# THE USE OF SLOW-RELEASE FERTILIZERS

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A large amount of research has been carried out in recent years by a number of organizations throughout the world in the development and testing of various slow-release fertilizer materials. A substantial amount of experience and knowledge has been gained from this work and progress continues in this field. Such interest by many people in slow-release sources of plant nutrients is based on the recognition that conventional fertilizer programs in current use are generally not very efficient and slow-release fertilizers are considered as a potential means of optimizing crop results with improved fertilizer efficiencies. If conventional fertilizer materials could be used efficiently there would be little interest in slow-release fertilizers. I will make several comments regarding conventional fertilizer practices and the fertilizer efficiencies involved.

**What is meant by "fertilizer efficiency"?** Fertilizer efficiency is simply that proportion of the plant nutrients applied in fertilizers which is actually taken up by the plants. Those portions of fertilizer nutrients not recovered by the plants are largely lost by such mechanisms of leaching from the root-zone, fixation into unavailable chemical forms by the soil, and volatilization into the atmosphere (with regard to nitrogen). Fertilizer efficiency can be considered in terms of how many pounds of a given plant food must be applied in order to obtain uptake and utilization of one pound of that nutrient by the plants.

**How efficient are conventional fertilizer programs in ornamental plant production?** If one studies a large number of conventional fertilizer programs in common use for various ornamental and horticultural crops, he can only conclude that they are generally inefficient, wasteful, and more expensive than is commonly recognized. In years gone by, many growers of ornamental plants have turned to fertilizer programs based on the application of conventional soluble fertilizers applied in the irrigation water in order to do away with the labor of frequent hand applications of dry fertilizers. While such liquid feed fertilizer programs save on labor, they are very wasteful in terms of fertilizer efficiency.

For example, many container-grown woody ornamental nurseries using constant liquid-feed fertilizer programs are applying 150 to 200 parts per million nitrogen in the water and, with overhead sprinkler irrigation systems, the water applied will range from 5 to 12 acre-feet per year. This means that with such systems from 2,040 to 6,528 lbs. of nitrogen per acre are being applied annually. Yet, various estimates of nitrogen uptake by ornamental plants indicates only 200 to 600 lbs. N. per acre is taken up by the plants annually. Obviously, much more is being applied than is being utilized by the plants.

If, in a given container-grown crop, 5,000 lbs. of nitrogen per acre were applied annually and only 300 lbs. taken up by the plants, the fertilizer efficiency would be only 6%. This means one would be buying 16.7 lbs. N. to obtain the use of 1 pound. This is equivalent to the purchase of about 50 lbs. of ammonium nitrate of which only 3 lbs. were used by the plants and the remaining 47 lbs. discarded. It is apparent from such calculations that while the cost per pound of conventional fertilizers might be cheap, the waste factors involved present a much more costly fertilizer program per unit of production than most people are aware. Slow-release fertilizers offer potential means of reducing such losses, improving the fertilizer efficiency and decreasing the fertilizer cost per unit of production.

**Excesses of fertilizer salts can have detrimental effects.** Aside from the fertilizer efficiency standpoint, one should also consider that excesses of fertilizers can have detrimental effects on the growing media and on plant growth. Our principal goal in fertilizing plants is to achieve optimum growth or yields, but if a given fertilizer program has harmful effects to any degree, optimization of crop results is then not possible. We should consider the following mechanisms through which excesses of fertilizers can impose harmful effects:

*Salinity:* Fertilizer salts contribute to the salinity of irrigation water and the soil solution. We are all aware of salinity problems where plants are seriously injured from high levels of soluble salts, but consideration should also be given to the fact that even moderate excesses of salinity can reduce the evapotranspiration rates and thereby growth rates of plants. The more fertilizer applied in excess, the greater the risk of detrimental salinity effects. For instance, a commonly used liquid-feed program of 200 ppm each of nitrogen and potassium from ammonium nitrate and potassium chloride will produce a conductivity or salinity level in distilled water of about 1.7 (ECx $10^3$). This salinity level superimposed on the natural salinity of many irrigation waters could be sufficient to produce total salinity levels which could restrict growth of various plant materials. Irrigation waters with conductivity readings about 1.5 (ECx $10^3$) are generally considered poor in quality for most ornamental plants. Yet, a good many ornamental growers using liquid feed programs are developing salinity levels in this range from the concentrations of fertilizers used.

*Soil acidity:* Many conventional fertilizer sources have a potential effect on soil reaction or pH. Most common nitrogen sources have an acidic effect on soil reaction and the magnitude of this effect is generally expressed for each nitrogen source in terms of the pounds of calcium carbonate (limestone) which would be required to counteract the potential acidity. For example, one pound of nitrogen from ammonium nitrate has a potential acidity equivalent of 1.8 lbs. of calcium carbonate lime. When one calculates the potential acidity possible from various conventional ornamental programs, especially for long-term crops, it can be seen this effect can be substantial. More efficient fertilizer programs, requiring lower rates of nitrogen, would help minimize this potential problem.

*Specific ion effects:* Certain plant nutrient ions, as well as other non-nutrient ions, can produce undesirable effects on plant growth, especially so when applied in excessive amounts. Examples are:

(a). Ammonium nitrogen, while an effective nitrogen source at low levels, is toxic in excess amounts. Ammonium toxicity problems are difficult to research and to evaluate, but many fertilizer injury problems have appeared to result from the mechanism rather than to the better understood problems relating to salinity.

(b). Excess phosphate ions tend to reduce the availability to plants of certain trace elements, such as iron.

(c). High amounts of potassium decreases the uptake of calcium and magnesium. The reverse is also generally true.

(d). High amounts of chlorides may develop, such as might be derived from the use of potassium chloride as a potassium source — which is rather common practice. For example, Holley at Colorado State University found a 20% reduction in carnation growth from a constant liquid feed program which supplied 3 milliequivalents per liter Cl, which is equivalent to about 113 ppm potassium in the liquid feed. High chlorides have also been shown to reduce the uptake of phosphorus by plants.

A number of other relationships and interactions occur between chemical ions whereby excesses of one can affect another. To reduce the risks of such effects, it is important that fertilizer programs provide sufficient nutrients to adequately feed plants without substantial excesses. Improved fertilizer efficiencies from slow-release fertilizers offer improvements in this area.

*Contribution to Pollution:* Inefficient fertilizer programs contribute to pollution problems, principally through the loss of soluble fertilizer salts by leaching and this can be a substantial factor. In the previous example where 5,000 lbs. of nitrogen per acre is applied annually and only 300 lbs. of this nitrogen is taken up by the plants, then 4,700 lbs. N., which is equivalent to over 14,000 lbs. of ammonium nitrate per acre, is being lost to the environment except for that portion which would be retained in the soil nitrogen cycle.

It is now apparent, in some areas of the U.S., government regulations are in the formative stage which will restrict such additions to runoff and ground waters. When such regulations come into being, maximum efficiency in fertilization will become necessary and slow-release fertilizers can be helpful with this problem.

**Consider the characteristics of each slow-release fertilizer:** If one studies the various slow-release fertilizers which have been developed, it becomes apparent that each material has its own specific characteristics and it is these characteristics which will influence whether or not a given product will offer a high potential for providing improved plant nutrition and plant growth for a given crop regime. In order to better understand how to evaluate the potential values of a given material, we can consider some of the more important characteristics which would be desirable if one were to propose an "ideal" slow-release fertilizer.

*Release patterns:* Nutrients should release in a pattern to coincide reasonably well with the uptake pattern of the crop in question and a high proportion of the nutrients supplied should be released during that crop cycle. Obviously, a product which released its nutrients over a twelve month period would not be efficient if utilized for a 3 to 5 month crop. The release rate would likely be too slow to adequately feed the crop unless very high rates of application were made to compensate for the slow rate of release but, if this were done, a large amount of the applied nutrients would remain at the end of that crop cycle — which would be inefficient.

*Variations in release patterns:* To achieve good efficiency of nutrient uptake with minimal rates of application, it is desirable that the manufacturing process for a controlled-release fertilizer provide sufficient flexibility to allow production of materials with various release patterns and longevities to meet the differing requirements of various crops. Certainly, a slow-release product which has one unchangeable release pattern and longevity cannot be expected to provide efficient results in both short-term crops, such as potted chrysanthemums, and long-term crops, such as container-grown woody ornamentals.

*Predictable release:* The nutrients from an "ideal" controlled-release fertilizer should release in a reasonably predictable manner over a broad spectrum of soil and environmental conditions. If the release characteristics are unknown or unpredictable, it becomes difficult to select the appropriate rate of application for a given crop which can efficiently supply optimum nutrition.

*Minimum external effects:* The release characteristics of controlled-release fertilizers may be influenced to some degree by one or more environmental factors external to the product itself, such as soil temperature, moisture regime, soil pH, and bacterial activity. The greater the number of external factors which affect the release from a given material, the more difficult it becomes to predict how it will release and perform in a given situation.

*Potential harmful characteristics:* Ideally, a controlled-release fertilizer should not have characteristics which could restrict or harm plant growth or have detrimental residual effects on the soil. For instance, a material which releases large amounts of ammoniacal nitrogen at one period might produce injurious effects on plant material sensitive to ammonia.

*Slow-release nutrients in addition to nitrogen:* While most controlled-release products developed to date provide only nitrogen, many soil areas and crops could also benefit from slow-release potassium and, perhaps, other plant nutrients. Some materials provide slow-release potassium and phosphorus as well as nitrogen. Some controlled-release fertilizers provide nitrogen in both the ammoniacal and nitrate forms and, in certain crops, this is believed to be an agronomic advantage.

Now we might review the specific characteristics of several of these slow-release fertilizers which have proved to have several of the desirable characteristics mentioned and which are available for trial use:

**Sulfur-coated products:** Sulfur-coated fertilizer is one type of coated material which has been widely tested and it appears to offer some desirable characteristics. This process involves the spray application of atomized molten elemental sulfur to encapsulate certain soluble fertilizer substrates, followed by the application of various waxy or oily water-repellent sealants to which has been added a microbial toxic agent to inhibit the degradation of the sealant by soil microbes. Variations in release pattern can be achieved in these products by the use of different thickness of the sulfur coating, quantities and types of sealants (including microbiocides), and substrate particle sizes. External factors which may influence the rate of release of sulfur-coated products include soil temperature, soil moisture, and placement.

The sulfur-coating process has generally utilized urea as the substrate for coating, although other fertilizer materials including ammonium phosphate and potassium chloride have also been successfully coated by this process. Unfortunately, this sulfur coating is not applicable to those materials containing nitrate nitrogen due to the fire and explosion hazards involved with these combinations. In acid, poorly-buffered soils, the long-range acid residual effects from the sulfur applied in these materials may be a detriment, especially for ornamental crops where comparatively high application rates are involved. On the other hand, this sulfur may be beneficial in later years in those soils deficient in sulfur.

**Isobutylidene diurea (IBDU):** This is a condensation product of urea and iso-butyraldehyde, with an ammoniacal nitrogen content of about 31%; the slow-release mechanism is obtained through the slow solubility of the compound which, in solution, hydrolyzes to urea and isobutyraldehyde. Variations in release rates of this material are possible by selection of particle size, by regulating the hardness of the granules, and by adjusting the pH of the finished product when it is used in a compound fertilizer. External factors which appear to have significant effects in regulating the rate of release include soil temperature, soil moisture regimes, and soil pH. IBDU is produced in Japan. These IBDU products, as they are now marketed, are reported to release nitrogen quite slowly for the first 3 to 4 weeks with longevity of 12 to 28 weeks depending on soil factors involved and particle size of the product.

**Urea-formaldehyde:** Ureaforms (urea-formaldehyde) are synthetic non-protein, slow-release sources of nitrogen produced by the polymerization reactions of urea with formaldehyde and usually contain 38% ammoniacal nitrogen. These products are composed of combinations of various proportions of methylene ureas of varying, molecular weights. The lower the water-soluble low molecular weight polymers and the higher the water-insoluble, higher molecular weight polymers contained, the slower the release rate and the longer the duration of nitrogen release.

Nitrogen from ureaform products is made available to plants through the action of soil microbes on the compounds. Any soil factors which influence the degree of bacterial activity such as moisture, temperature and soil pH will also affect the rate of release from ureaform. Smaller particles sizes of ureaform release more rapidly than larger sizes, presumably due to the greater surface area exposure to bacterial activity.

Urea-formaldehyde is widely marketed and used for turf, nursery and ornamental horticultural uses and these products, as now produced, provide approximately one-third of their total nitrogen as cold-water soluble forms which are available soon after application. Another one-third of the nitrogen exists as hot-water soluble molecules and this fraction is released over about a 4 to 6 month period by bacterial action. The remaining one-third of the nitrogen is from hot-water insoluble, complex molecules which release very slowly over a period of many months. Their release characteristics make ureaform more suitable for permanent plantings, such as turf, with comparatively high nitrogen requirements soon after application.

**Multiple, plastic polymer-coated products:** Another type of coated controlled-release fertilizer is produced by the Osmocote process which involves the application of multiple, plastic polymer coatings to prills of various water-soluble fertilizer substrates. The rate of nutrient release and the length of life of such formulations can be controlled over a wide range by the use of various types and thicknesses of coatings which, with a wide selection of fertilizer sources that can be coated, presents the flexibility to produce numerous controlled-release fertilizer formulations with varied nutrient-release patterns, nutrient sources, and plant-food ratios. These can meet the known or estimated requirements of a range of plant and soil requirements. Blending of various coated Osmocote materials in any proportions offer additional flexibility in formulating products with specific characteristics.

When such coated fertilizers are placed in contact with moisture, water enters through the coating, dissolves the soluble substrate core; nutrients in solution diffuse outward through the membrane into the soil solution where they become available for uptake by plants. There is no evidence of degradation of the coating during the release period and deterioration of the coating is not a causative factor in release of nutrients.

Studies have shown the following effects of external factors on the release rate from these coated formulations:

(1). Warmer soil temperatures increase the rate of release from Osmocote and cooler temperatures have the reverse effect. Soil temperatures below freezing produce a temporary cessation of release without injury to the coating; the resumption of soil temperatures above freezing reactivates the release process.

(2). Intermittent, moderate drying of plastic-coated prills, as might occur with surface applications, reduces the rate of release and thereby increases the longevity due to the lack of continuity of moisture to carry out the release process.

(3). External factors which have little or no influence on release rates include soil pH, microbiological activity, external salt concentrations in the soil mass, and soil moisture levels — ranging from permanent wilting point to exceeding field capacity. It is believed that moisture enters the Osmocote prill largely in the vapor phase which explains why the amount of water in the soil has only minor effects on release. As soil temperature is the only external factor which substantially influences the release rate, one can more readily predict how a given Osmocote formulation will release in a given regime.

Since the development of the Osmocote process about 1960, many fertilizer materials have been encapsulated with various coatings and the nutrient release characteristic of these studied. The nutrient release pattern of any of these formulations can be determined in the laboratory by incorporating a known quantity in moist washed sand and then periodically leaching with distilled water. A chemical analysis of each leachate determines the amount of each plant nutrient released during each time period and a release curve can be constructed for each nutrient from this data. By this simple technique, comparisons can be made to evaluate the effect of process variables, such as different compositions and thickness of coatings on a given fertilizer substrate. Also, factors external to the fertilizer itself, such as the effect of various soil temperatures can be studied.

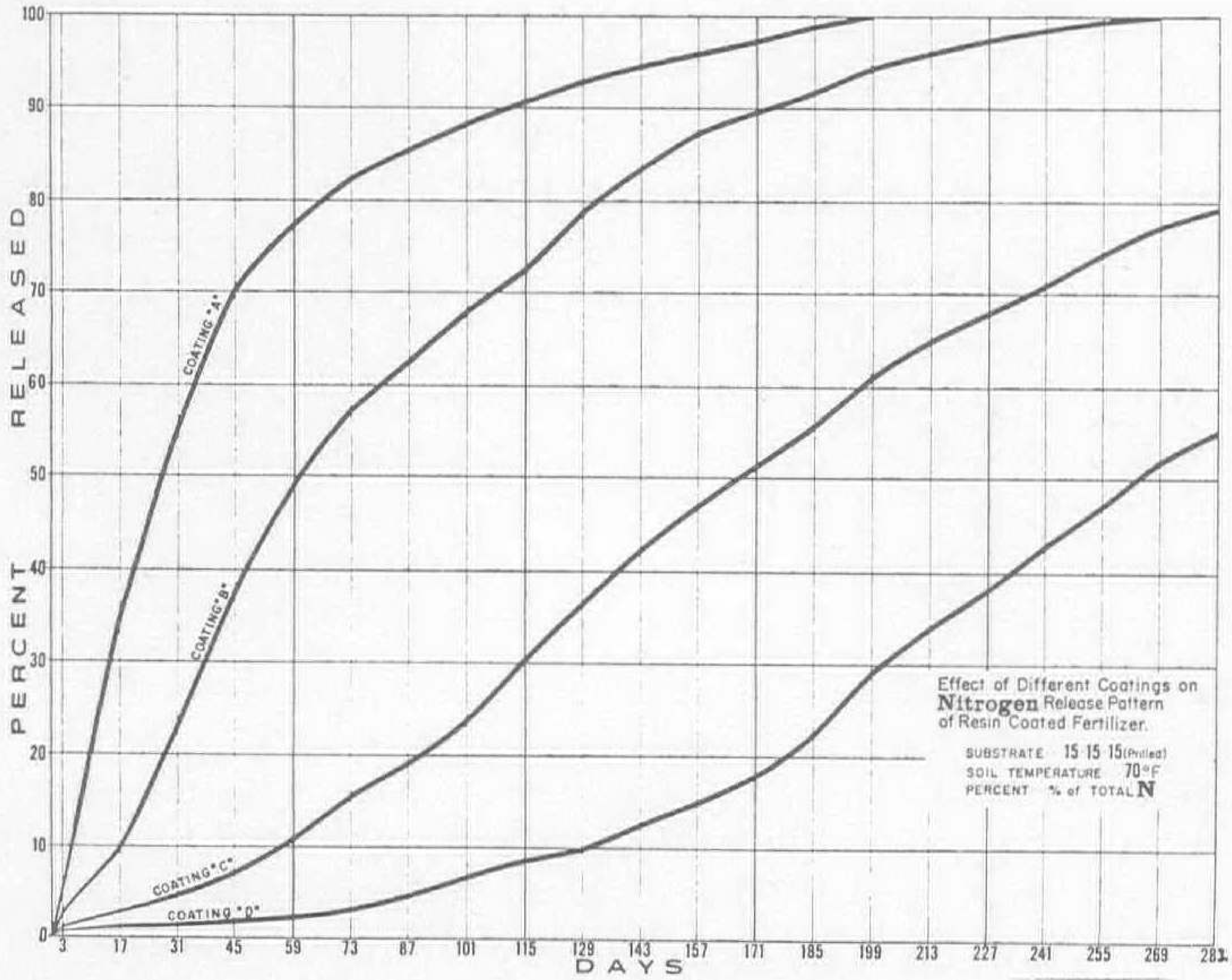


**Figure 1.** Release patterns obtained from different coatings on the same fertilizer substrate.

**Example of effect of different coatings:** Figure 1 illustrates the release patterns obtained from different coatings on the same fertilizer substrate. Note that coating "A", a relatively permeable coating, permitted a fairly rapid release, with about 86% of its nitrogen being expended during the first 90 days. Such a release pattern would be most suitable for short-term crops such as bedding plants, cucumbers, celery, lettuce and flue-cured tobacco.

Coating "B", a moderately permeable coating provided a uniform release of about 80% of its nitrogen over a period of 160 days. Osmocote formulations with similar release patterns are best suited for crops such as field-grown tomatoes, cauliflower, potted floricultural plants, and others with similar growing periods.

Coating "C", a less permeable coating, allowed a comparatively slow release for the first 45 days, followed by an increased moderate rate for the ensuing eight months. Products with similar release characteristics are utilized for once-a-season feeding of long-term crops, such as greenhouse tomatoes, turf, roses, carnations, various nursery stock and strawberries.

Coating "D", a relatively impermeable coating, provides an extremely slow nitrogen release over an 18 to 20 month period. Such materials can be utilized in designing formulations for feeding those long-term crops where efficient reapplication of fertilizer is difficult, such as sugarcane, forest tree plantings, or highway plantings. Such long-term formulations have been evaluated on roses and carnations. Trials with sugarcane in Australia and Hawaii are now being carried out.

**Conclusions:** Various slow-release fertilizers have characteristics which allow their utilization for certain crops and plant materials as a means of improving fertilizer efficiency and optimization of plant nutrition. Long-lasting fertilizers are now widely used in various horticultural and floricultural crops and to a more limited degree in certain agricultural crops such as strawberries and tomatoes. Continued experience and greater knowledge regarding these materials by all of us will certainly lead to greater usage in other crops.