HS-756

A Summary of N, P, and K Research on Potato in Florida[1]

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Potato production in Florida in 1996-97 represented 6.1% of the $1.6 billion state vegetable industry (Fla. Agric. Stat. Serv., 1998). Eighty percent of potatoes grown in the state are harvested in May and June in what is considered the spring planting. Of this amount, 85% are harvested from the Hastings area including Flagler, Putnam, and St. Johns counties and the remaining potatoes are harvested from areas in central and south Florida. Potatoes harvested in January through April from the winter planting season are grown in southeast (Dade county) and southwest (Collier and Lee counties) Florida.

Current nutrient recommendations for potatoes specify maximum rates of 175, 120, and 140 lb/acre N, P_2O_5, and K_2O (Hochmuth and Hanlon, 1995). The recommended rate of applied phosphorus (P) is reduced to 60 lb/acre P_2O_5 when potato is grown on soils having medium concentrations of this nutrient and zero lb/acre when high and very high soil P concentrations are present. Results of a survey of potato growers fertilization practices in the late 1980s showed that average fertilizer rates used were 270-100-270 lb/acre (N-P_2O_5-K_2O). A random sampling of potato growers from St. Johns, Flagler, and Putnam counties were asked if they had changed their application rates of N, P, and K over the years 1983 to 1993 (Swisher et al., 1995). Of the respondents, 55% had not changed their nitrogen (N) application rate, 61% used the same amount of P, and 32% continued to apply the same rate of K. Those who answered positively to using less N, P, and K during this period were 24%, 15%, and 29%, respectively, while a similar number said they used more, 21%, 24%, and 29%, N, P, and K, respectively. How nearly these applied fertilizer rates approached the recommended rate was not given, but, researchers were encouraged by the positive response of all surveyed growers to the use of a calibrated soil test either annually or before each crop season.

Potato fertilization research has been conducted in Florida for fifty years. During this time, changes have occurred in potato production practices including new cultivars, refinements in fertilizer application timing, use of fertilizer recommendations based on soil nutrient analysis, use of nematicides, and improved weed and pest management practices. The purpose of this publication is to summarize potato fertilization research leading to current University of Florida recommendations for potato fertilization and to summarize needs for additional

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research. Unless otherwise indicated, all potatoes were irrigated by subsurface irrigation.

Data Summary Method

To evaluate potato yield response to variable rates of fertilizer, a method was needed to standardize statewide yield results expressed in units of tons/acre, metric tons/hectare, or hundred-weight/acre (cwt/acre). Relative yield (RY), a calculated percentage, was chosen as the unit to express potato yield responses to fertilization. The highest yield obtained for each fertilizer experiment was assigned a 100% value and other yields were expressed as a percentage of the highest yield. The actual yield in cwt/acre units was presented for the treatment corresponding to 100% RY. The RYs were plotted against rates of nutrient to determine how potato yields responded to fertilizer in Florida. The RY presentation allowed inclusion of data from different experiments and locations throughout the state representing various cultivars, planting seasons, and growing conditions in a graphical summary of yield responses to fertilization. For most studies, RYs of 95 to 100% were not significantly different.

Nitrogen Mixed Fertilizer Trials

Mixed fertilizers were used in potato trials from 1947 through 1967 to establish crop nutrient requirements and evaluate fertilizer application methods (Fig. 1). Attributing crop response to a single nutrient, however, could not be done with certainty from a blended N-P-K material. Since N was usually the most limiting nutrient in sandy soils, yield responses in mixed studies are considered here as responses to N. All trials discussed in this section were conducted in Hastings, Florida, unless otherwise indicated.

Side-dress applications of fertilizer from a 5-7-5, 5-7-6, or 6-8-8 ($N-P_2O_5-K_2O$) fertilizer were used to evaluate the effects of N-P-K on potato yield in experiments from 1947 through 1955 (McCubbin and Myhre, 1955). Fertilizer applied at planting was banded on either side of the plant row to supply 100 lb/acre N in 1947 and 1948, and 110 and 120 lb/acre N in 1949 and 1950, respectively. Due to a wet season in 1947, additional fertilizer was applied to the sides of the row 70 days after planting. Continued rainfall after fertilizer side-dressing resulted in similar potato yields as potatoes that had received no side-dressed fertilizer. Average yield during the 1947 season was 60 cwt/acre. In the other seasons, additional fertilizer was side-dressed before blossom time or 45 to 60 days from planting. Leaching rainfall occurred before fertilizer was side-dressed in 1948, and a significant yield response to side-dressed fertilizer resulted. Plots that received 100 lb/acre side-dressed N (200 lb/acre total N) from mixed fertilizer yielded 141 cwt/acre compared to 74 cwt/acre from potatoes that received no fertilizer side-dressing (100 lb/acre total N). Though rainfall was below normal in 1949 and 1950, rain occurred in sufficient amounts after fertilizer side-dressing for acceptable yields. Yield responses to high side-dressed N rates were minimal. Optimum yield occurred with 160 lb/acre total N (226 cwt/acre, 100% RY) in 1949, and with 145 lb/acre total N (152 cwt/acre) in 1950. Yields in all four experiment seasons with higher N rates were not significantly different from yields with lower N rates.

Comparison of yield responses to side-dressed fertilizer continued in 1954 and 1955, with side-dress mixed-fertilizer applications applied in addition to a base (at planting) application of 120 lb/acre N. In 1954, 30 lb/acre N was side-dress applied in experiments on Leon, Bladen, and Rutledge fine sand soils. Yield on the nutrient-poor, Leon fine sand soil, was higher with the 30 lb/acre side-dress application, 150 lb/acre total N (187 cwt/acre, 100% RY), than with the base fertilizer application only (86% RY). Similar yields resulted with or without the side-dress fertilizer application on the heavier Bladen and Rutledge fine sand soils. High yields occurred each year with the base-mixed-fertilizer application supplying 120 lb/acre N, resulting in 285 cwt/acre and 257 cwt/acre, respectively. Yields in 1955 on Bladen fine sand soils were also unaffected by additional side-dressed fertilizer. High yield resulted this season with 15 lb/acre of side-dressed N, 135 lb/acre total N (191 cwt/acre, 100% RY) and did not increase with 30 or 60 lb/acre side-dressed N to 180 lb/acre total N. Researchers concluded that side-dressed fertilizer had little yield effect on dark sand soils, but when applied to light sand soils, yields were significantly improved. The soil organic matter concentration, not measured in these experiments,

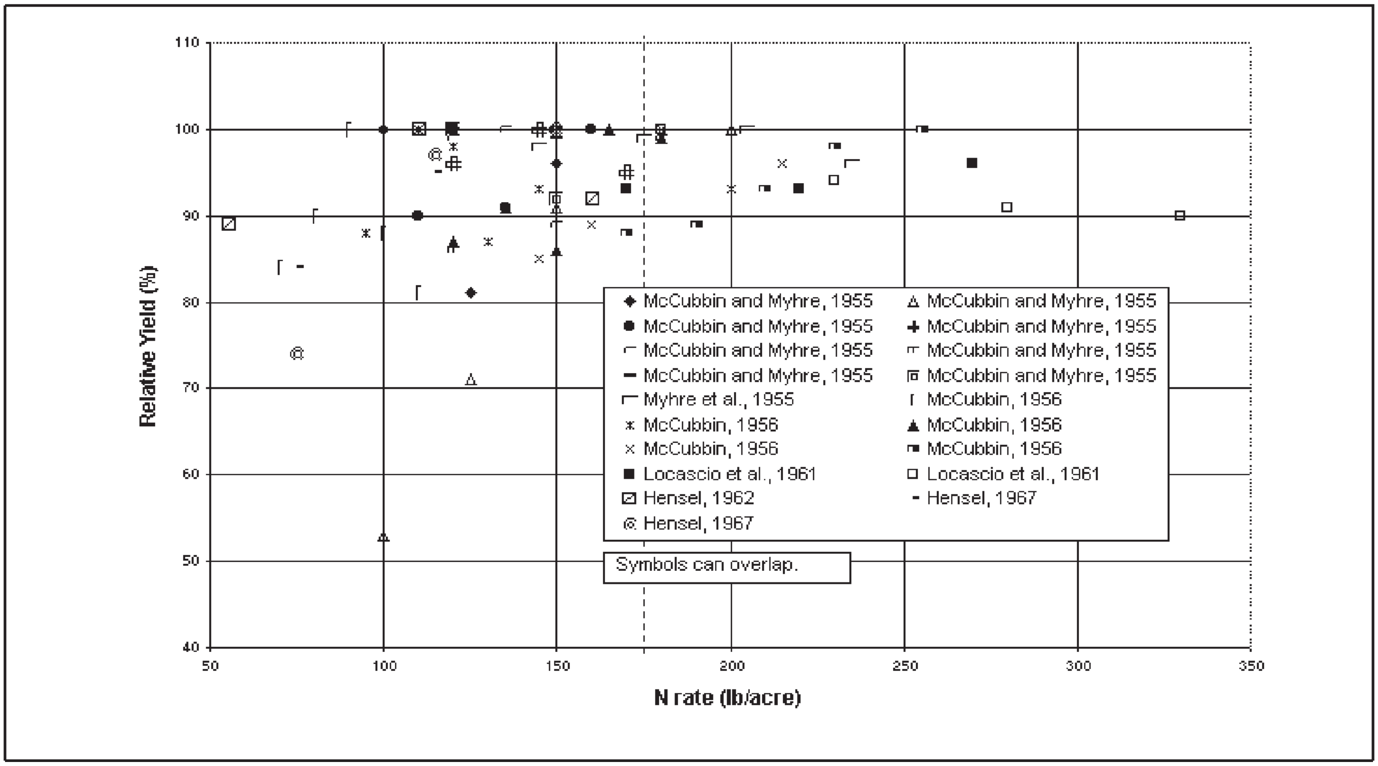

Figure 1. Relative yield of potatoes for experiments, years, and seasons as a function of added N (mixed fertilizer).

was described as moderate for both the Bladen and Rutledge fine sand soils.

Soil moisture content, seeding rate, and fertilization are factors used by growers to increase potato yields (Myhre et al., 1955). Researchers conducted a factorial experiment using sixteen soil moisture concentrations, four N rates, and two seeding rates on Bladen loamy fine sand soil, considered an old potato production soil. Soil moisture concentrations were achieved by running water through every other furrow. The water height in the "wet" furrow was maintained at four inches from the bed top. All fertilizer treatments received 6N-8P_2O_5- 8K_2O as 100 lb/acre N at planting and an additional 40 lb/acre N, 40 days from planting. Total applied N treatments were 140, 170, 200, and 230 lb/acre from additional side-dress applications of 30 lb/acre N from $NaNO_3$, 58 days after planting (treatment 2), 60 lb/acre N from 6N-8P_2O_5-8K_2O, 18 days before planting (treatments 3 and 4), and 30 lb/acre N from $NaNO_3$, 58 days after planting (treatment 4). Because higher yields occurred with the seeding rate of 2,450 lb/acre or seeds spaced 8 inches apart, yields with the lower seeding rate of 1,470 lb/acre will not be presented.

Soil moisture concentrations were generally 12, 10, and 8%; considered wet, center-bed moist, and dry, respectively, as estimated on an oven-dry basis. The highest potato yields resulted from moist soil-water conditions, lower yields from dry field conditions, and lowest yields from wet soils where root knot nematodes and pink rot disease reduced yields. Total marketable yields were nearly double the local average yields of about 160 cwt/acre in 1955. Marketable yields were similar with all N rates, optimizing with 200 lb/acre N (307 cwt/acre, 100% RY). Marketable yields with 140, 175, and 235 lb/acre N were 98%, 99%, and 96% RY, respectively. Researchers noted no yield advantage from application of 60 lb/acre N three weeks before planting, but suggested additional studies were needed to confirm the findings of this trial.

Experimentation to increase yield continued as researchers sought to evaluate the profitability of potato yields from plants grown 13 inches apart to plants grown 10, 8, 6.5, or 5.6 inches apart (McCubbin, 1956). Experiments were conducted on leveled land prepared in furrows for subsurface irrigation. Yield results were presented for each seeding rate. Fertilizer from 6N - 8P_2O_5 - 8K_2O was banded on each side of the plant row before planting to supply from 70 lb/acre to 255 lb/acre N, with the higher N rates applied with the closer seed spacing rates.

The optimum seeding rate for potato was determined by research (1943 to 1953) to be 2,450 lb seed/acre or seeds spaced eight inches apart in rows 40 inches apart. After leveling the field and improving the irrigation system, researchers in 1956 again found the eight-inch seed spacing to be the most profitable for potato production based on the net profit after sale of US 1A and US 1B potatoes. Optimum yields occurred with this seed spacing with 165 lb/acre N (355 cwt/acre, 100% RY). Yields of 383 cwt/acre resulted from potatoes spaced 5.6 inches apart and fertilized with 255 lb/acre N, but profit was reduced 6% by the higher costs associated with the closer seed spacing.

Attempts at finding a stable material to enrich the organic matter composition of Florida sand soils were marginally successful with application of eight- to ten-year-old pine sawdust applied at 0, 5, 10, 15, or 25 tons/acre (Locascio et al., 1961). Experiments were conducted on Kanapaha fine sand soils near Gainesville. Applied sawdust was disked into the upper six inches of soil and N rates of 0, 50, or 100 lb/acre (from 6N- 8P_2O_5-8K_2O) were applied broadcast. Additional fertilizer from 6N-8P_2O_5-6K_2O was banded in the row at 120 lb/acre N in 1957 and at 180 lb/acre N in 1958. Yield responses were averaged over four rates of applied sawdust for each rate of applied N in potato experiments conducted in 1957 and 1958. Marketable US No. 1 and 2 potato yields were not affected in either season by the rate of applied N or by the rate of applied sawdust. High yields occurred with 120 lb/acre N (187 cwt/acre, 100% RY) and with 180 lb/acre N (178 cwt/acre, 100% RY), in 1957 and 1958, respectively. Soil organic matter, tested in 1958 with the Walkley method, had not changed one year after application of 0 tons/acre of sawdust, 1.81% organic matter, to 25 tons/acre of sawdust, 1.85% organic matter.

Black polyethylene mulch had a positive effect on potato yield and quality (increased yield of size A potatoes) in 1961 and 1962 experiments (Hensel, 1962b) but, had a negative effect on yield and potato quality (specific gravity) when the planting season was delayed one month to February 14 in a 1964 experiment (Hensel, 1967). All black polyethylene mulch treatments in 1965 resulted in higher yields than unmulched treatments with three planting dates, January 13, 27, or February 10, and two harvest dates, April or May (Hensel, 1968). As the planting date was delayed this year, yields of polyethylene mulched and unmulched plants increased. In 1966, only January planted, polyethylene or aluminum-foil mulched, potatoes resulted in higher yield than unmulched potato plants. February planted potatoes yielded similarly this season whether mulched or unmulched. The 1961 and 1962 experiments were conducted on Ona fine sand, while the remaining experiments were conducted on Rutledge fine sand.

No interaction occurred between mulch and fertilizer rates in 1962 through 1964. Yield responses to increasing N rates from 6N-8P_2O_5-8K_2O fertilizer were averaged over mulched and unmulched treatments. In 1962, yield responses to N rates 55, 110, or 160 lb/acre were optimized with 110 lb/acre N (147 cwt/acre, 100% RY) (Hensel, 1962b). In 1963 and 1964 (Hensel, 1967), yields responded to N rates 75, 115, or 150 lb/acre and were optimized with 150 lb/acre N in both seasons (213 and 193 cwt/acre, respectively, 100% RYs).

Nitrogen

Current fertilizer application recommendations for potato specify no fertilizer application before planting (Hochmuth and Maynard, 1996). Band applied fertilizer is recommended at planting or at crop emergence for all applied P_2O_5, 70 lbs/acre K_2O, and 60 to 90 lb/acre N with side-dress application of the remaining N and K fertilizers 35 to 40 days later. Split-application of N in this manner is a safeguard against leaching with subsurface or overhead irrigation common to potato production.

Comparison of yield responses to factorial combinations of three N and P rates were conducted on long-term potato cropped soils and newly cleared soils in Hastings (Hensel, 1962a). Fertilizer, including 240 lb/acre K_2O, was placed preplant in bands beneath and to the side of each plant row. On old cultivated soils, potato yields were not different with increasing N (70, 140, or 210 lb/acre N) optimizing with 140 lb/acre N (146 cwt/acre, 100% RY). On newly cultivated soils, potato yields responded quadratically to increasing N rates (70, 140, or 210 lb/acre). Researchers suspected a drier season limited yields with higher N rates when high yields resulted with 70 lb/acre N (178 cwt/acre, 99% RY).

Researchers conducted trials in Gainesville and Hastings to reduce fertilizer losses through the use of controlled-release (CR) N fertilizers (Elkashif et al., 1983). Fertilizer treatments included 100% preplant applications of isobutylidene diurea (IBDU), sulfur-coated-urea (SCU), or NH_4NO_3, or split N applications, 67% of N applied preplant as IBDU (coarse or fine grain), or SCU followed by side-dress application of NH_4NO_3 four weeks from plant emergence. Preplant fertilizers were placed three inches below and to each side of the seed tuber. Side-dress fertilizer applications were banded 7.5 inches from the plant. Seed tubers were planted in mid-February at each site and the crop received above average rainfall through March. Very dry weather in April and May was supplemented with overhead irrigation in Gainesville (0.75 inches/week) and subsurface irrigation in Hastings (2.2 inches/week). Applied fertilizer rates were 100 or 180 lb/acre N, 230 lb/acre P_2O_5 from concentrated superphosphate (applied preplant), and 240 lb/acre K_2O from K_2SO_4 (33% side-dressed).

In Gainesville, marketable yields were not significantly affected by N source (average yield, 237 cwt/acre) or by N rate (average yield, 237 cwt/acre). Marketable yields were 7% higher, however, with split-N applications (average yield, 245 cwt/acre) than when all fertilizers were applied preplant (average yield, 230 cwt/acre). Researchers indicated that with overhead irrigation, split-applied N reduced fertilizer leaching losses and resulted in higher yields. With subsurface irrigation in Hastings, however, marketable yields were similar with 100% preplant NH_4NO_3, or split-N applications of IBDU (coarse grain), IBDU (fine grain), or SCU with NH_4NO_3 side-dressed (average yield, 270 cwt/acre). Researchers cited better nutrient retention in the root zone with subsurface irrigation, compared to overhead irrigation, for the equal response to 100% preplant NH_4NO_3 and the split-N application method. Yields were lower with 100% preplant CR - N sources IBDU (coarse) or SCU (average yield, 219 cwt/acre) due to reduced N release from these sources under cooler winter to spring soil temperatures. Significantly higher yields resulted at Hastings with 180 lb/acre N (266 cwt/acre, 100% RY) than with 120 lb/acre N (91% RY).

Measurable changes in leaf-tissue concentrations of N, P, and K occurred for leaf samples taken between four and eight weeks after plant emergence. Leaf tissue N, P, and K concentrations fell 31%, 40%, and 35%, respectively, during this period when nutrients are largely translocated to the developing tuber. Leaf tissue concentrations of Mg and Ca increased by 50% at eight weeks, compared to concentrations at four weeks.

The heat requirement of some CR fertilizer sources for the release of nutrient can lead to reduced efficiency of these fertilizers for cool season crops such as potato. In the Hastings experiment described above, split application of SCU or IBDU with NH_4NO_3 performed as well as a single preplant application of NH_4NO_3. Researchers working with a hydrophilic gelling agent incorporated into liquid urea-ammonium-nitrate (UAN) in the spring of 1990, hoped to develop an efficient, leach resistant, single application N-fertilizer source that was not dependent upon heat for release (Locascio and Hensel, 1990). As with all CR - N sources, only during seasons of excessive rainfall are the full benefits of these fertilizers realized. In this study, average to below average rainfall minimized the effect of the gelled fertilizer.

Two N rates, 125 and 225 lb/acre, were applied from four liquid N treatments, with or without the gelling agent. A fifth dry fertilizer treatment was included. Liquid urea-ammonium-nitrate (UAN) treatments included UAN combined with a non-ionic gel, with an anionic gel, with a cationic gel, and without a gel. A dry UAN fertilizer treatment was also applied. All treatments were applied after planting, Februrary 7, 1990, using a liquid N-fertilizer applicator. The experiment was conducted near Hastings on Ellzey fine sandy soil to which subsurface irrigation was applied at 3 inches/week.

An interaction occurred between gel treatment and fertilizer rate. Marketable yields were higher when potato plants were fertilized with liquid or dry UAN and liquid UAN with cationic gel or anionic gel than those fertilized with liquid UAN with nonionic gel. Marketable yields with all N treatments were similar with 225 lb/acre N and generally higher except with the liquid UAN where high yield resulted with 125 lb/acre N (300 cwt/acre, 100% RY), and 90% RY with 225 lb/acre N (plotted in Fig. 2).

Experiments were conducted in 1983 and 1984 on Ca and P rich Ellzey sands (Yuan et al., 1985c). Researchers planned to balance the high Ca and P concentrations in these soils and increase yields, by raising the soil N and K fertility. Yield responses were evaluated for N rates of 150 or 200 lb/acre N (50 lb/acre side-dressed five weeks from planting). Three K rates, 0, 140, and 200 lb/acre K_2O, were applied with each N rate at planting, and an additional 50 lb/acre K_2O were side-dressed at five weeks. The effect of increased N rates on marketable yields (averaged over all K rates) was not significant in either year. Marketable yields with 200 lb/acre N each season were 202 and 194 cwt/acre (100% RYs) and with 150 lb/acre N were 90 and 96% RY each year. More N and K were removed from the soil with harvest than with any other nutrient. Nitrogen removed from the soil with the harvested potato was between 70 to 80 lb/acre and did not change between plants fertilized with 150 or 200 lb/acre N in either experiment year. Researchers concluded that application of N to 200 lb/acre provided no yield advantage over 150 lb/acre N on soils high in Ca and P. This N rate complied with the recommendation at that time for irrigated mineral soils of 150 lb/acre (Montelero, 1978). Vegetative tissues sampled the day before harvest each year were within the sufficiency range of 2 to 3% N each year. As with yields for these experiment seasons, tissue N concentrations were similar with both applied N rates averaging 2.8% in 1983 and 2.5% in 1984.

The N-fertilizer rate recommendation remained 150 lb/acre through 1992 when experiments were conducted over three counties in northeast Florida from 1988 to 1991 (Hochmuth et al., 1993). Marketable potato yield and potato quality were evaluated following application of 150 to 400 lb/acre N (NH_4NO_3) at experiment sites in Putnam, Flagler, and St. Johns counties, and the University of Florida Agricultural Research and Education Center (AREC) in Hastings. Yields with P and K rates near the recommended amounts based on M-1 (pre-fertilization) soil testing (Kidder et al., 1989) were compared to commercial grower yields with N, P, and K rates which were above the recommended rate at each location. In 1988, N and K were banded at planting (near the tuber), two weeks after emergence, and 40 to 50 days after planting. In 1989, 1990, and 1991, N and K were applied once at planting and again 40 to 45 days after planting.

Yields of marketable (size A) potatoes were higher with the commercial fertilizer program than with the experimental fertilizer program in 1988 (1% probability). The authors attributed the lower yields to the second side-dressing of N, which was likely made too late in 1988 to benefit yields with the experimental program. The commercial fertilization program had a single side-dress N application. Highest yields among the experimental fertilizer rates occurred with 200 lb/acre N in Putnam (156 cwt/acre, 100% RY), 225 lb/acre N in Flagler (218 cwt/acre, 99% RY), and 225 lb/acre N in St. Johns (293 cwt/acre, 100% RY). Yields increased quadratically with increasing N rates at the AREC location this season. Highest yields occurred with 300 lb/acre N (240 cwt/acre, 100% RY) and 92% RY with 225 lb/acre N. Yields were significantly higher (1% probability) with the commercial fertilization program at each location with the exception of the AREC experiment where yield with the commercial rate was lower. Corresponding yields with commercial N rates from 212 to 360 lb/acre were 259, 267, 321, and 231 cwt/acre in each respective county. Leaf tissue N concentrations sampled at full bloom at Flagler and AREC were above adequate (> 4.0%) and not affected by increasing rates of applied N including the commercial N rate. Leaf samples taken at early bloom in St. Johns county were also above the sufficiency range (> 4.0%) with significantly higher N concentrations with the commercial fertilizer application.

A single side-dress fertilization at 40 to 45 days after planting was used in 1989-1991, compared to two side-dress fertilizer applications in 1988.

Marketable size A potato yields were higher in 1989 with 150 lb/acre N at Putnam county resulting in 262 cwt/acre (100% RY) as compared to 157 cwt/acre yield with the commercial fertilizer N rate of 250 lb/acre (Hochmuth et al., 1993). Leaf-tissue N concentration at full bloom was also significantly lower with the commercial fertilizer rate compared to experimental rates, though all tissue N concentrations were above adequate (> 4%). Yields decreased linearly with N rates from 150 to 300 lb/acre at St. Johns county and the AREC. Marketable yields were optimized at both locations with 150 lb/acre N (335 and 212 cwt/acre, respectively, 100% RY). Yields with the commercial rate were significantly lower, 260 and 189 cwt/acre with 240 and 228 lb/acre N at each St. Johns county and the AREC, respectively. Leaf-tissue N concentrations with the commercial N rate were significantly lower at St. Johns county and not different from N concentrations of plants fertilized with experimental rates at AREC. High yield occurred with 225 lb/acre N at Flagler county (238 cwt/acre, 100% RY), which was greater than 226 cwt/acre with the 215 lb/acre N commercial grower rate.

Marketable yields were similar with experimental and commercially applied N, P, and K rates in 1990 experiments at Putnam and St. Johns counties (average yields, 205 and 85 cwt/acre, at each site). Marketable yields differed at 5% (Flagler) and 1% (AREC) probability with all applied fertilizer rates at these sites (Hochmuth et al., 1993). Optimum, 100% RYs with experimental fertilizer rates resulted with 150 lb/acre N (Flagler, 302 cwt/acre) and with 225 lb/acre N (AREC, 227 cwt/acre). Yields fell with 300 lb/acre N to 95% and 96% RY at these sites, respectively. Leaf tissue N concentrations measured at pre-, early-, or full-bloom were above the sufficiency ranges for all locations. Significant differences in leaf-tissue N concentrations between the experimental and commercial fertilization programs occurred at St. Johns county, though yields did not differ, and at the AREC where yields were different (5% probability) between fertilization programs.

In 1991, yields were lower overall and responded little to fertilization practices (Hochmuth et al., 1993). Yields with some experimental rates were the same or higher than yields with the commercial grower fertilizer rates. From the four years of work, researchers concluded that 150 to 175 lb/acre N was sufficient for high potato yields and that N rates above 250 lb/acre often reduced potato yields. Effective side-dress N application occurred between 35 and 40 days from planting. Band application of 60 to 90 lb/acre N was recommended at planting and at side-dress. These revised recommendations were tested against the commercial fertilization program in field demonstration plots one-acre and larger in 1992 and 1993 (Hochmuth et al., 1993). Use of the revised fertilization rates and timing resulted in yields equivalent to the commercially fertilized plots and reduced N use by 100 lb/acre. Application of less than the recommended N rate reduced yields in Flagler (1992) where 140 lb/acre N resulted in 374 cwt/acre compared to 403 cwt/acre with the commercial N rate of 210 lb/acre. Delaying the initial fertilization from at planting to four weeks after planting also reduced yields in St. Johns county (1992) to 238 cwt/acre compared to 323 cwt/acre with the commercial fertilization applied near planting and at two weeks after emergence (cracking). Nitrogen deficiency symptoms or smaller plant size resulted in St. Johns county (1993) when the side-dress fertilization was delayed to 56 days from planting. The specific gravity of harvested potatoes was unaffected by N rate in these studies.

There was a lack of yield response to nitrification inhibitors (dicynandiamide and nitrapyrin) in experiments from 1983 through 1985 (Martin et al., 1993). For the purposes of this fertilizer summary, yield responses were averaged for N rates from treatments where inhibitors were not applied. Experiments were conducted in Gainesville, 1983, and Hastings in 1983 and 1985. Nitrogen from NH_4NO_3 at rates of 120 or 180 lb/acre were applied with 25 lb/acre P_2O_5, and 200 lb/acre K_2O in Gainesville and Hastings (1983). Fertilizers were mixed and applied in two bands at planting. Fertilizer bands were 1.5 inches deep and 1.5 inches to each side of the seed pieces. In Hastings (1985), N rates were 60, 120, and 180 lb/acre with 75% applied as NH_4 - N and 25% as NO_3 - N. Potassium from K_2SO_4 was applied equally at planting and two weeks after emergence. Subsurface irrigation was applied as needed on Ellzey sand soils in Hastings. In

Gainesville, Millhopper fine sand soils received overhead irrigation. These soils had higher CEC, organic carbon, and N concentrations, and lower sand content than the Hastings soils.

Yields of marketable tubers, grades A and B, were not affected by N rates in Gainesville (1983). Similar yields resulted with 180 lb/acre N (245 cwt/acre, 100% RY) as with 120 lb/acre N (97% RY). In Hastings (1983), marketable yields increased from 120 lb/acre (67% RY) to 180 lb/acre (195 cwt/acre, 100% RY). Yields increased quadratically in 1985 (Hastings) through 120 lb/acre N (302 cwt/acre, 98% RY) and were 2% higher with 180 lb/acre N. Potato quality was determined by changes in the specific gravity of tubers as affected by varying rates of applied N. Tubers with high specific gravities, such as 1.091, as occurred in Gainesville, would yield nearly15% more potato chips than those with specific gravities of 1.071 (1.078 occurred in Hastings, 1985). Rates of applied N had no effect on the specific gravity of tubers grown in Gainesville in 1983, while in Hastings, the specific gravity of tubers increased slightly with N rate in 1983 up to 180 lb/acre N (1.084) and increased quadratically through 120 lb/acre N (1.079) in 1985.

The Hastings experiment, summarized above, resulted in higher yields than the Gainesville experiment. Researchers did not attribute the Hastings yield advantage to the 3:1 ratio of NH_4 to NO_3-N fertilizer applied at planting but, earlier Hastings experiments resulted in higher yields with unequal proportions of NH_4 to NO_3-N at planting (Hensel and Locascio, 1987). This previous experiment was conducted in the spring of 1986 on subsurface-irrigated Ellzey sands. Fertilizer was applied in a 3 x 3 x 3 factorial treatment arrangement with 100, 200, or 300 lb/acre N applied in proportions of 5, 25, and 45% from NO_3-N. The total amount of N applied at planting increased from 0 to 33 to 67% with the remainder applied 33 days later.

Strong interactions resulted among all factors. A definite yield reduction occurred when 5% NO_3 - N was applied with 67% of the total N (at 300 lb/acre) applied at planting. Higher rates of ammoniacal N applied at planting resulted in reduced tuber set and lower yields. Researchers concluded that optimum yields were dependent upon the right combination of NO_3 to NH_4- N applied at planting and upon how much N was applied at planting and later side-dress. Based on data from this experiment, researchers recommended application of 25% NO_3-N at planting with 67% of the total N (200 lb/acre) applied at planting and 33% applied at a later side-dress. Higher yields could not be expected at N rates above 200 lb/acre.

The importance of NO_3-N in potato plant and tuber development was described in 1950 (Volk and Gammon, 1950). Researchers determined that a condition of potato plants characterized by leaf roll in new leaves, becoming most pronounced at blossom time, was related to high soil NH_4-N concentration. Tubers of affected plants were found to develop too closely to the stem for normal enlargement. Disease was not a factor in expression of these symptoms. Analysis of soils at the Federal Point and Bimini sites were found to be very acidic and had insufficient bacterial activity to convert NH_4-Nto NO_3-N. Field studies were conducted using fertilizers with varied ratios of NO_3 to non NO_3-N applied in combination with lime treatments. Potatoes were planted on plots where leaf-curl had occurred in 1949. Yields were 46% higher when fertilized with 5N-6P_2O_5-6 K_2O where 40% of the fertilizer N was from a NO_3 source (241 bushels/four plots, unspecified plot size) than where NO_3-Nwas omitted from the fertilizer mix (165 bushels/four plots). Correction of the soil pH did not eliminate leaf roll incidence. Plants grown on dolomite treated soils (pH neutral) and fertilized with 5N-6P_2O_5-6K_2O without NO_3 -N, resulted in lower yields (183 bushels per four plots). On soils where leaf roll had not previously occurred and the pH was 4.7 to 4.9, yields were also improved by application of 5N-6P_2O_5-6K_2O, with 40% NO_3-N(292 bushels per four plots). Further yield increases resulted when the fertilizer application was split, 60% at planting and 40% at 60 days (331 bushels per four plots). The difference in these two yield responses was attributed to leaching losses of NO_3-N when applied entirely at planting. Application of some NO_3-N was further cited for yield improvements during water stress periods when soil nitrification was reduced.

A comprehensive study of Florida potato production areas required research in south Florida where 20% of the state potato production occurs. Experiments were conducted near Homestead, Florida during the winter seasons of 1993-1994 (grower 1), 1994-1995 and 1995-1996 (growers 1 and 2) (Hochmuth et al., 1998). Nitrogen was applied at 0, 40, 80, 120, or 160 lb/acre at all sites except in 1994-1995 (grower 1) where 0, 50, 100, 145, or 190 lb/acre N were applied. A grower fertilization program was included at each location and N rates with these treatments ranged from 96 to 115 lb/acre.

Yields of size A potatoes and total marketable potatoes followed the same yield response patterns as to N fertilization. Marketable potato yields increased through N rates of 190 and 160 lb/acre (198 and 141 cwt/acre, respectively, 100% RY) in two experiment seasons, decreased with N from 100% RY (83 cwt/acre) with 0 lb/acre N to 81% RY with 160 lb/acre N in a third study, were not affected by N in a fourth study, and had no discernable yield response to N in a fifth study. Leaf tissue N concentrations were adequate or above the sufficiency range in all experiments and increased or remained unchanged by N fertilization. Yields with the grower fertilization programs were not different from yields with experimental N rates.

Nitrogen Summary

The earliest research on the effects of increasing rates of N fertilizer consisted of mixed fertilizer studies beginning in 1955 and continuing through 1967. The effects of increasing N rates were presented graphically against RYs from 19 experiments in Fig. 1. Yields generally increased through 175 lb/acre N, as indicated by the dashed line in Fig. 1, and then leveled off or declined with N rates greater than 200 lb/acre. Among other findings of this research period were that side-dress fertilizer applications were most effective on soils with low organic matter content. Wet soils, measured at 12% moisture content on an oven dry basis, increased potato disease susceptibility and resulted in the lowest yields while soils with 10% moisture content resulted in the highest yields. An eight-inch seed spacing was the most profitable plant spacing and polyethylene mulch use increased potato yields, but authors did not evaluate the economics of mulch use on potato production.

Fig. 2 is a graphic summary of potato N fertilization from 1962 through 1998. Seven research reports involving 29 individual experiments are presented. Yields of potatoes responded positively, 96 to 100% RYs, to N fertilization rates through 180 lb/acre in 66% of experiments and to N rates through 200 lb/acre in 79% of experiments. Marketable yields were often reduced by N fertilization at rates greater than 200 lb/acre N, as demonstrated in Fig. 2. Nitrogen fertilization demonstration trials on commercial farms showed that potato yields with 225 lb/acre N were the same as yields with 300 lb/acre N in 11 out of 16 trials (Hochmuth et al., 1993). In three trials, yield was reduced when N fertilization was increased over the range from 150 to 300 lb/acre N. Reports spanning more than 30 years of research with potato fertilization showed that potatoes rarely responded positively to more than 200 lb/acre N. Concentrations of N in leaf tissue generally reflected adequate N fertilization with greater than 150 lb/acre N.

Nitrogen and K leach easily in sandy soil, therefore supplemental additions of N and K might be needed after periods of heavy rainfall. Supplemental applications of 30 lb/acre N and 20 lb/acre K_2O might be needed after a rainfall of 3 inches in 3 days or 4 inches in 7 days (Kidder et al., 1992). Nitrogen efficiency was not improved by nitrification inhibitors in four out of five studies. Yields of potatoes with NH_4NO_3 were equal to, or better than yields with CR fertilizers or mixtures of NH_4NO_3 and CR fertilizers.

Nitrogen application timing is critical to successful potato production. Approximately two-thirds of the N should be applied at planting. The remainder should be applied between 30 and 40 days after planting. About 25% of the total N should be supplied from NO_3-N sources.

Phosphorus and Potassium Soil Testing

Knowledge of soil nutrient levels, particularly P and K, before planting is the starting point to predicting crop response to varying rates of applied nutrient. Using soil testing to determine preplant soil

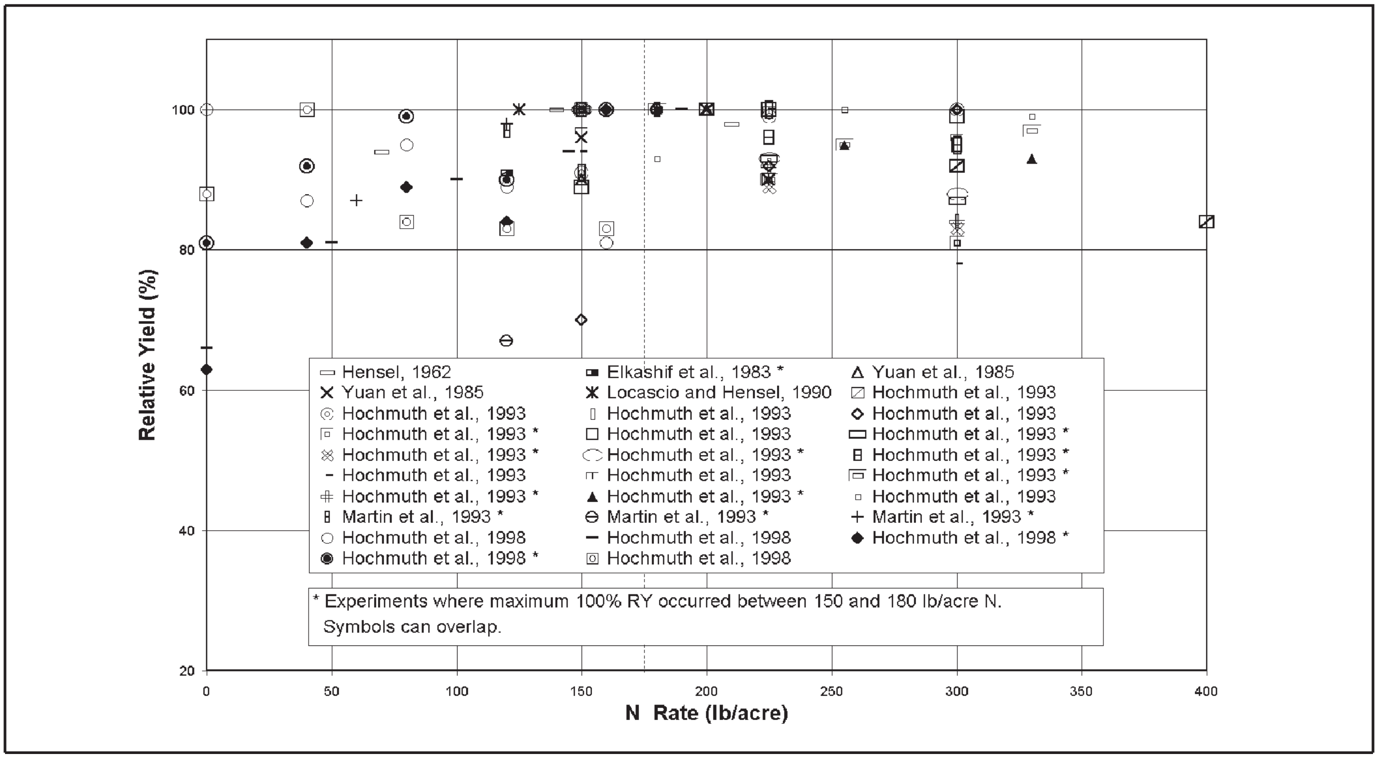

Figure 2. Relative yield of potatoes for experiments, years, and seasons as a function of added N .

nutrient concentrations provides information so research results may be reviewed for the degree of support of existing fertilization recommendations established by M-1.

Mehlich-1 extractant indices (expressed as ppm soil-extracted nutrient) are classified as very low, low, medium, high, and very high, and a crop specific fertilizer recommendation is made from that classification (Hochmuth and Hanlon, 1995). The M-1 solution became the accepted extractant standard in 1979 at the University of Florida. Previous to M-1, ammonium acetate and water extractants were used. Indices recorded from these methods cannot be directly equated with M-1 indices or fertilizer recommendation rates but review of the research results with these extractants presents a profile of crop response to fertilizer under varying conditions. For potato, yield response did not correlate with soil K concentrations and a recommendation of 140 lb/acre K_2O was made for all soil test K indices. Water management practices, fertilizer sources and application methods, and the effect of mulch in the nutrient management system are also summarized.

Phosphorus

Phosphorus experiments were conducted at the same Hastings field sites on “old” soils, cropped for 60 years, and on newly cleared Ona fine sand soils (Hensel, 1962). Other old and newly cleared sites were chosen for experiments in 1962. Fertilizer was applied in bands below and to the side of the seed pieces at rates of 150 lb/acre N, 240 lb/acre K_2O, and P_2O_5 rates of 0 to 400 lb/acre (1960 and 1961) and in factorial combinations of three N rates, 70, 140, and 210 lb/acre with three P rates, 80, 160, and 240 lb/acre P_2O_5 (1962). Soil P concentrations in 1960 to 1961 were reduced from 65 to 50 ppm, measured by ammonium acetate extraction, on old soils and from 8 to 6 ppm on newly cleared soils. On old soils, potato yields were similar for plants fertilized with 0 to 400 lb/acre P_2O_5. Average yields were 181 and 316 cwt/acre for 1960 and 1961, respectively. Plants on newly cleared soils required 400 lb/acre P_2O_5 (significance not described) each year to produce optimum yields of 157 and 242 cwt/acre (100% RYs) as compared to 15% and 31% RYs with 0 lb/acre P_2O_5. In 1962 experiments, yields optimized on old and new soils with 240 lb/acre P_2O_5 (146 and 177 cwt/acre, respectively, 100% RYs). Slightly lower

RYs, 98 and 97%, resulted with 160 lb/acre P_2O_5 applied to each soil type, significant differences among yields were not described. Soil P concentrations (ammonium acetate extracted) were 18 ppm (old soil) and 21 ppm (new soil). At planting, an optimum potato pH of 5.5 existed at all sites with 550 lb/acre of hydrated lime applied in 1960 to increase the pH on new soils.

Potato yield response was evaluated following P applications over three consecutive seasons, 1960, 1961, and 1962, on Ona and Kanapaha fine sands (Locascio and Breland, 1963). Researchers sought to determine the effects of different soil types on P recommendations for potato. Kanapaha soils were described as having twice the P content of the Ona soils though soil P analytical results were not provided in the report. Concentrated superphosphate (CSP) was broadcast before a fall snapbean crop at rates of 0, 90, and 180 lb/acre P_2O_5. The potato crop was planted the following spring after broadcast application of 90 lb/acre N (NH_4NO_3) and 90 lb/acre K_2O (K_2SO_4). An additional 30 lb/acre N and K_2O were side-dressed each season. Except for potatoes grown on Kanapaha soil in 1960, potato yields increased linearly in all years on both soil types through P rates of 180 lb/acre P_2O_5. Averaged over all seasons, yields from Kanapaha soils were 172 cwt/acre (100% RY) with 180 lb/acre P_2O_5 and were 126 cwt/acre (75% RY) with 0 lb/acre P_2O_5. A similar average yield increase occurred on the Ona soils with applied P from 0 lb/acre P_2O_5 (117 cwt/acre, 72% RY) to 180 lb/acre P_2O_5 (161 cwt/acre, 100% RY). Although yields were similar with both soils, the leaf-tissue P concentrations were nearly double in potato plants grown on the Ona soil. Based on these leaf P concentrations and soil data (not presented) researchers concluded that more P was fixed in an unavailable form on the Kanapaha soils than in the Ona soils.

Initiation of M-1 soil testing in 1977 renewed interest in P fertilization of Hastings grown potatoes where previously uncropped soils were typically low in P compared to soils in potato production for seventy years (Rhue et al., 1981; Rhue et al., 1981a). Lime was applied in November 1977 to raise the pH of uncropped soils from 5.1 to 6.5 before seeding with Atlantic potato pieces in February 1978. Applied P rates were 0, 115, 230, or 345 lb/acre P_2O_5 from diammonium phosphate (DAP) or liquid ammonium polyphosphate (APP). Fertilizers, including 140 lb N/acre and 180 lb/acre K_2O, were applied in two bands eight inches apart and one band eight inches beneath the seed piece followed by side-dressing at 35 days with 50 lb/acre each of N and K_2O. The water table was maintained eight inches beneath plot alleys throughout the crop season. On these Placid sand soils with 5 ppm M-1 soil-extracted P, significant marketable yield increases occurred between 0 lb/acre P_2O_5 (60 cwt/acre) and 115 lb/acre P_2O_5 (150 cwt/acre, 100% RY). Thereafter, P rates to 345 lb/acre P_2O_5 had no further effect on marketable yields. Yields of grade B potatoes were lower (1% probability) with APP than with DAP.

In 1979, M-1 soil tests revealed P concentrations had increased due to the 1978 applications of DAP or APP to 12 and 11 ppm with 115 lb/acre P_2O_5 of each respective P source, to 24 and 21 ppm with 230 lb/acre P_2O_5, and to 35 and 24 ppm with 345 lb/acre P_2O_5. To these residual P concentrations, half of the plots received no P and the other half received 115 lb/acre P_2O_5. Sebago potatoes were planted and N and K was applied as in 1978. On those soils where no P was applied, yield response to increasing residual soil P concentrations was quadratic with yield leveling off with 25 to 35 ppm extracted P (308 cwt/acre; 100% RY). Potatoes receiving 115 lb/acre P_2O_5 produced similar yields to those that received no P. Researchers concluded that 35 ppm of M-1 soil-extracted P provided sufficient nutrient for optimum potato yields and no more than 115 lb/acre P_2O_5 were needed when soils tested less than 30 ppm.

In 1980, all plots received 115 lb P_2O_5/acre except the zero P check treatment. Similar pre-fertilization concentrations of M-1 soil-extracted P resulted with P sources DAP and APP. Average soil P concentrations for each rate of previously applied P were 8 ppm (zero applied P), 20 ppm (115 lb/acre P_2O_5), 28 ppm (230 lb/acre P_2O_5), and 35 ppm (345 lb/acre P_2O_5). Optimum yields occurred on soils testing 35 ppm P (294 cwt/acre, 100% RY). Response to the added 115 lb/acre P_2O_5 was more apparent this season than the previous season where yields were similar with or without the added P.

Where soils were very low in M-1 P, (<10 ppm) (1978), yields were significantly higher with DAP than with APP but, both P sources performed equally on soils with M-1 P concentrations greater than 10 ppm (1979 and 1980).

While these experiments were conducted, simultaneous experiments (1978 and 1980) were conducted on a nearby high P site (237 ppm) which had been in potato production for the previous seventy years. Phosphorus rates of 0, 50, or100 lb/acre P_2O_5 were applied from DAP or APP and N and K were applied at 140 lb/acre N and 180 lb/acre K_2O banded preplant with 50 lb/acre of each side-dressed 35 days later. Yields of A and B grade marketable potatoes were not different with either DAP or APP. Averaged marketable yields over both P sources did not increase above zero lb/acre of P_2O_5 (180 and 321 cwt/acre each season,100% RY). The Placid soils tested here were typical flatwoods soils, pH 5.3, where a 1977 application of dolomitic lime at 2800 or 5600 lb/acre elevated the pH to 6.5 (a zero lime treatment was also included). Application of lime did not interact with applied P for effects on potato yields.

The above summarized Hastings trials of 1978, 1979, and 1980 on old, high P soils were extended through 1981 and 1982 (Yuan et al., 1985a; Yuan et al., 1985b; Yuan et al., 1985c). In 1981, researchers noted that higher M-1 soil P concentrations, 340 ppm, resulted in plots where 5600 lb/acre of dolomite was applied in 1977 compared to 259 ppm P where no dolomite was applied in 1977 (Rhue et al., 1981a). They concluded that Ca from previous lime applications had acted to retain P in the soil which would otherwise be leached from acidic soils low in Fe and Al. Phosphorus combined with Ca was held in the soil in a form available to plants. The potential water solubility of P, (greater in unlimed soils than limed), was also examined in this study where P leaching was reduced by maintenance of the water table at eight inches below the alley bottom. The authors concluded that water table maintenance and lime, applied as needed, were important to proper soil P management on long-term cropped sandy acidic soils.

By extending the experiment an additional two crop seasons, researchers also sought to observe the long-term effects of accumulated P on potato yields and determine how much soil P was removed with successive potato harvests. No additional lime or P was applied to the high P, Ellzey sand soils (formerly termed Placid sand), and N and K applications were reduced to 125 lb/acre N and 170 lb/acre K_2O. All other experimental conditions were the same as before.

Residual M-1 soil-extracted P concentrations from plots fertilized in 1980 with 0, 50, and 100 lb/acre P_2O_5 were 308, 272, and 292 ppm, respectively (1981) and 235, 229, and 240 ppm, respectively (1982). The reduction in soil P content was attributed to nutrient removal by the crop and leaching. Tuber yields in 1981 and 1982 were similar with all applied P rates averaging 257 and 293 cwt/acre each year. Dry weight tissue analysis revealed nutrient concentrations were 10 to 100 times higher in the vegetative tissue of the potato plant than in the tuber. Phosphorus concentrations in the tuber, however, were 35% higher than P concentrations in the vegetative tissue. Early P uptake with potato is known to promote good tuber development (Fiskell, 1961) and ultimately most of the absorbed P is translocated to the tuber. The measured annual amount of P removed from the soil with harvest was between 30 to 40 lb/acre P_2O_5 in 1980 and 1981 harvests. Extraction of soil P by vegetative tissues was quadratic in 1981 and linear in 1982, but extraction of P by tubers did not differ with soil P concentrations. The authors concluded that potato harvest would not deplete high P soils sufficiently to require additional P application for a long time.

Spurred by the research in Hastings, a Flagler County potato experiment was conducted

in 1981 to determine if the basic recommended P rate for irrigated mineral soils, 200 lb/acre P_2O_5 (Montelaro, 1978), was too high (Kidder, 1982). Soil from the chosen field tested 10 ppm in M-1 soil-extracted P, had previously been cropped in cabbage, but was uncultivated before 1979. The very low soil-P concentration would assure a yield response to applied P (CSP) at the recommended rate of 200 lb/acre P_2O_5 or with the high yielding rate used earlier in Hastings, 115 lb/acre P_2O_5. Nitrogen (NH_4NO_3) was applied at 170 lb/acre N in all treatments while K (KCl) was applied at either 0 or 135 lb/acre K_2O. Grower fertilizer rates of 225-60-135 lb/acre N-P_2O_5-K_2O were applied to an adjacent commercial field area. When the potatoes sprouted, fertilizers were banded four inches to the side of the plant row and four inches beneath the bed surface. Potato yields were not different with any experimental fertilizer rate, but yields were significantly lower with the grower fertilizer rates of 60 lb/acre P_2O_5 (260 cwt/acre) compared to yields with 115 lb/acre P_2O_5 (347 cwt/acre, 100% RY). Insufficient P (60 lb/acre P_2O_5) was cited as the limiting nutrient in the grower treatment while 115 lb/acre P_2O_5 resulted in high yields on these very low P soils. The author suggested that additional research be conducted before reducing the recommended P rate from 200 lb/acre P_2O_5.

Researchers applied 180 lb/acre P_2O_5 from four P sources in experiments in 1980 and 1981 near Gainesville (Locascio and Rhue, 1990). Two liquid P sources were tested on beds of St. Johns fine sand, ammonium containing ortho-P and APP along with tests of two granular P sources DAP and CSP. Beds were fertilized with 80 lb N (NH_4NO_3) and 95 lb/acre K_2O (KCl and K_2SO_4) applied in two bands placed 2.5 inches to each side of the bed center and two inches below the seed. Atlantic seed potatoes, planted in mid-February each year, were side-dressed six weeks later with 80 lb/acre N and 100 lb/acre K_2O. Potatoes were overhead irrigated as needed.

Yields on the low P soils, 15 ppm M-1 P, in 1980 were highest with APP (154 cwt/acre), significantly lower with ortho-P and CSP (133 cwt/acre), and lowest with DAP (108 cwt/acre). These findings directly conflict with earlier P source findings (Rhue et al., 1981; 1981a) on Placid sands (Hastings) where higher yields resulted with DAP compared to other P sources. Application of P sources APP, ortho-P, and CSP resulted in similar yields (180 cwt/acre) in 1981 on very low P soils, 8 ppm M-1 P, and lowest yields with DAP (150 cwt/acre). Mehlich-1 soil P concentrations, measured after harvest, increased 14 ppm on average with DAP and CSP compared to 9 ppm on average with liquid APP and ortho-P. Greater plant uptake of P from DAP was measured in recently matured leaves at flower formation with 0.63% P (1980) and 0.56% P (1981) but, both concentrations were in the sufficient range.

By 1989, P recommendations for soils very low (<10 ppm P) and low (<15 ppm P) in M-1 soil-extracted P were revised to 120 lb/acre P_2O_5 based on yield responses summarized above (Kidder et al., 1989). Researchers in St. Johns, Putnam, and Flagler counties, including a research center in Hastings, confirmed the 1989 P recommendation of zero lb/acre P_2O_5 for soils high and very high in M-1 soil-extracted P (Hochmuth et al., 1993), over four consecutive crop seasons from 1988 to 1991. Soils from all sites each year had high or very high P concentrations except the St. Johns site in 1991 which had medium P concentrations. Experiments were conducted to compare varying rates of N and K fertilizer; P fertilization was generally omitted from all but the grower fertilization program. No yield advantage occurred with grower P applications from 10 to 90 lb/acre P_2O_5 (CSP) over yields where no P was applied. As a result of these experiments, P recommendations were not changed in 1995 (Hochmuth and Hanlon, 1995) from the 1989 recommendations.

Five experiments were conducted in Homestead, Florida, among the South Florida areas where 15 - 20% of state potato production occurs. These experiments were conducted during the winter seasons of 1993-1994 (grower 1), 1994-1995 and 1995-1996 (growers 1 and 2). Due to the marl and rockland soils in this area, the ammonium bicarbonate-diethylenetriamine pentacetic acid extractant, AB-DTPA, soil extractant was used. Results of this soil extractant cannot be directly related to results with the M-1 soil extractant.

Yields did not respond to P fertilization above 100 lb/acre P_2O_5 in all five experimental seasons. Optimum, 100% RY was produced with 100 lb/acre P_2O_5 (84 cwt/acre) in one experimental season, with 0 lb/acre P_2O_5 in two experimental seasons (191 and 140 cwt/acre), and they were similar yield results with all P rates in two additional experimental seasons. Because yield responses to increased P fertilizer varied on sites with similar soil P concentrations, further experiments are needed to calibrate AB-DTPA soil-extracted P concentrations with yield. Where soil P concentrations were 304 ppm, high yield was produced with 0 lb/acre P_2O_5 (140 cwt/acre, 100% RY) and 90% RY with 200 lb/acre P_2O_5 while similar yields were produced with all P rates on soils with 285 ppm AB-DTPA soil-extracted P. Yield responses to P fertilizer in three experiments with 45, 70, and 60 ppm soil-extracted P, were quadratic, producing a peak yield with 100 lb/acre P_2O_5 (84 cwt/acre, 100% RY), were reduced from 0 lb/acre P_2O_5 (191 cwt/acre, 100% RY) to 96 % RY with 200 lb/acre P_2O_5, and were not affected by P rates to 200 lb/acre. Whole leaf tissue P concentrations were above the sufficiency range in all experimental seasons and were generally not affected by increased P fertilizer.

Phosphorus Summary

Yield responses to applied P rates are presented in Fig. 3. Experiments where P was not applied were conducted to evaluate yield response to residual soil P concentrations. Among the 21 graphed experiments,11 required more than the maximum recommended P rate of 120 lb/acre P_2O_5 as indicated by the dashed line in Fig. 3. Yields from seven of these trials were in the range of 136 to 176 cwt/acre and were considered poor (Hensel, 1962; Breland and Locascio, 1963 indicated on the graph with an asterisk). In the remaining 14 trials, including those where optimum yields occurred with the recommended zero lb/acre P_2O_5, 64% optimized with or below the maximum 120 lb/acre P_2O_5 and 79% optimized with 180 lb/acre P_2O_5 or less. Current P recommendations for potato were based heavily on later experiments, including experiments over four seasons in a tri-county area using M-1 soil extractant data (Hochmuth et al., 1993), with less emphasis placed on earlier work where ammonium acid extractant was used (Hensel, 1962). Based on summarized yield responses, P fertilization of soils with high M-1 P concentrations greater than 30 ppm is not warranted.

Research with P fertilizer sources provided mixed results. In early work on a Placid fine sand, which does not fix large amounts of P, potato yields were reduced one year out of three with APP compared to DAP (Rhue et al., 1981). Other work on St. Johns fine sandy soil testing low in M-1 soil-extracted P, showed that yields were generally better with liquid APP, liquid ortho-P, or CSP compared to DAP (Locascio and Rhue, 1990).

Potassium

Potassium plays a role in sugar translocation and starch synthesis in plants. Due to the high starch of the potato tuber, K is an important nutrient in tuber development (Rhue et al., 1986). Analysis of K removed from the soil by tuber and vegetative tissues revealed two-thirds of the removed K was accumulated in the tuber (Yuan et al., 1985c). Measured in crop seasons 1983 and 1984, K removed from the soil by tubers represented from 125 to 150 lb/acre K_2O when 140 lb/acre K_2O was applied and removal of 130 to 170 lb/acre K_2O when 200 lb/acre K_2O was applied in 1983 and 1984, respectively.

Researchers sought to compare the University of Florida computerized "Standard Fertilizer Recommendation System," a M-1 based fertilizer recommendation, with actual yield results in a Flagler County, 1981 experiment (Kidder, 1982). Potassium (KCl) was applied at zero lb/acre K_2O or the recommended rate of 135 lb/acre K_2O for soils then considered medium in M-1 soil-extracted K (81 ppm). Nitrogen, NH_4NO_3, was applied at 150 lb/acre and P as CSP, was applied at 115 or 200 lb/acre P_2O_5. All fertilizer was applied in a band 4 inches to the side of the emerging potato and 4 inches deep. Yields with zero or 135 lb/acre K_2O were not different, averaging 344 cwt/acre of size A and B potatoes. These yields were considered high compared to the state average yield of 220 cwt/acre for this season. High yields with zero lb/acre K_2O indicated 135 lb/acre K_2O, recommended from the "Standard Fertilizer Recommendation System," was excessive for soils with 81 ppm M-1 soil-extracted K.

The effects of excessive K application on soils with high M-1 soil-extracted Ca and P were evaluated in 1983 and 1984 experiments (Yuan et al., 1985c). Humaquept soils at this Hastings site were not tested for M-1 soil-extracted K in 1983 or 1984, previous K concentrations were 55 and 37 ppm from

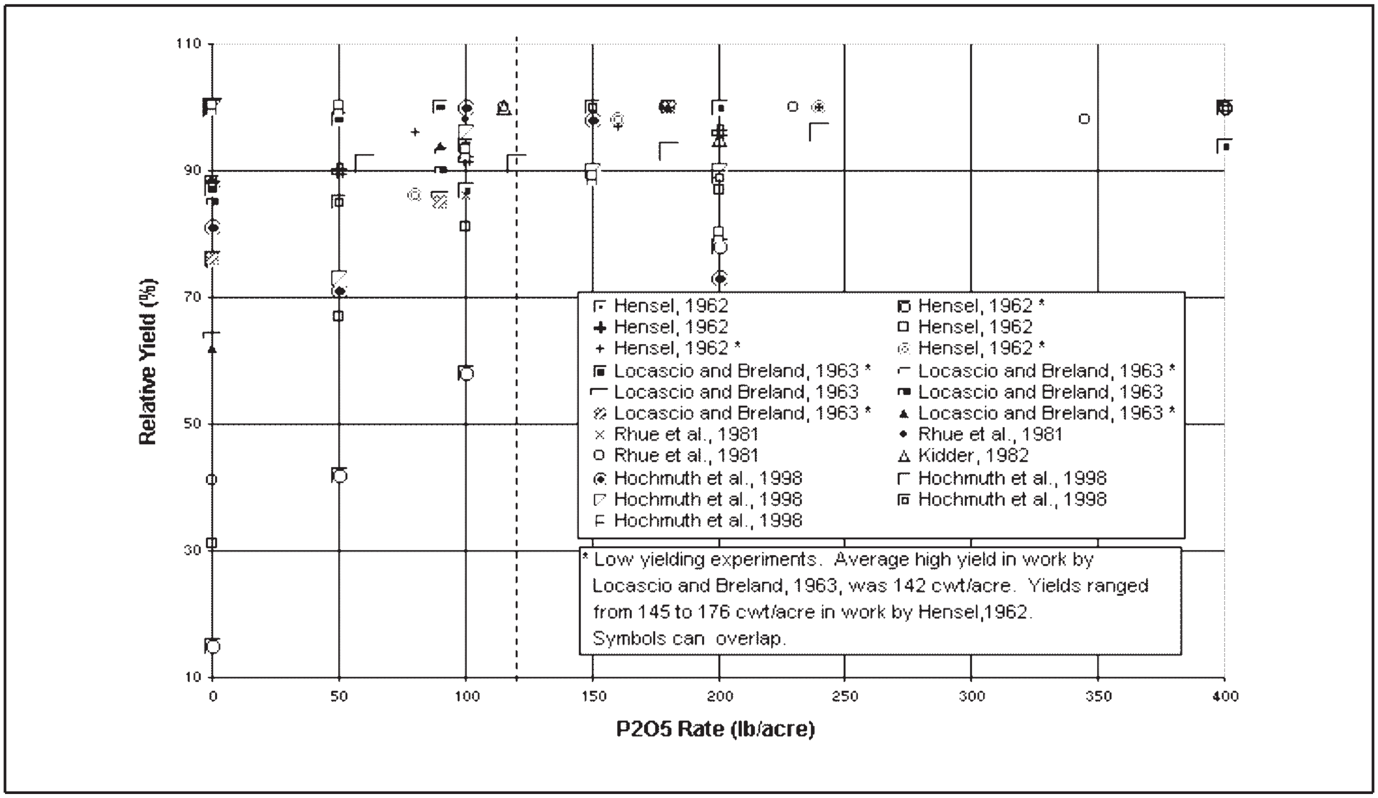

Figure 3. Relative yield of potatoes for experiments, years, and seasons as a function of added $P_2$05.

experiments conducted there in 1981 and 1982, respectively (Yuan et al., 1985a). Further reduction in soil K concentrations, following the 1982 and 1983 potato crop seasons, were expected and K concentrations were presumed to be less than 37 ppm. Potassium was applied at planting in rates of 0, 140, or 200 lb/acre K_2O combined factorially with 100 or 150 lb/acre N. A side-dress application of 50 lb/acre N and K_2O was applied five weeks after planting. The effect of applied K on yield of size-A potatoes was not significant in either year resulting in high yields with 200 and 140 lb/acre K_2O (199 and 195 cwt/acre, 100% RY) and 88% and 90% RY with zero lb/acre K_2O, each year. Yields were averaged over both rates of applied N and approached the annual state average yield each year. Where no K was applied at planting, the K content measured in tuber tissue declined from 1.9% in 1983 to 1.8% in 1984 (tuber tissue is about 2% K). Depletion of soil K was suspected on these zero-K plots. Excessive K application to 200 lb/acre K_2O did not reduce yields in either experiment season nor was the concentration of Ca in tuber and vegetative tissue affected by higher rates of applied K.

Researchers sought to determine critical K concentrations in leaf tissue at various sampling dates in a four-year study from 1981 to 1984 (Rhue et al., 1986). Experiments were conducted on Ellzey fine sand soil near Hastings where land was in potato production for 70 years. Potato yield responses were evaluated with respect to applied K and soil K concentrations

determined by M-1 soil analysis each season. Fertilizer application each year included 125 lb/acre N applied at planting in bands to each side of the plant row and 8 inches apart. In 1981, N and K were side-dressed 35 days from planting at 50 lb/acre N and 0, 25, 50, or 75 lb/acre K_2O. Researchers expected a yield response to the side-dressed K with a M-1 soil test of 73 ppm K, recommendations of the time were for 135 lb/acre K_2O (Rhue and Kidder, 1984). Yields did not change with side-dressed K rates through 75 lb/acre K_2O. Optimum yields occurred with 50 lb/acre K_2O (328 cwt/acre, 100% RY). Potassium concentrations in leaf tissue were above the sufficiency range (3.0 to 4.0%) at first blossom with 0 to 75 lb/acre of side-dressed K_2O. Later tissue samples had adequate K concentrations (2.0 to 3.0%)

and were unchanged by added K. Interpretation of a M-1 soil concentration of 73 ppm was changed from medium to high in 1989 (Kidder et al., 1989) and the K recommendation was reduced from 135 to 0 lb/acre K_2O (Kidder et al., 1989; Rhue and Kidder, 1984).

Soils in 1982 and 1983 experiments tested low in M-1 soil-extracted K, 34 and 32 ppm, respectively. Potassium was applied at 150 or 250 lb/acre K_2O in 1982, and at 50 and 250 lb/acre K_2O in 1983. Potassium recommendations of the time were for 200 lb/acre K_2O. Fertilizer was applied as in 1981 with 125 lb/acre N, 0 or 200 lb/acre K_2O applied in two bands at planting followed by a side-dress application of 50 lb/acre N and K_2O, 35 days after planting. Yield responded significantly (5% probability) to K rates in both seasons. Optimum yields occurred with 250 lb/acre K_2O each year (350 and 260 cwt/acre, 100% RY, each season) and 95% and 88% RY with 150 lb/acre K_2O and 50 lb/acre K_2O each year, significant at 5% probability. Leaf tissue K concentrations were within the adequate range of 3.0 to 4.0% at first flower and 2.0 to 4.0% when tubers were half grown with the lowest K application. Leaf tissue K concentrations in excess of adequate concentrations occurred with 250 lb/acre of applied K_2O each year.

In 1984, soils at a Hastings research site tested 39 ppm in M-1 soil-extracted K. Total applied K rates were 100 to 300 lb/acre K_2O or rates below and above the recommended K rate. Side-dress applications of 50 or 100 lb/acre K_2O were applied as part of the total K rate. Yields were not different with increasing K rates or with higher amounts of side-dressed K. High yields resulted with 300 lb/acre K_2O (273 cwt/acre, 100% RY) averaged over side-dress applications of 50 or 100 lb/acre K_2O. All yields exceeded the average yield for the Hastings area of 240 cwt/acre for these years. Rates of K fertilization through 250 and 300 lb/acre K_2O did not result in yield reduction in any season. Leaf tissue K concentrations increased significantly with higher K rates though tissue concentrations were adequate with the lowest rate of applied K, 100 lb/acre K_2O. Researchers concluded that a critical leaf tissue K concentration could not be determined citing annual differences in leaf tissue K concentrations with a given K rate to seasonal changes in rainfall, temperature, and the exact time of sampling. Excessive leaf-tissue K rates to 7.0% at late season sampling (1984) was indicative, however, that K recommendations of 200 lb/acre K_2O were too high for soils with 39 ppm M-1 K.

Application of large amounts of K to 485 lb/acre K_2O had no effect on yields in three experiment seasons in Hastings from 1984 to 1986 (Locascio et al., 1991; Locascio et al., 1992). Experiments were conducted on Ellzey fine sands to test the yield response of potato to increasing rates of Ca and K and to determine the correlation of Ca and K concentrations with the severity of bacterial soft rot (discussed later). Fertilizer, including 240 or 485 lb/acre K_2O (no zero K treatment) from K_2SO_4, was applied factorially with 0, 400, and 800 lb/acre Ca. Nitrogen from NH_4NO_3 was applied at 150 lb/acre. Formulated fertilizer was applied at planting in bands 4 inches to each side of the row and 4 inches below the seed piece. Of the three crop seasons, 1984 was characterized by heavy rainfall, 1985 less than average rainfall, and 1986 was considered very dry. Yields were similar with both N treatments in all experiment seasons with slightly higher yields with 485 lb/acre K_2O in 1984 (239 cwt/acre, 100% RY) and in 1985 (277 cwt/acre, 100% RY), both yields were above state average yields for these seasons (Fla. Dept. of Agri. Serv., 1997). In the dry season, 1986, high yields resulted with 240 lb/acre K_2O (193 cwt/acre, 100% RY), which was below the state average yield of 262 cwt/acre for 1986. With M-1 extracted soil K concentrations from 38 to 44 ppm during this period, researchers did not expect a yield response to the higher K rate.

In spring 1992, researchers applied several K rates to Ellzey fine sand beds in Hastings including the then-recommended 70 lb/acre K_2O (Kidder et al., 1989) for medium M-1 soil-extracted K soils, 46 ppm (Hensel and Locascio, 1992). High yields of size A and B potatoes occurred with 70 lb/acre K_2O (267 cwt/acre, 100% RY). This yield exceeded the state average yield for 1992 of 240 cwt/acre (Fla. Dept. of Agri. Serv., 1997). Yields with all K rates, 0, 50, or 70 lb/acre K_2O, however, were similar. Twenty treatments were evaluated in this experiment, five experiments were conducted with K sources; coated KNO_3, uncoated KNO_3, KCl, or K_2SO_4, and 50%

coated KCl with 50% uncoated KCl applied at 50 lb/acre K_2O. An additional five treatments consisted of these same K sources at 70 lb/acre K_2O. Nitrogen was applied from NH_4NO_3 at 150 lb/acre. The remaining treatments included six treatments with coated KNO_3 in combination with 25%, 50%, or 75% coated urea applied at both K rates and two treatments of 50% coated urea combined with 100% KNO_3 applied at both K rates. Fertilizer formulations were applied to the bed surface and lightly worked into the soil before planting. Researchers found that no yield variation resulted from any of the K and N source treatments.

Experimentation with K fertilization was conducted in a tri-county area surrounding Hastings from 1988 to 1991 (Hochmuth et al., 1993; Hochmuth et al., 1993a). Based on yield responses in this series of experiments, researchers concluded that M-1 soil tests on Spodosol or flatwoods soils had little predictive capability for effective K rate recommendations and reliance on soil testing for K was discontinued for potato in this area. From observation of yield results with increasing rates of K fertilization, including the grower fertilization practices, researchers found that potato yield and quality did not increase with K fertilization rates above the 1989 recommended rates (Kidder et al., 1989). In six of seven experiments in 1988 and 1989, yields were similar with application of from zero to 300 lb/acre K_2O.

Excessive leaf-tissue K concentrations were measured at early bloom (> 5.0%, 1988) and at full bloom (> 4.0%, 1988 and 1989) with all rates of applied K (Hochmuth et al., 1993; Hochmuth et al., 1993a). In 1990, leaf-tissue K concentrations were within the sufficiency range or above sufficient concentrations at pre-, early-, and full-bloom sampling with applied K rates from 70 to 140 lb/acre K_2O.

In 1990 and 1991, four of the eight experiments resulted in linear or quadratic responses to applied K (Hochmuth et al., 1993; Hochmuth et al., 1993a). Three of these required greater than the 1989 recommended rates (Kidder et al., 1989) to produce optimum yields, the fourth required less than the recommended rate, and the remaining four trials resulted in similar yields with K rates from zero to 310 lb/acre K_2O. Average yield response over all four experiment seasons to K rates of 140 or 160 lb/acre K_2O, from 12 of the 15 experiments where these K rates were evaluated, resulted in 97% RY. Based on this average yield response and frequently excessive leaf K concentrations with lower K rates, researchers determined 140 lb/acre K_2O was sufficient for optimum yields and adjusted the K rate recommendation to 140 lb/acre K_2O for all soils regardless of their concentration of M-1 soil-extracted K (Hochmuth and Hanlon, 1995). Commercial growers surveyed in northeast Florida were found to apply an average of 280 lb/acre K_2O (Kidder et al., 1992).

In 1992 and 1993, large-scale demonstrations were conducted on sites that were a minimum of one acre in size (Hochmuth et al., 1993; Hochmuth et al., 1993a). Experiments in 1992 were conducted with commercial K rate applications from 235 to 280 lb/acre K_2O and reduced K rate applications from 135 to 180 lb/acre K_2O. Yields with the lesser K rate were generally equal to yields with the higher K rate. Delayed application of the side-dressed K was attributed to lower yields (74% RY) as compared to the grower yields in one of the four experiments. Yields were up to 2.4 times greater than the average Hastings area yield of 200 cwt/acre for this season. In 1993, yields with commercial K rates from 225 to 340 lb/acre K_2O were generally equal to yields with reduced K rates from 85 to 190 lb/acre K_2O. As with the previous season, yields were up to 1.8 times higher than the average Hastings area yield of 180 cwt/acre for this season. Both commercial and reduced K rate applications were well in excess of 1989 recommended rates based on M-1 soil test results. Poor N or K application timing was cited in two experiments resulting in lesser yields with the reduced rate compared to the commercial rate. Adherence to the recommended application of 175 lb/acre N, one-half to two-thirds at planting with the remainder applied 35 days from planting, and application of 140 lb/acre K_2O applied in equal amounts at planting and side-dress was cited for high yield results (Kidder et al., 1992).

The single K rate recommendation of 140 lb/acre K_2O (Hochmuth and Hanlon, 1995) for soils with any M-1 tested K concentration, based on the above summarized tri-county research, was evaluated for potatoes grown in South Florida (Hochmuth et al., 1998). Five experiments were conducted in Homestead, Florida in the winters of 1993-1994 (grower 1), 1994-1995 and 1995-1996 (growers 1 and 2). Potassium was applied from 0 to 200 lb/acre K_2O in four of these experimental seasons and from 0 to 240 lb/acre K_2O in a fifth experimental season. The soil extractant ammonium bicarbonate-diethylenetriamine pentacetic acid, AB-DTPA, was used due to the marl and rockland soils in this area to evaluate soil K concentrations. Soil nutrient concentrations determined with AB-DTPA extractant are not interpreted as soil concentrations determined with M-1 extractant.

Yields maximized with between 99 and 100% RYs in all of these experiments with K rates below 140 lb/acre K_2O (Hochmuth et al., 1998). Maximum yields occurred between 50 and 120 lb/acre K_2O resulting in yields of 87, 193,134, 239, and 146 cwt/acre. As with the tri-county experiments, yield responses to applied K fertilizer were not dependent upon soil-extracted K concentrations. A yield response to 120 lb/acre K_2O resulted where the extracted soil K concentration was 60 ppm. No yield response, however, resulted where the soil K concentration was 71 ppm. An increased soil-extracted K concentration of 122 ppm resulted in a quadratic yield response leveling off with 100 lb/acre K_2O. Yield responses did not differ to K rates where soil-extracted K was 274 ppm and no discernable yield trend resulted to increased K rates where soil-extracted K was 787 ppm. The predictive capability of the AB-DTPA soil test, as with the M-1 soil test in North Florida, was not effective for K fertilization recommendation on marl and rockland soils and the 140 lb/acre K_2O recommendation appeared sufficient for high yield on soils throughout the state. Whole leaf- tissue K concentrations were above the sufficiency range in all experiments.

Conditions Linked to Over Fertilization with Potassium

Over-fertilization with K is cited through the literature as a factor for reduced specific gravity in potato and increased occurrence of potato soft rot in some experiments. Higher soil fertility generally results in increased water uptake by plants, which in potato plants, results in lower solids content and specific gravity of the tuber (Hensel, 1967). Although potatoes with high specific gravity produce more potato chips, other quality characteristics such as crispness and color uniformity of chips, which are not affected by specific gravity, can be more important. Florida Sebago potato was described as the favored chipping potato in Hastings since 1942 for these quality characteristics, despite the relatively low specific gravity (1.0696). Research on the effects of K sources K_2SO_4 or KCl, on the specific gravity of potato was evaluated over six planting seasons from 1954 through 1959 in Hastings (Myhre, 1959). In the last season, changes in specific gravity were evaluated over three K rates, 100, 200, or 300 lb/acre K_2O applied in bands at planting, or applied broadcast at 200 lb/acre K_2O.

Generally potato plants fertilized with K_2SO_4 - K resulted in tubers with higher specific gravity than those fertilized with KCl. Exceptions occurred, where higher specific gravity resulted from KCl fertilized plants, when excessive rainfall required midseason K side-dressing. Specific gravity increased through 200 lb/acre of band applied K_2O and decreased significantly with 300 lb/acre K_2O. Other factors had an observed effect on specific gravity of Sebago potato tubers, including soil moisture. Tubers grown further from the irrigation furrow, to 55 feet, had higher specific gravity than those grown 5 feet from the irrigation furrow (1.0635 to 1.0655, respectively). Broadcast fertilizer application resulted in tubers with increased specific gravity compared to tubers grown where K was applied in bands at 200 lb/acre K_2O.

Specific gravity of potatoes decreased significantly (at 1% probability) in two of three seasons with increased K rate fertilization from 240 to 485 lb/acre K_2O in Hastings research (Locascio et al., 1991; Locascio et al., 1992). Researchers sought to identify excess K fertilization as a factor in bacterial soft rot development in potato tubers. This disorder and other disorders of potato tubers can be worsened by Ca deficiency, which can occur in soils where K^+, NH_4^+, and Na^{++} from dissolved fertilizer compete with Ca^{++} for uptake by the root. Florida potato production soils with typically low to moderate, 400 to 800 ppm (M-1), concentrations of Ca prompted spring 1984, 1985, and 1986 experiments with Ca and K in Hastings. Calcium was applied at rates of 0, 400, or 800 lb/acre in factorial combination with 240 or 485 lb/acre K_2O. Fertilizers were formulated and applied in bands 4 inches below the bed surface and 4 inches to each side of the seed potato. Soil K concentrations extracted by M-1 soil test were medium each season.

Tuber decay responses to varying rates of K and Ca fertilizer varied with the cultivar, but rainfall had the greatest effect on tuber decay resulting in 49% disease severity in the wet 1984 season compared to 11 and 4% in the drier seasons of 1985 and 1986, respectively. Calcium and K were moved downward through the soil during the wet season resulting in less Ca accumulation in the tuber compared to the drier seasons where subsurface irrigation maintained soil fertility, increased tuber Ca and K accumulation, and decreased severity of bacterial soft rot. Variation among 'LaChipper', 'Superior' and 'Atlantic' over three seasons to Ca and K fertilization made a decay response difficult to assess.

Potassium Summary

The 1978 recommendation of 200 lb/acre K_2O for irrigated mineral soils (Montelaro, 1978) was reduced in 1989 to 140 lb/acre for very low and low K soils, 70 lb/acre for medium soils, and zero lb/acre for high and very high K soils based on M-1 soil test (Kidder et al., 1989). Potassium recommendations were revised further in 1995 (Hochmuth and Hanlon, 1995) to a blanket recommendation of 140 lb/acre K_2O for soils testing from very low to very high in M-1 soil-extracted K in north Florida and for all soil K concentrations extracted with the AB-DTPA soil test in south Florida. Researchers cited inconsistent yield response to applied K regardless of soil K concentrations as reason for the revised K recommendation. Yields maximized in 71% of the summarized experiments with K rates below 140 lb/acre K_2O (these experiments are indicated by an asterisk in Fig. 4). Potassium rates were not tested below 140 lb/acre K_2O in data from four of the summarized experiments. If these four experiments are omitted from the pool of experimental data, yields maximized in 81% of the experiments with K rates below 140 lb/acre K_2O. Data on leaf-tissue K concentrations supported the revised recommendation with K concentrations often above the sufficiency range with low rates of applied K. Such variability was likely due to the mobility of this nutrient in sandy soils. Yield responses to K rates greater than 140 lb/acre K_2O were split. In some experiments, yields remained high through 500 lb/acre K_2O, while in others, yields dropped as much as 50% with applied K rates through 300 lb/acre K_2O (Fig. 4). Potato yield responses to K fertilization from 31 experiments, summarized in Fig. 4, appeared to level off after 100 lb/acre K_2O. Reduction in the specific gravity of potatoes, or decreased chipping quality, frequently resulted with higher rates of applied K. Favorable growing conditions expressed as the number of growing degree days (Rhue et al., 1986) often had a greater effect on potato yields than rates of applied K fertilizer.

Since K leaches in sandy soils, total K application should be split into two applications with some K applied at planting. Potato yield did not respond to K source on a soil testing medium in M-1 K. Yields were similar for soluble KNO_3, KCl, and K_2SO_4, for a controlled-release (CR) KNO_3, and for various mixtures of soluble and CR sources.

Summary

Research over the past 40 years supports a maximum N application of 175 lb/acre for optimal potato yields with only sporadic yield increases with up to 200 lb/acre N. Excessive N sometimes reduced specific gravity of potatoes. Controlled-release N sources SCU, IBDU, and a gel infused urea-ammonium-nitrate did not increase yields over potatoes grown with soluble N sources. Studies are needed to follow N in the soil system as it relates to N and irrigation management. Additional large-scale demonstrations on commercial farms of recommended nutrient management programs are

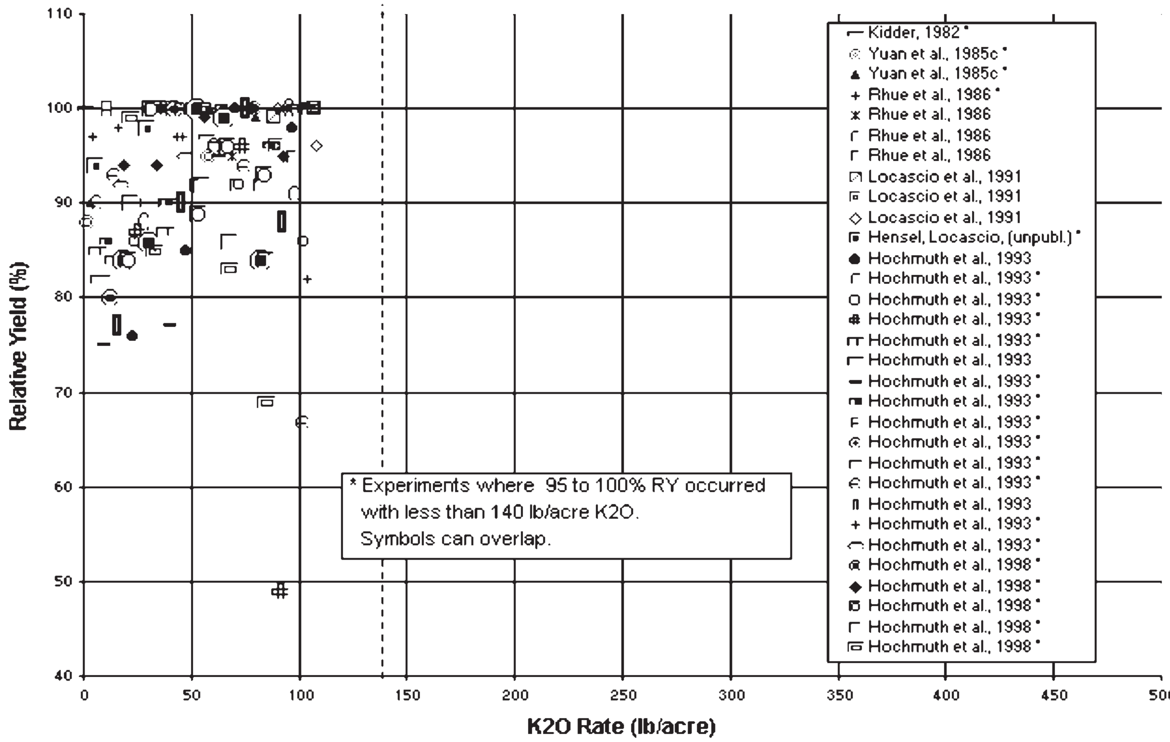

Figure 4. Relative yield of potatoes for experiments, years, and seasons as a function of added K_20.

needed in all potato production areas. Phosphorus and K recommendations tested through experimentation appear to be on target for the needs of potato while minimizing impact on the environment. The mobility of K in the sandy Hastings area soils and the reduced predictive capability of soil K tests, M-1 in the Hastings area and AB-DTPA in the Homestead area, led to abandonment of K testing in favor of a simple rate of K, 140 lb/acre K_2O. Excessive K, often resulted in a reduction of specific gravity of potatoes. Timing of application of mobile nutrients, such as N or K was important for greatest yields. All N and K need to be applied by 35 to 40 days after planting.

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