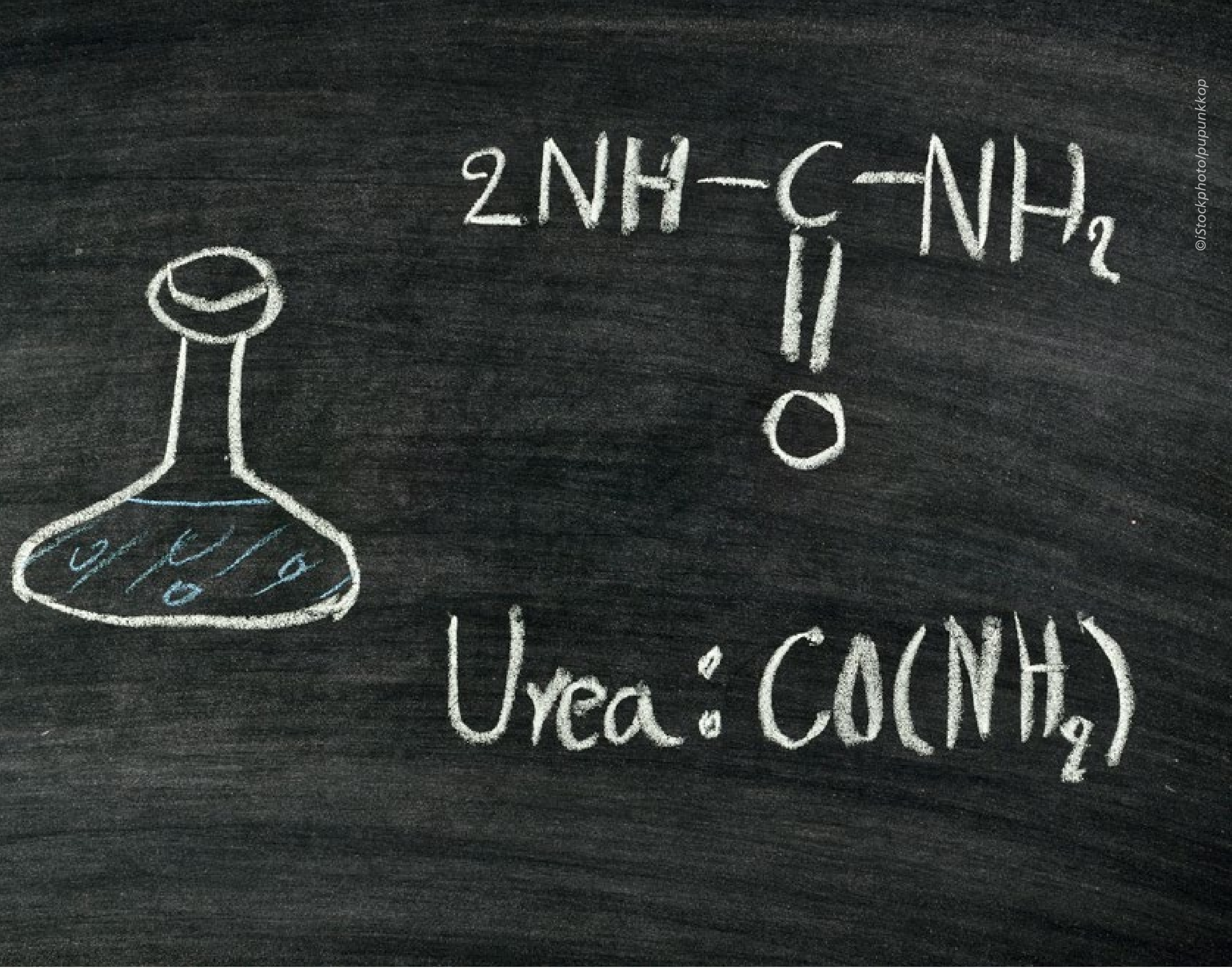

UREA — CITRACULTURE'S AMAZING LITTLE MOLECULE

UREA CAN INCREASE CITRUS FLOWERING, YIELDS, FRUIT SIZE AND GROWER INCOME WHEN APPLIED AT SPECIFIC STAGES OF CITRUS TREE PHENOLOGY

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EXECUTIVE SUMMARY

Timing the application of foliar fertilizers to key stages of tree phenology (periods of intense growth and development, such as flowering, fruit set, exponential fruit growth, vegetative shoot growth and root flushes) when demand for the nutrient is likely to be high, especially when soil conditions are likely to compromise nutrient uptake by roots, has proven successful for increasing yield, fruit size and grower income even when the tree is not nutrient deficient by standard leaf analysis.

Foliar applications of urea (≤ 0.25% biuret) timed to specific stages of citrus tree phenology provide excellent examples of the efficacy of this approach. Winter pre-bloom foliar-applied urea was documented to increase total yield of both navel and Valencia oranges (Citrus sinensis), with an accompanying increase in the yield of commercially valuable-size fruit for navel and juice total soluble solids for Valencia. Adaptation of this treatment to Nules Clementine mandarin (C. reticulata) increased the yield of commercially valuable-size fruit in four separate experiments. A later foliar application of urea to navel orange trees when fruit were at maximum peel thickness increased the total number of fruit per tree and the number of commercially valuable larger-size fruit.

Replacing soil-applied nitrogen fertilizer with foliar-applied urea contributes to fertilizer best management practices and reduces the potential for nitrogen to negatively impact the environment and human health. When properly timed, foliar-applied urea is a cost-effective production management tool for increasing yield of commercially valuable-size fruit and grower profit.

THE BENEFITS OF FOLIAR-APPLIED UREA TO THE ENVIRONMENT, HUMAN HEALTH AND CITRUS PRODUCTION

The benefits of foliar-applied fertilizers in protecting the environment are well known. Specifically, foliar-applied urea reduces the potential for nitrogen (N) accumulation in the soil, run-off water, surface water (streams, lakes and the ocean), and groundwater (drinking water supply), where it can contribute to salinity, eutrophication and nitrate contamination, all of which have a negative impact on the environment and also human health. With less water of good quality available to leach accumulating fertilizer salts from orchard soils, replacing soil-applied nitrogen fertilizers, at least in part, with foliar-applied urea in citrus best management practices will contribute to the sustainability of the industry.

Citrus growers in California have an excellent reputation as stewards of the land. Many adopted the use of foliar-applied urea to partially replace soil-applied nitrogen fertilizer in the late 1970s based on the results of the pioneering research of Embleton and Jones (1974), which demonstrated that maximum nutritionally-attainable yields for sweet orange cultivars annually required between 0.99 and 1.32 lb nitrogen per tree, independent of fertilization method. Foliar-applied urea is a rapid and efficient way to supply nitrogen to citrus trees during periods of high nutrient demand (e.g., flowering, fruit set, exponential fruit growth), or when soil conditions (cold wet soils in spring, hot dry soils in summer, salinity, pH) during the growing season render soil nitrogen, and hence soil-applied nitrogen fertilizers, less available to the tree. Even a transient or incipient nitrogen deficiency needs to be corrected quickly.

The longer the nitrogen status of the tree remains at the low end or below the optimal range during key stages of tree phenology, the greater the negative effects on yield, fruit size, quality and next year's bloom. Foliar urea fertilization provides the nitrogen required for photosynthesis and other important metabolic functions to prevent reductions in carbon fixation, DNA, RNA and amino acid synthesis, hormone metabolism and plant productivity.
For citrus trees grown in California, urea is taken up by young leaves at one-half to two-thirds full expansion, mature leaves and other organs in sufficient quantities to elicit a physiological response. According to PureGro, n.d. of Sacramento, California, the uptake of urea is rapid, with 50 percent of foliar-applied urea moving into

leaf tissues in only 30 minutes to two hours after application, and 96 percent by the end of 12 to 24 hours. Urea-N is phloem mobile and thus can be translocated to all parts of the tree, including the feeder roots. It is no wonder that foliar fertilization can be 5 to 30 times more efficient than soil fertilization in achieving the same yield, depending on the nutrient, crop and soil in which the tree is growing. Thus, foliar fertilization can save growers money over soil fertilization, because the amount of a nutrient applied to the foliage is significantly lower than the amount that must be applied to the soil to achieve the same yield.

The cost of foliar fertilization is frequently associated with application cost. To mitigate this, the goal has been to identify the role that essential nutrients play in the physiology of a tree crop and then to apply that nutrient as a foliar fertilizer at the appropriate time in the phenology of the tree, i.e., a time when the demand for the nutrient is likely to be high in order to stimulate a specific physiological process that increases yield, fruit size or fruit quality. With this knowledge, foliar application of a fertilizer can result in a net increase in grower income, even when the tree is not deficient in the nutrient by standard leaf analysis.

THE EFFECT OF UREA ON CITRUS TREE PHYSIOLOGY

When applied to the foliage, urea is broken down by the enzyme urease into one molecule of carbon dioxide and two molecules of ammonia:

$$(NH2)2CO + H2O \Rightarrow CO2 + 2NH3.$$

The increasing concentration of ammonia quickly activates the citrus tree's metabolic pathways for ammonia detoxification, which includes the accelerated synthesis of the amino acid arginine, which is subsequently used in the synthesis of polyamines. Polyamines are known to regulate many physiological processes, among them flowering, fruit set and fruit size.

Our research provided clear evidence that increasing citrus tree (leaf) ammonia concentrations with foliar-applied urea was accompanied by the accumulation of both arginine and polyamines and also an increase in inflorescence number, flower number, fruit set and fruit size. Flowering in citrus is initiated by low temperature (59-64°F day and 50-55°F night) and moderate water-deficit stress, both of which cause ammonia accumulation in citrus leaves. Thus, foliar-applied urea is used to artificially raise the leaf ammonia content of citrus trees, trigger arginine and polyamine biosynthesis and increase flowering.

Whereas our research on the role of urea in citrus flowering was conducted with five-year-old trees under controlled, optimal temperature conditions, the capacity of foliar-applied urea to increase flower number was confirmed in a commercial Valencia orange grove in Florida by Gene Albrigo. Valencia trees treated with a winter prebloom foliar application of urea produced 45 percent more flowers than untreated control trees.

PROPER TIMES TO APPLY UREA TO CITRUS FOLIAGE

The most effective time to apply urea as a winter pre-bloom spray is around early January in Southern California. In most years, December 15 to February 15 seems to be appropriate for Clementine mandarins and sweet oranges. Later applications (March and April) are better than those that are too early (October and November). This is because once the opportunity to increase flower number has passed, late applications of foliar urea fertilizer can still increase the retention of reproductive organs by improving their nitrogen status and contribute to increasing fruit set and fruit size. However, as time progresses from flowering through early fruit set to June drop, the contribution that foliar-applied urea can make to increased yield has diminished. This is due to the steady increase of flowers and fruit abscision; yield potential also has steadily declined.

When used as a winter pre-bloom foliar spray, urea (46% N, ≤ 0.25% biuret) is applied as a single spray most frequently between January 1 and February 15 for navels and December 15 and January 15 for Clementine mandarins at the rate of 50 lbs. in 200 gallons of water per acre. Lower volumes can be used as long as tree coverage is good, but high volumes (500-700 gallons per acre) show greater incidence of tip burn due to pooling of the urea spray at the leaf tip and increased potential for ammonia toxicity. The summer application of urea is designed to extend the cell division stage of fruit development to achieve an increase in fruit size without increasing yield. Fortunately, in citrus, the end of the cell division stage of fruit development is associated with maximum thickness of the peel. We experimentally determined that in California (Irvine to Madera), maximum peel thickness occurs between approximately June 11 and July 26 for navel, Valencia and Clementine mandarin. In an alternate bearing orchard, maximum peel thickness occurs earlier within this period in high-yield, on-crop years, because peels are thinner than in the low-yield, off-crop years.

When applied in the summer at maximum peel thickness, urea (46% N, ≤ 0.25% biuret) is applied as a single spray typically between July 1 and July 26 for navels or between June 15 and July 7 for Clementine mandarins at the rate of 50 lbs. in 200 gallons of water per acre. Applications of urea that are too early (May and June for Clementine mandarin and navel orange, respectively) increase fruit retention and thus are less effective in increasing fruit size.

Urea applied to the foliage of citrus should not contain more than 0.25% biuret, a compound formed from two urea molecules during the manufacture of urea. Biuret is toxic to citrus, causing leaf chlorosis and tip burn. Urea applications should be made to give good canopy coverage, much like applying a pesticide or plant growth regulator. Solutions should be between pH 5.5 and 6.5. Applications of urea should be made taking into consideration the potential maximum daytime temperature. Winter applications should be made toward midday when it is warm enough for the tree to be metabolically active. If temperatures are projected to exceed 100ºF, summer applications should be made early

High yielding mandarin trees

morning when the air temperature is below 80ºF or early evening as temperatures start to drop. Applications of foliar-applied urea should not be repeated at less than two-week intervals; 30- day intervals are recommended by Unocal Agriproducts.

POTENTIAL YIELD INCREASES WITH A WINTER PRE-BLOOM FOLIAR APPLICATION OF UREA TO CITRUS SWEET ORANGES

A single winter pre-bloom foliar application of urea (54 lbs./acre, 46% N, ≤ 0.25% biuret) significantly increased yield in all three years of the research compared to control trees, which received five times more urea applied to the soil. Urea applied in January or February produced a three-year cumulative net increase of 181 lbs./tree and 143 lbs./tree, respectively. Based on a standard planting density of 96 trees per acre, the foliar-applied urea treatments would have resulted in a net increase of 17,355 and 13,757 lbs. per acre for the three years of the research, respectively. For both application times, with the increase in total yield, there was an increase in the yield of fruit of packing carton sizes 88 and 72 (fruit transverse diameter 2.7-3.1 inches). At the time of this research, the emphasis was on total yield and not on large size fruit. Hence, the yield of fruit of packing carton size 56 (3.2-3.5 inches in diameter) was not determined.

The capacity of a winter (December 25-31) pre-bloom foliar application of urea (54-60 lbs./acre, 46% N, ≤ 0.25% biuret) to increase total yield per tree was tested with Valencia juice orange trees in Florida by Albrigo. The treatment resulted in a four-year cumulative net increase of 14,247 lbs. of fruit per acre and a four-year cumulative net increase in juice total soluble solids of 1,183 lbs. per acre.

CLEMENTINE MANDARINS

To adapt the winter pre-bloom foliar application of urea to Nules Clementine mandarin, orchards in two different growing areas of the state, Grapevine (35° N, 119° W) and Fresno (36° N and 119° W), were treated with urea (50 lbs./acre, 46% N, ≤ 0.25% biuret in 200 gallons of water/acre) applied monthly from November through February to the foliage of different sets of trees. For Nules Clementine mandarin trees in either orchard, foliar-applied urea did not increase total yield per tree in any year of the study or as two-year cumulative total yield compared to untreated control trees. In contrast, in both orchards, the winter pre-bloom foliar application of urea significantly increased the yield of commercially valuable-size fruit in pounds and number of fruit per tree.

In Grapevine, at the southern end of the San Joaquin Valley, the most effective application time was mid-December. Fruit yield of jumbo size (fruit transverse diameter 2.54-2.79 inches) was significantly increased in both years of the experiment and thus significantly increased the two-year cumulative yield of jumbo-size fruit as both pounds and number of fruit per tree compared to the

California grows picture perfect fruit for the fresh fruit market

control trees. The December application of urea also increased the two-year cumulative yield of mammoth-size fruit (fruit diameter >2.79-3.05 inches) compared to all treatments, except the January foliar application of urea. At planting densities of 242 trees per acre (12 x 15 feet) to 538 trees per acre (9 x 9 feet), the December foliar application of urea would have resulted in a two-year cumulative net increase in yield of jumbo-size fruit (2.54-2.79 inches in diameter) of 5,593 and 12,426 lbs./acre for the two planting densities, respectively.

In Fresno, 140 miles north of Grapevine, it was the early January (January 9) winter pre-bloom foliar application of urea that significantly increased the two-year cumulative yield of commercially-valuable fruit of packing carton size 28 (fruit diameter 2.32-2.40 inches) as both pounds and number of fruit per tree compared to the untreated control trees. These results confirm that for Clementine mandarin, the winter pre-bloom foliar application of urea increases the yield of commercially valuable-size fruit with no effect on total yield. At planting densities of 242 to 538 trees per acre, the two-year cumulative net increase of only 16.5 lbs. (66 fruit) of commercially valuable larger-size fruit per tree would have resulted in a net increase of 3,467 lbs. (15,972 fruit) to 7,710 lbs. (35,508 fruit) per acre.

OTHER CULTIVARS OF MANDARIN

The potential efficacy of this foliar fertilization strategy when used on other cultivars of *C. reticulata* is suggested by the results obtained with a winter pre-bloom foliar application of urea (57.6 lbs./acre, 46% N) to Nour and Cadoux mandarin trees in Morocco. For both cultivars, the January application produced better results than the November or December applications and resulted in a significant increase in total yield, total number of fruit per tree and the yield (and number) of commercially valuable export-size fruit (fruit transverse diameter >2.04 inches). The net increase in total yield compared to the untreated control trees was 105 lbs./tree for Nour and 98 lbs./tree for Cadoux, with net increase in export size fruit of 43 lbs. and 68 lbs. per tree, respectively. At planting densities of 242 to 538 trees per acre, the winter pre-bloom foliar application of urea would have resulted in a net increase in export-size fruit ranging from 10,406 lbs. to 23,134 lbs. per acre for Nour and 16,456 lbs. to 36,584 lbs. per acre for Cadoux.

In all experiments, the winter pre-bloom foliar application of urea tended to increase juice total soluble solids and the ratio of total soluble solids to acid each year. No negative effects on any fruit quality parameter measured (individual fruit size and weight, peel quality, peel thickness, total juice and percent juice per fruit, total soluble solids [ºBrix], percent acidity, total soluble solids to acid ratio) resulted from foliar application of urea. Regreening was not observed.

THE INFLUENCE OF ALTERNATE BEARING ON THE WINTER PRE-BLOOM FOLIAR APPLICATION OF UREA

For navel orange trees and the Nules Clementine mandarin trees located in Grapevine, the winter pre-bloom foliar application of

Navel orange flowers at (A) anthesis and (B) petal fall.

urea had a significant effect on yield and fruit size, respectively, for each year of the experiment, despite the fact that the orchards were alternate bearing. In contrast, for the Nules Clementine mandarin orchard in Fresno, the positive effect of the January winter pre-bloom foliar urea application was due to a significant increase in the pounds and number of larger fruit per tree in the lower-yielding, off-crop year and a numerical but non-significant increase in the yield of larger-size fruit in the higher-yielding, on-crop year (> 1,000 fruit per tree).

In the experiments presented above, the winter pre-bloom foliar application of urea had a significant effect on fruit size only when the crop load of the untreated control trees was less than 1,000 fruit per tree. This result is consistent with research demonstrating that gibberellic acid (GA3) was only effective in the low-yield years (less than 1,000 fruit per tree) of two Clementine mandarin orchards. In these cases, increased fruit size was achieved even when foliar-applied urea or GA3 increased fruit number above 1,000 fruit per tree.

The effect of crop load on the response of Clementine mandarin to foliar fertilizer and GA3 treatments was likely due to the differences in the number of flowers produced at bloom in the lower and higher yield years. The intense bloom resulted in a large number of fruit being set that likely saturated the carrying capacity of the trees and made it difficult to enhance fruit set further with foliar-applied urea or GA3. The capacity of the winter pre-bloom foliar application of urea to increase yield of commercially valuable-size fruit when yield was less than 1,000 fruit per tree was likely due to supplying nitrogen early in the season, when soil conditions could compromise uptake of nitrogen from the soil, to support fruit growth at the cell-division stage of fruit development. In addition, it is important to point out that the winter pre-bloom foliar application of urea did not initiate or exacerbate alternate bearing in any orchard.

POTENTIAL INCREASES IN THE YIELD OF LARGE-SIZE FRUIT WITH A SUMMER MAXIMUM PEEL THICKNESS

A single summer application of urea (54 lb/acre, 46% N, ≤ 0.25% biuret) to the foliage of navel orange trees in early July significantly increased the total number of fruit per tree with a numeric, but not significant, increase in total lbs. per tree, and increased yield of commercially valuable-size fruit of packing carton sizes 88 (fruit transverse diameter 2.7-2.9 inches), 72 (fruit diameter 3.0-3.1 inches) and 56 (fruit diameter 3.2-3.5 inches) as both pounds and number of fruit per tree compared to control trees. The treatment resulted in a net increase of 76 lbs. of fruit in the combined pool of fruit 2.7 to 3.5 inches in diameter per tree. At a planting density of 96 trees per acre, the summer application would have resulted in a net increase of commercially valuable large-size fruit (packing carton sizes 88-56) of 7,296 lbs./acre in a single year, of which 2,947 lbs./acre was fruit of packing carton size 56.

GROWER INCOME

The increases in yield of commercially valuable-size fruit obtained with the foliar urea fertilization strategies described herein should increase grower revenue. Low-biuret urea is relatively inexpensive. Depending on application costs, properly-timed foliar urea applications have the potential to increase grower net income in a given year and especially over time.

Additional information is provided in the chart below. It is designed to aid in deciding whether to use foliar-applied urea as a production management tool in a given year. Please keep in mind that this information is the best interpretation of our results and those of others to date and that they are subject to modification as additional results are obtained. Application time is important. Results for a specific cultivar in a specific production area might be improved by determining the best application time for the cultivars growing in that area. However, keep in mind that the time of irreversible commitment to flowering or maximum peel thickness, the two phenological stages targeted for urea application, can occur earlier or later than is typical due to the greater variations in climate that are occurring as a result of global climate change. Thus, despite all our best efforts, there will be some years in which the urea sprays are not properly timed, and the only benefit derived from the foliar application of urea is increased tree nitrogen status.

When to use a winter pre-bloom foliar application of low-biuret urea

- When your production goal for the year is to increase yield
- When your current harvest is a heavy on-crop and you anticipate a low return bloom and an off-crop; spray urea in the winter preceding the anticipated off-bloom
- When you hang your fruit late, which reduces return bloom, a winter pre-bloom urea application will provide nitrogen to support the mature fruit and flower development
- If we have a mild winter with insufficient chilling to induce a good bloom
- If winter soils are cold and/or wet; if this condition occurs in February and March, late foliar urea applications can be beneficial for increasing yield and fruit size
- When you wish to increase total soluble solids in your fruit or pounds solids per acre

When to use summer maximum peel thickness applications of low-biuret urea

- When your production goal for the year is to increase fruit size
- When you are carrying a heavy on-crop and need to increase fruit size

Other considerations

- When cost is an overriding consideration, low-biuret urea is an inexpensive fertilizer, and only one application is required to increase yield of commercially valuable-size fruit or increase fruit size; use low-biuret urea after considering the above
- When your production goal is to increase fruit size, do not use a winter pre-bloom urea spray as the increased yield will make it more difficult to increase fruit size; use urea as a summer application only
- If maturing fruit have rough, thick peels, do not use urea as a winter pre-bloom spray when the mature fruit are still on the tree; similarly, if young developing fruit exhibit this peel disorder, do not use urea as a summer maximum peel thickness spray
- When spring soils are cold and wet and trees are yellow, use urea as a winter pre-bloom spray after considering the above; the trees could be nitrogen deficient until the soils warm up sufficiently for nitrogen and other nutrients to be available to the roots and for the roots to be able to take them up; nutrient deficiencies, even transient or incipient deficiencies, need to be corrected quickly to prevent negative effects on citrus tree physiology, flowering, yield, fruit size or quality
- If you have high leaf nitrogen concentrations (>3.3% N), do not apply urea: (a) it will likely have no effect on yield; and (b) it could reduce fruit size, especially if leaf potassium is not sufficient or not in balance with leaf nitrogen

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