimart (1985) showed that cuttings of *Viburnum*, *Stewartia*, *Cornus florida*, and other species died when treated with fertilizer containing 200 ppm of nitrogen after rooting. Although it was not specified as to the source of the nitrogen there is reason to believe ammonium ion may have played a part in the death of the cuttings.

Smalley and Dirr (1986) gave a definitive review of the overwintering problem in cuttings. Their recommendations centered on fertilizer as being a culprit in the overwintering losses. Specifically they advised that cuttings should not be fertilized after rooting unless the cuttings had broken bud. Then and only then can fertilizer be of benefit to a newly rooted cutting. They also demonstrated that fertilizer cannot be used as an instrument to promote bud break in cuttings, and, in fact, when used in this capacity fertilizer usually leads to the death of the cutting. Stimart (1985) attributed losses in *Acer palmatum* and *C. florida* cuttings to nitrogen delaying vegetative growth and lack of cold acclamation. In particular he attributed a substantial cause and affect to ammonium ion.

Wright and Niemiera (1987) suggested that excess fertilizer applied late in summer may prolong growth and cause freeze damage. Baldwin apples treated with ammonium nitrate in October exhibited severe stem splitting. Pellett and Carer (1981) offered that nitrogen-deficient plants accumulate carbohydrates and are capable of hardening upon exposure to cold temperatures. Stimart's (1985) observations were that ammonium sensitivity varied as a function of physiological state, time of year, and climatic conditions.

CONCLUSIONS

In general the survival of cuttings during the first winter after rooting is best if they are not fertilized (Smalley and Dirr, 1986; Stimart and Michael, 1985). Actions taken to increase winter survival can be accomplished by the use of light (Waxman, 1965); however, subsequent hardening of the cutting can be a problem. Evidence clearly shows that ammonium forms of fertilizer can be particularly harmful to established plants as well as newly rooted cuttings (Pellett and Carter, 1981). Further, the proper timing for ammonium fertilizers is best during spring and early summer (Pellett and Carter, 1981; Stimart and Michael, 1985). Plants are naturally more tolerant of nitrate and are highly intolerant of ammonium (Bryan, 1976).

Clearly the use of the proper source of nitrogen at the right time of the year will do much to alleviate problems associated with overwintering.

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