

Fluid JOURNAL

Official Journal of the Fluid Fertilizer Foundation

Fall 2015 • Vol. 23, No. 4, Issue #90



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- **Supported millions of dollars of applied crop production research**
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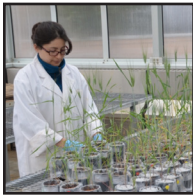
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THE FLUID JOURNAL - MISSION

The Fluid Journal is published by the Fluid Fertilizer Foundation. The FFF is a non-profit organization committed to researching and providing information about fluid fertilizer technology. Since its formation, the FFF has funded over \$3 million in fluid fertilizer research. We have accumulated thousands of pages of research data. The main goal of the Fluid Journal is to transfer this technical information into easy to read form to farmers and dealers so they may be better informed as to the technological advancements that the fluid fertilizer industry has achieved.

FOCUS

The Fluid Journal is focused on disseminating fluid fertilizer technology to universities, dealers, equipment manufacturers and fertilizer producers. Our editorial matter focuses on several areas:

- Evaluate the agronomics of fluid fertilizers in the production of maximum economic crop yields
- Evaluate application techniques for fluid fertilizers.
- Investigate and inform our readers of innovative uses of fluid fertilizers under varied cultural, pest control and water management practices.
- Evaluate the efficiencies and conveniences of fluid fertilizer systems.
- Evaluate methods of controlling environmental problems with fluids.

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From The Publishers

Improving crop yields through fluids.

Moving on Ahead

The Fluid Journal • Official Journal of the Fluid Fertilizer Foundation • Fall 2015 • Vol. 23, No. 4, Issue #90

This issue of the Fluid Journal magazine continues to do what it has done for its 22 years: report on the multitude of ways fluid fertilizers continue to lead the way in advancing the cause of agriculture: to increase crop yields and quality. Researchers within our universities and agriculturists, who manage our increasingly abundant farm fields, continue their search for better ways to increase crop yields and report their findings to an awaiting world. In 1949 the average corn yield was 38.2 bu/A and by 2013 it was 158.2 bu/A with some researchers today reporting as high as 220 bu/A. Fluid fertilizers have played a key role in achieving this yield improvement in a world with an ever-increasing population, now topping 7 billion compared to 813 million in 1800. The Fluid Fertilizer Foundation (FFF) is dedicated to playing its part in financially supporting these research projects, totaling some \$2.3 million over 18 years.

An article by Dr. Julian Smith in this issue covers a history of the FFF and

its birth through the National Fertilizer Solutions Association (NFSA). He gets into the basics of how the NFSA was formed to advance the concept and advantages of fluid fertilizers and why, over the years, it also decided to form the FFF. Dr. Smith further describes the meaningful accomplishments of the FFF in advancing the fluid concept and the values it continues to pass on to the world of agriculture.

An article by Dr. Terry Tindall, describes the role and advantages of fluid fertilizers in drip irrigation, explaining the importance of timing of fluid fertigation injections to effectively improve plant development and yields. He further explains how drip irrigation is helping to expand limited water supplies while still remaining economically viable.

Potassium partitioning in cotton is an article about research, led by Dr. Derrick Oosterhuis, that shows how K partitioning decreased in leaves and increased productive components over the growing season. Regardless of cultivar or K

level, percent of total plant K in leaves increased significantly at each growth stage throughout the growing season.

An article by Dr. Daniela Montalvo and associates at the University of Adelaide in Australia, on management of P nutrition in plants, shows that application of fluid P in calcareous soil is highly

“FFF has played key role in achieving yield improvements worldwide”

effective. The article also cautions to minimize the impacts of over-fertilization.

These articles are substantive evidence of the value of fluid fertilizers in the world of agriculture. The accumulative knowledge contributed by university researchers and member companies has done much to advance the use of fluid fertilizers in producing crops to feed an ever-growing world population.

Benefits Of The FFF

A history trip is in order.

Dr. Julian Smith

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Summary: The FFF remains a fruitful source of cutting edge research to provide strong product and technique benefit statements and an outstanding forum for agronomic and production information via the annual Technology Round Up and Fluid Forum.

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Phone: 785-776-0273 • E-mail: fluidfertilizer@fff.kscoxml.com
Research and education for efficient use of fluids.

To fully understand the role of the Fluid Fertilizer Foundation (FFF) in modern fertility practices and the current benefits of membership and association, a history trip is in order. This should be of particular benefit to the miners and MBA's that currently proliferate the industry. The recent stock quote and “value proposition” (whatever that is) so commonly pursued and held as the Holy Grail of business achievement would, in many cases, not be possible without the endeavors of a select few brilliant minds and pioneers that birthed the fluid fertilizer industry.

The early post WWII years were full of bright graduates looking for a role in a revolutionary new industry--namely, agriculture! A generation of American entrepreneurs could call agriculture “home” at this time--we had engineers returning from Princeton, chemists from Iowa State, Merchant Navy veterans and many more in my circumstance. As a privileged youngster with no particular

pedigree in the early 80's, this history enthralled me.

As crop yields continued an inexorable rise upwards to feed the post-war generation, fertilizer became of massive significance. Land Grant institutes and extensions did their part. Soil testing, and to some extent tissue testing, started to evolve. Subsequent diagnosis and calibration experimentation provided massive advances in crop productivity. Similarly, the availability of fertilizers began to evolve: super-phosphate, ammonia (aqua and anhydrous) and mined potassium salts.

Potential

Since the production of dry P and N involved liquid intermediaries (K was mined but soluble K became important as the latter two grew), potential for fluid fertilizers came to mind. Several key points here:

- Why take a fluid and make a solid that needs to be fluid again after soil application? As a preeminent fluid pioneer, Bill Lohry and his company Nutraflo, always said, “plants drink their food, not eat it”
- Mixed grades--the demands of modern production were calling for multiple nutrient mixes, not just straight. Agronomic research also placed demands on timing considerations: how long to sidedress corn at knee high?
- Solubility is an issue
- Industrial by-products such as ammonium sulfate in surfeit
- Unabated pollution in the US culminating in the Love canal and EPA
- Post-War Tennessee Valley Authority: what to do with all this urea and ammonium nitrate nitrogen? Urea,

- as essentially a stable storage for ammonia and ammonium nitrate, used as an explosive nitrate? Both would be sought in alternative markets in agriculture as obvious fertilizer candidates
- Mix dry urea and ammonium nitrate and stand back! However, mix fluids of both and voila!: fluid urea/ ammonium nitrate--a eutectic taking 18 percent N material to 32 percent
 - How do we make a stable NP solution? Use anhydrous N and super phosphoric acid and voila!: 10-34-0 via a T-Reactor
 - What about K? Simple. We suspend it using bentonite clay to get the 3-9-27 grades, since solubility of K is limited
 - We need zinc. Pioneers such as Glen Brandt opened the metal chelate market in fluid fertilizer in the late 60's.

Driving force

Irrespective of the phenomenal efforts of the TVA and later the National Fertilizer Development Center (NFDC), there was an upsurge in agricultural production and nutrient requirements. The driving force behind these developments? A nascent fluid fertilizer industry and pioneers such as Lohry, Tinsman, Hopwood, Stutsman, Simplot, Abell, Garrett, Willard, Brandt, and many others. In our office, for example, we have a picture of Glen Brandt and a host of others, including Orville Redenbacher as a part of a delegation to the TVA/NFDC in Alabama to discover the next great fluid invention.

At about this time, in the 1960's, the Nitrogen Institute morphed into The Fertilizer Institute (TFI). Other players became the Potash and Phosphate Institute (PPI), but among certain cadre of independents, the role of fluid fertilizers needed a focus. Hence, the formation of the National Fertilizer Solutions Association (NFSA). The pioneers who pushed the TVA now pushed the NFSA in the interest of fluid fertilizers.

The industry had phenomenal support and momentum at this time from the likes of Texas Sulphur, Arcadian, Agrico, IMC, PCS, and Texas Gulf--an era when oil companies were entering and exiting the fluid fertilizer business at a whim.

Contributors

Agronomic research in fertilizer use was probably unprecedented, but few

land grants dabbled in fluid sources, despite the attention of the NFSA and its members. A notable exception here was Arcadian corporation and agronomist Don Johnson. These folks made significant advances in nitrogen technology via applications from aqua to UAN solutions. Early slow release work and foliar nitrogen studies--split applications, and starter fertilizers--owe their origin to these pioneers. Other significant contributors at this time were Dr. Larry Murphy (Kansas State) and Dr. Stanley Barber (Purdue) who both elaborated the role and efficiencies of fertilizer placed close to the seed or developing plants that essentially gave rise to the modern era of "strip, starter, split" applications.

Despite the obvious implications of nutrient efficiencies (yield, economics, environment, and so forth) fluids carried a premium price in the field, for the most part, that required a little more attention than the usual NPK peddlers.

The NFSA, through its annual Round-Up and Convention gatherings, sought to include agronomic research and data but primarily through member companies. Similarly, the events became excellent opportunities for industry chemists and engineers to exchange experiences and assist one another in this fledging industry. However, widespread recognition and acceptance, in a largely dry fertilizer, anhydrous N business, was a significant hurdle, not so much at the independent dealer level, but particularly at the Land Grant university research level.

Formation of FFF

I recall talking to several university and consultant researchers at the time about doing fluid research. The major stumbling blocks were measurement and application of treatments (coffee can) versus no application equipment for fluids. It was too expensive and I couldn't get the controls I needed (e.g. P vs APP). These were mostly cop-outs and ignorance but also an issue. The NFSA thus commissioned Scott Tinsman to chair a committee to address these issues and in 1981 the Fluid Fertilizer Foundation was born, a tribute to the independent pioneers of 30 years before and the foresight of the major nutrient producers who saw a route to farms via the informed dealer and crop consultant.

Its value

The value of the FFF is still crystal

clear today. We have a research and education foundation dedicated to fluid fertilizer research--a unique organization still serving dealers, consultants, land grants, and major nutrient producers.

Some of the early work included:

- Fluid education in the university systems
- Through member support, donation of application equipment and custom blends to facilitate research
- Multi-nutrient starters (NPKS and Zn)
- East coast phosphate rate recalibrations
- Slow release nitrapyrin, DCD, and NBPT research
- Split N regimes in multiple crops
- DRIS
- Foliar nutrition related to pesticide
- Weed N' Feed--actually the origins of the AMS/glyphosate surfactant business
- Seed N' Feed
- Chelated micronutrients
- Resolution of late K deficiency in cotton
- Pioneering fertigation work
- High yield systems agriculture
- Precision ag systems

Summing up

And the work continues with millions of dollars granted to high yield, economically viable, and environmentally sensitive agronomic research.

For me personally, one of the most significant founding and existing benefits of the FFF is the interaction between industry colleagues and the very important personal relationship between business and academia. It's still a people business.

Many companies in this business owe their products to the pioneers and pioneering research of the FFF. A little dose of history would help. Moreover, the FFF remains a fruitful source of cutting edge research to provide strong product and technique benefit statements and an outstanding forum for agronomic and production information via the annual Technology Round Up and Fluid Forum.

Dr. Smith is Director of Discovery and Innovation at Brandt Consolidated, Inc. in Springfield, Illinois.

Using Fluid Fertilizers In Drip Irrigation

Timing of fertigation injections may range from daily to weekly to monthly, depending on crop.

Drs. Terry A. Tindall and Galen Mooso

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Summary: Grape production areas of CA and other western states are grown almost exclusively on drip or micro sprinklers. Water is the greatest limiting factor and allows exceptionally high efficiency rates of water, but also creates the value-added opportunities for using high- quality fluid fertilizers within these systems.

Western agriculture depends on water for all aspects of production agriculture as it relates to plant development. Without water and its efficient delivery systems, all else pales in comparison. As crop production expands into other marginal areas of the world, irrigation will need to follow. As climates become less predictable, there will continue to be a reliance on water and concerns with the quantity and quality of that resource. Factor that with an ever-increasing population (plus the dietary changes within those populations) will be a major concern for advancing water delivery systems and making the most out of an already limited resource--water. It is easy to understand how advancing drip irrigation into areas where it has not been used before is becoming an everyday reality and concern.

Limited water

California (CA) and other parts of the west rely so heavily on irrigation water to bring (CA) an estimated 6 million acres

into production. This past year that amount of land has been decreased to less than 600,000 acres. It is all related to the shortness of irrigation. With the limited supply of water there also comes a price for water delivery and the extreme need to improve efficiency. The majority of acres in (CA) and the West still remain surface irrigated with water-use-efficiency ranging from 40 to 60 percent. To expand the limited supply of water and still remain economically viable, drip irrigation is being expanded at a rapid rate. It has always been a part of a management strategy for certain high-value crops like berries, vegetables, and tree crops, but with the advent of drip irrigation, and especially subsurface drip irrigation (SDI), even row crops of cotton, corn, sorghum, and alfalfa are becoming more common.

Advantages

Subsurface drip irrigation has several advantages that would include both the obvious observation of increased water

efficiency, but also additional attributes of increased yields, improved crop quality, and less disease. The latter advantage would also relate to less crop protectants being needed. As a better understanding of drip takes place, marginal water can be more fully used to grow a crop. However, caution needs to be taken when using water with high osmotic potential (salts) to assure that enough leaching would take place to avoid salt damage from high concentrations of those salts on the wetting boundaries to the system. The authors would recommend studying papers specifically related to the advantages and disadvantages of drip in articles like "Subsurface Drip Irrigation in California Here to Stay?" (J.E. Ayars, A. Fulton, and B. Taylor).

Disadvantages

It should also be pointed out that there are also disadvantages to drip that also need to be considered:

- One factor is certainly that within

a watershed there is only so much water to be had. If a grower uses water more efficiently on one part of his farm, there is a tendency to use any extra water in another location. This makes sense, but the result ends up with no extra water leaving the watershed.

- The other challenge, especially with drip irrigation, is maintenance. What cannot be seen may not be readily fixed and, therefore, excellent monitoring of a system is also essential.

Managing

Fertilizer management through these drip systems is an expanding interest and deserves to be explored. If greater water efficiency can be obtained with drip, then it would be reasonable to assume that fertilizer efficiencies can also be achieved, but this is only true as long as a grower understands both the crop requirements of nutrients based on yield and quality estimations. This can be done, but not on a casual basis or relying on norms that might have been the standards of performance in the past.

Knowledgeable

Understanding of drip fertility requirements will always begin with a detailed understanding of soil nutrient background status as a base level for anything being applied through the drip system. Without this understanding, high potential for waste and economic challenges can easily occur. Local laboratories that are reputable and participate in a certification program are highly recommended.

NPK

Nitrogen, phosphorus and potassium (NPK) are major nutrients that need to be addressed and can be used through drip irrigation. However, it is wise to balance dry fertilizer programs with the use of fluid fertilizers (or dry soluble fertilizers) being applied through the drip system.

Nitrogen availability through a growing system can be a challenge with both mineral forms of ammonium and nitrate, as well as that of N, being released from the organic matter being accounted for. Organic N can be released anywhere from .5 to 2.0 pounds/A/day.

Adjustments will also need to be based on cropping system and residual stover as well as soil texture. For example, sandy coarse- textured soils may need an

additional 20 to 30 lbs. more N compared to finer-textured soils growing the same crop. Western agricultural crops generally will follow biomass production, with peaks of nutrient use usually associated with crop development. Potatoes, for example, will have a peak above ground concentrations but these higher levels of nutrients will always be translocated from the above-ground biomass into the tubers. Onions will follow a similar pattern.

Nitrogen and K are the most easily injected and are also required at the highest level for all cropping systems. Nutrient applications through the drip system are an efficient way to incorporate these nutrients to meet crop requirements. There is a greater potential to address specific crop needs of both N and K with minimum leaching or environmental losses of N.

Other forms

Improvements in manufacturing of N have created clean, very soluble, and reliable N solution products. All of the dry N formulations can easily be solubilized and put through drip. The most common source of fluid fertilizer is urea ammonium nitrate (UAN). However, potassium nitrate, calcium ammonium nitrate, or calcium nitrate are all suitable and acceptable forms being currently applied with drip. Potassium dry forms may have impurities in them that can contribute to plugging emitters. Potassium chloride is soluble and lends itself to fertigation, but does have a high salt index. Dry soluble or fluid forms of K are excellent forms of K to apply through the drip lines. These include potassium nitrate or potassium thio-sulfate (KTS) and will provide other essential nutrients as well as the K.

Managing P

Phosphorus fluids are the most difficult, but not impossible to manage. Much of the P should be applied at planting for row crops or vegetables prior to forming beds. However, much of the seasonal use of P can be applied through the drip lines by controlling or solubilizing the bi-carbonates, which is measured by lowering water pH to between 5 and 6.5. This can be done by injecting an acid (sulfuric, N phuric, or phosphoric) prior to P injection. Measurements of pH become essential to avoid insoluble precipitates that will form primarily from Ca. Once the pH is controlled and

monitored, P solutions can be injected successfully. Large commercial scale drip farms with permanent crops are especially interested in fluid P use and quite often will use phosphoric acid. The challenge with over-use is in creating a large, available concentration of P within the drip beds. The authors have observed P soil test levels well over 100 ppm where P acid only has been applied. It would make much more sense to use N–Phuric or be skilled enough to use sulfuric acid to lower water pH.

Four fundamentals

To make the most efficient application of fluid fertilizers, crop advisors and growers should consider four fundamental factors:

- Nutrient requirements of the crop
- Specific soil and environmental site considerations
- Timing of nutrients being injected to meet yield and quality demands
- Water controls within the drip irrigation system to avoid leaching of soluble nutrients below the root zone.

The latter is especially concerning as it relates to both environmental stewardship and grower economic returns. Leaching losses of N are of the greatest concern as they carry with them the added negative challenge of potentially building up high levels of nitrates in groundwater. There are no environmental or health challenges associated with K losses, but certainly economic ones. With the increased concern of dissolved soluble P and losses from land, crop advisors and growers need to be especially mindful of both increasing high P levels within the field, as well as the drip zone.

Timing

Timing of fertigation injections may be variable and range from daily to weekly to monthly, depending on the targeted crop. Both fertilizers (N and K) are rather straight forward and injected fairly easily with calculations of nutrients often based on the rate per area needed, amount of water being delivered over a period of time, and an injection system developed to deliver those specific quantities.

Other options

Zn and other micronutrients can also be applied through an acidified water delivery system. It appears that the most effective source of Zn is an EDTA (chelated form of micronutrients). This source can be added to both APP and

ortho-based P sources like 3-18-18 or other low-salt fluid fertilizers with limited problems. Other micro-nutrient sources can also be applied, but doing a self-test would be advisable.

Working together

The Fluid Fertilizer Foundation

(FFF) continues to support directed research with fluid fertilizer management strategies on drip irrigation. It is currently supporting Dr. Fred Below from the University of Illinois and has supported studies in California, Kansas, and other states. It is imperative that the fluid fertilizer industry directs programs that

promote nutrient use and water use efficiency. This works hand-in-hand with the larger priorities of the 4R Nutrient Stewardship program. With drip as a delivery mechanism for water and nutrients both of these critical programs can be addressed.

Dr. Tindall is Senior Agronomist for J.R. Simplot Company in Boise, Idaho, and is chair of the FFF Board of Directors and a member of the Fluid Journal Editorial Committee. Dr. Mooso is the Agronomy Manager for Simplot and a member of the FFF R&E Committee.

Going on Twenty-Two Years of Archives!

The Fluid Journal, flagship publication of the Fluid Fertilizer Foundation (FFF), makes over two decades of archives available on its web site. The magazine investigates and informs its readers on innovative uses of fluid fertilizers under varied cultural, pest control, and water management practices, focusing on evaluating:

- ***the agronomics of fluid fertilizer in the production of maximum economic crop yields***
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The Fluid Journal also provides links to its articles on Twitter: <http://www.twitter.com/fluidjournal>

For information on how to become a member of the FFF, contact the foundation's office at 785/776-0273 or the foundation's website: <http://www.fluidfertilizer.com>

Potassium Partitioning In Cotton

Taylor Coomer, Derrick Oosterhuis, and Leo Espinoza

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Summary: Potassium (K) is very mobile, moving throughout the plant with K concentrations in individual plant parts shifting throughout the growing season. Results from this study showed that K partitioning decreased in leaves and increased in reproductive components over the growing season, but there were no cultivar differences between growth stages at individual K levels. Results also showed that PHY499 was a lower yielding cultivar than DP0912 and ST5458, especially in low K environments.



For cotton to grow and develop properly, plants need to uptake the necessary amount of nutrients and use those nutrients in a beneficial fashion. It is well established that cotton requires a certain nutrient tissue concentration to achieve and maintain growth rates (Siddiqi et al., 1987).

One of the most essential and abundant nutrients in cotton is potassium (K) second only by mass to nitrogen (N) (Marschner, 1995). Potassium plays a vital role in plant growth and metabolism. Potassium deficiencies can affect numerous plant characteristics such as reductions in lint yield and biomass production (Pettigrew and Meredith, 1997).

Traditional K deficiency symptoms differ from recent K deficiency symptoms due to genotypic changes in cultivars over time (Oosterhuis et. al. 2013). Even though K is not a component of any singular plant part, physiologically, K is an essential macronutrient for plant growth and development and affects many fundamental physiological processes such as cell pH stabilization, regulating cell metabolism by acting as a negative charge neutralizer, maintaining cell turgor by acting as an osmolyte (Marschner, 1995), activating enzymes and regulating the stomatal mechanism (Dong et al., 2004).

Whole plant K accumulation generally follows a curve that has maximum uptake around 112 days after planting. However, K is very mobile, moving throughout the plant with K concentrations in individual plant parts that shift throughout the growing season (Gerardeaux et al., 2010).

The K uptake curve follows a similar

pattern of dry matter production. However, dry matter production continues after K uptake has reached a maximum. Mullins and Burmester in 1990 showed that mature cotton took up an average of 99 to 108 kg K ha⁻¹ with 24.8 percent of K in the shoots, 20 percent in the leaves, 36.5 percent in capsule walls and 18.4

“One of the most essential nutrients in cotton is K, second only by mass to N.”

percent in the seed. Plant dry matter can have as much as 10 percent K by weight, but the optimum range for cotton is 2 to 5 percent (Oosterhuis et al., 2013). Cottons bolls can accumulate K to concentrations above 40 mg g⁻¹ of the dry weight (Kafafi and Xu, 1996). Potassium uptake is slow during the seeding stage, increases rapidly at flowering, and slows after the maximum is reached at boll maturity.

Cotton’s K requirements are highest during boll set because bolls are a major K sink. During the development of a boll, K concentrations in plant tissue increase from 10 g kg⁻¹ to 55 g kg⁻¹ at maturity. There have been few studies observing K partitioning in recent transgenic, high-yielding cultivars.

Objective

This study, therefore, was conducted to investigate the effects of K deficiency on the partitioning of K in boll components and leaves beginning at squaring and continuing through six weeks after first flower.

Methodology

A field trial to evaluate K partitioning

was conducted at the Lon Mann Cotton Research Station of the University of Arkansas. Three cotton cultivars, DeltaPine 0912 B2RF, Phytogen 499 WRF, and Stoneville 5458 B2F, were planted on May 21, 2014. All fertilization, except K, was applied according to soil test recommendations. Four treatments of 0, 33.6, 67.2, and 100.8 kg K ha⁻¹ (0, 30, 60, and 90 lb K ac⁻¹) were applied as potassium chloride (KCL) at approximately pinhead square (PHS) on June 25. Plots were four 1-m (38 inches) wide and approximately 15.24 m (50 feet) long. Plots were furrow irrigated as needed.

One meter of whole plants was sampled from four replications from each of the 12 treatments at PHS, first flower (FF), three weeks after first flower (FF3), and six weeks after first flower (FF6). Whole plant samples were then separated into four main plant components: stems, leaves, petioles, and reproductive components (squares, flowers, and bolls). Plant components were dried at 60oC for at least one week, weighed, ground, and analyzed for K concentration. This experiment was also analyzed as a two factor factorial completely randomized design with four replications. Statistics were analyzed using JMP Pro 11 (SAS Institute, Cary, North Carolina) with alpha level of 0.05 as an indication of significance. Differences between treatments were determined using Tukey’s HSD test. Before partitioning and yield data were analyzed, outliers were determined using the multivariate method of jackknife distances.

Yield data were obtained at harvest on October 23, 2014. Partitioning data were separated by K levels with growth stage and cultivar as main factors. Yield data

Table 1. Percent of total K in leaves at four growth stages, pinhead square (PHS), first flower (FF), three weeks after first flower (FF3), and six weeks after first flower (FF6) of cotton plants treated with two K levels, 0 and 100.8 kg K ha⁻¹.

K Level	PHS	FF	FF3	FF6
0 kg K ha ⁻¹	52.15 a	39.6 b	25.99 c	11.18 d
100.8 kgK/ha ⁻¹	49.87 a	41.11 b	23.94 c	11.14 d

Different letters indicate significant differences among the growth stages within the same K level, according to Tukey’s HSD test (p<0.05).

Table 2. Percent of total K in reproductive components at four growth stages, pinhead square (PHS), first flower (FF), three weeks after first flower (FF3), and six weeks after first flower (FF6) of cotton plants treated with two K levels, 0 and 100.8 kg K ha⁻¹.

K Level	PHS	FF	FF3	FF6
0 kg K ha ⁻¹	2.1 d	8.28 c	39.28 b	70.07 a
100.8 kgK/ha ⁻¹	3.05 c	7.43 c	38.41 b	60.75 a

Different letters indicate significant differences among the growth stages within the same K level, according to Tukey’s HSD test (p<0.05).

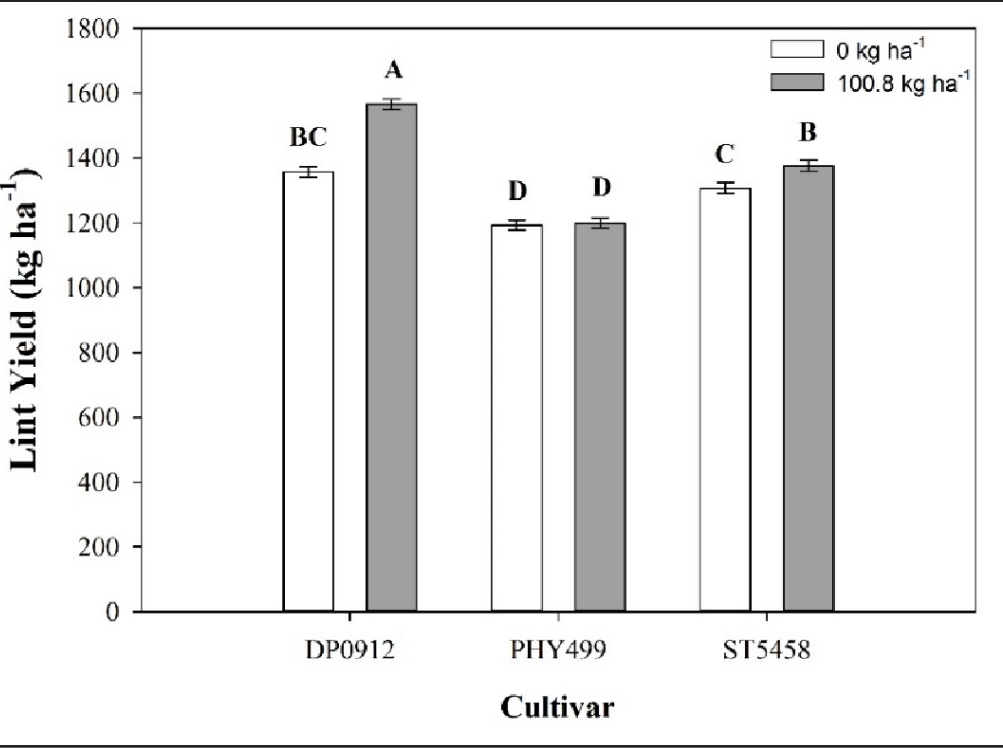


Figure 1. Lint yields (kg/ha) of three cotton cultivars, DeltaPine 0912, Phytogen 499, and Stoneville 5458, at two K levels, 0 and 100.8 kg K ha⁻¹. All values are means ± standard error (n=4). Different letters indicate significant differences across all treatments according to Tukey’s HSD test (p<0.05).

were analyzed with K level and cultivar as main factors.

For this article, only K levels of 0 and 100.8 kg K ha⁻¹ will be discussed in leaves and reproductive units (squares, flowers, and bolls).

Study results

Leaves. Regardless of the cultivar or K level, percent of total plant K in leaves increased significantly (p<0.05) at each growth stage throughout the growing season (Table 1). There were no cultivar differences in percent of total plant K

in leaves at any K level. At 0 kg K ha⁻¹, PHS had the highest percent of total plant K in leaves with a mean percentage of 52.15 percent, and decreased throughout the growing season with 11.18 percent at FF6. At 100.8 kg K ha⁻¹, PHS mean percent total plant K in leaves was 49.87 percent and decreased to 11.14 percent at FF6.

Reproductive components. Potassium partitioning in reproductive components showed no significant (p<0.05) differences between cultivars

at either K levels, however, growth stage showed significant differences (p<0.05) at each K level (Table 2). In the 0 kg K ha⁻¹ treatments, FF6 had 70.07 percent of total K in RC, and only 2.1 percent of total K in RC at PHS on average. With 100.8 kg K ha⁻¹ applied, PHS and FF showed no significant differences (p<0.05) and were lower than FF3 and FF6 with 3.05, 7.43, 38.43, and 60.75 percent total K in RC, respectively (Table 2).

Lint yield analysis showed significant (p<0.05) differences for the interaction of K level and cultivar (Figure 1). The highest lint yield was found in cultivar DP0912 treated with 100.8 kg K ha⁻¹ with an average of 1565.52 kg lint ha⁻¹, which was significantly higher than all other treatments. The two lowest yielding treatments were PHY499 100.8 kg K ha⁻¹ and PHY499 0kg K ha⁻¹ treatments, with yields of 1,198 and 1,193 kg lint ha⁻¹, respectively. DP0912 with 0 kg K ha⁻¹ out-yielded both other cultivars at 0 kg K ha⁻¹.

Conclusions

It can be inferred that over the growing season, as boll load increases, K moves from leaves to reproductive components due to an exponential increase in percent of total K in reproductive components and a decrease in percent of K in leaves over time. However, there were no cultivar differences at either K level in either plant part, indicating that these genotypes do not respond differently to low or high K environments.

When yield is considered, both low and high K levels on DP0912 and ST5458 out-yielded either K level of PHY499. DP0912 was numerically the highest yielding cultivar at both K levels, and statistically both DP0912 and ST5458 at 0 kg K ha⁻¹ out-yielded PHY499 at 0 kg K ha⁻¹. These results suggested that DP0912 and ST5458 could be potential cultivars to be planted under low K conditions.

Taylor Coomer is an M.S. candidate and graduate research assistant, Dr. Derrick Oosterhuis is a Distinguished Professor with the Department of Crop, Soil, and Environmental Sciences at the University of Arkansas in Fayetteville, and Dr. Leo Espinoza is an Associate Professor and Soil Scientist with the Cooperative Extension Service, University of Arkansas in Little Rock.

Summary: Our study demonstrated that in acidic and oxide-rich soils, where the availability of phosphorus (P) is restricted by strong adsorption reactions, P fluid fertilizers did not provide any additional advantage to plant growth over the granular sources. In contrast, fluid P fertilizer was highly effective in calcareous soil. Chemical properties of the soils need to be considered prior to the selection of P fertilizers as they play a vital role in the fate of P in soils.



Andisols and Oxisols are rich in P-sorbing minerals, such as Al/Fe oxyhydroxides or allophone. Management of P nutrition in these soils is often very challenging. To overcome P deficiency and to increase the bio-available P pool in soil, the application of fertilizer P is necessary. In these soils, a substantial quantity of fertilizer P is required to achieve economically acceptable yields; however, over-fertilization can result in environmental problems and accumulation of P in the soil. Phosphate fertilizers come from a finite resource and recently there has been speculation of exhaustion (in the next few centuries) of the more accessible sources, which may lead to an increase of the already high fertilizer prices.

Phosphorus fertilizers are commonly applied in the form of granules, but the use of fluid P is also a viable alternative. The selection of fertilizer type (granular vs. fluid) should be made, taking into consideration the chemical properties of the soils. It has been shown that there is more bio-available P in calcareous soils fertilized with fluid P than with granular P fertilizers. However, our previous work has indicated this is not the case for Andisols and Oxisols. A greater percentage (34%) of added P with granular fertilizer remained in a labile

form (potentially plant available) than with fluid fertilizer (24% labile). These results indicated that when adsorption (not precipitation) reactions reduce the availability of fertilizer P, the use of fluid sources may not provide any agronomic advantage over the conventional granular formulations.

Objective

This study aimed to investigate the relative effectiveness of fluid and granular P fertilizers for wheat grown in acidic, strongly P-sorbing soils under glasshouse conditions. Also a calcareous soil was included for comparison.

Methodology

Materials. Surface soil samples (0 to 10 cm depth) of two Andisols from Chile and New Zealand (North), two Oxisols from Australia (Greenwood and Redvale), and a calcareous Inceptisol from Australia (Port Kenny) were used for this pot experiment.

Soils. All soils were characterized by low soil test P level and high capacity to fix P. Selected soil chemical properties are presented in Table 1.

Fertilizers. The P fertilizers evaluated were:

- Granular triple super-phosphate (TSP, 20% P)

- Mono-ammonium-phosphate (MAP, 22% P)
- Di-ammonium-phosphate (DAP 20% P)
- Fluid mono-ammonium-phosphate (fMAP, 26% P).

Rates. Fertilizer rates were 150 mg kg⁻¹ for Chile, North, Greenwood, and Redvale soils, and 40 mg kg⁻¹ for Port Kenny soil. Higher P rates were used for the Andisols and Oxisols because of their very high P sorption capacity. Also a control (no fertilizer) treatment was included for each soil. Each treatment was replicated four times.

Soils. A total of 260 cm³ of dried-air and 2-mm sieved soil (weight of soil calculated based on the soil bulk density) was used in each pot. The soils were placed in double plastic bags and –basal macro- (100 mg N, 33 mg K, 21 mg Mg, 28 mg S per kg) and micro- (0.83 mg Fe, Mn, Zn, Cu, 0.083 mg Co, Mo, B per kg) nutrients were added as a solution. Consequently, soils were uniformly labeled with 500 kBq kg⁻¹ of carrier-free ³³P-orthophosphate and watered to field capacity.

Application. Three days after soil labeling and basal nutrient application, the P fertilizer treatments (granular and fluid) were applied at equidistant points around the pot and at 3 cm depth. One

day after the P fertilizer application, four pre-germinated wheat seeds (*Triticum aestivum*) with average weight of 40 mg ±0.05 mg were sown in each pot at an approximate depth of 1 cm. The seedlings were thinned to 2 plants per pot five days after planting. The pots were watered daily.

Harvesting. Six weeks after planting, the plants were harvested; shoots were cut about 1 cm above the soil surface, oven-dried at 70oC for 48 hours and the dry weight recorded. The dried plant material was ground and digested in hot HNO₃ prior to elemental analysis by inductively coupled plasma atomic emission spectroscopy (ICP-AES). The ³³P activity in the digests was measured

by fluid scintillation counting.

Calculating. In this experiment we used the isotopic dilution technique to calculate P fertilizer efficiency, the proportion of P in the shoots that derived from the applied fertilizer (Pdff%) Eq. 1:

$$33\text{ Pshoot}_f$$
$$\%Pdff = 100 \times \{1 - \frac{SA_{Pdffsoil} \times Pshoot_f}{SA_{Pdffsoil} \times Pshoot_f} - \%Pdffseed_f\}$$

Where ³³Pshoot is the shoot P activity (kBq plant⁻¹) of the fertilized plants, SA_{Pdffsoil} is the specific activity of the soil exchangeable P that was estimated from the plants grown in the control treatments (no fertilizer) (kBq mg⁻¹). Pshoot_f is the shoot P concentration of the plant grown in the fertilized treatment

(mg plant⁻¹). %Pdff_f is the % seed P contribution to the shoot in the fertilized plants.

The total wheat seed P content determined by acid digestion was of 3.3 mg g⁻¹ ± 0.3 mg g⁻¹, average of 10 seeds, so that total seed P was 0.13 mg plant⁻¹. The amount of P from the seeds that translocated to the shoots needs to be accounted for since it can vary between fertilized and non-fertilized treatments. The seed contribution of the plants in the control treatments was estimated by assuming that L-values (isotopic exchangeable P determined from plants grown in labeled soil) equal E-values (isotopic exchangeable P in soil suspension) as discussed in the Results section.

Analysis. The analysis of variance (ANOVA) by soil was performed using GenStat statistical package 15th edition. Treatment differences were analyzed with Fisher protected least significant difference (LSD, P≤0.05).

Results

Yield, P concentration. In the Andisols (Chile and North) and Oxisols (Greenwood and Redvale) there was no significant difference in dry matter growth between granular (MAP) and corresponding fluid MAP (fMAP) fertilizer (Figure 1). In contrast to the acidic soils, fMAP produced 31% more plant dry matter than its granular counterpart in the calcareous soil (Port Kenny). The results from this experiment sustain our initial hypothesis that no agronomic benefit is to be expected with fluid fertilizer in acidic and oxide-rich soils. The plausible explanation is that with fluid fertilizer, applied P is likely to be more diluted in a larger volume of soil, resulting in P being strongly adsorbed to the Al/Fe oxides of the soils. In the calcareous soil, precipitation of Ca-P minerals is the main P-fixation process. Thus, higher dilution with fluid P is beneficial because it likely results in less over-saturation and therefore less precipitation of these minerals.

Soils. In three of the five soils, there was no significant difference between the granular fertilizers.

In the Chile soil, wheat plants fertilized with the granular TSP grew better and produced significantly higher dry matter yields than the other fertilizers. The better performance of TSP in the Chile soil could be related to the addition of Ca

Table 1. Selected soil properties of the soils used in the study.					
Soil properties‡	Chile	North	Greenwood	Redvale	Port Kenny
Soil type	Andisol	Andisol	Oxisol	Oxisol	Calcareous Inceptisol
Country of origin	Chile	New Zealand	Australia	Australia	Australia
pH(1:5 in water)	5.3	5.72	5.87	6.4	8.44
Clay (%)	14	7	13	61	3
CaCO ₃ (%)	b.d.l.§	b.d.l.	b.d.l.	b.d.l.	28
Al _{ox} (g kg ⁻¹)	42.8	42	17.3	2.34	0.241
Fe _{ox} (g kg ⁻¹)	16.7	8.19	4.14	2.22	0.098
Total P (mg kg ⁻¹)	1122	1549	157	128	375
Ca ²⁺ (cmolc kg ⁻¹)	1.5	6.6	4	7.4	26.6
Mg ²⁺ (cmolc kg ⁻¹)	0.3	1	2.7	2.5	9.5
K ⁺ (cmolc kg ⁻¹)	0.6	0.48	0.42	0.37	1.6
C _{DGT} (µg L ⁻¹)	4	11	6	2	33

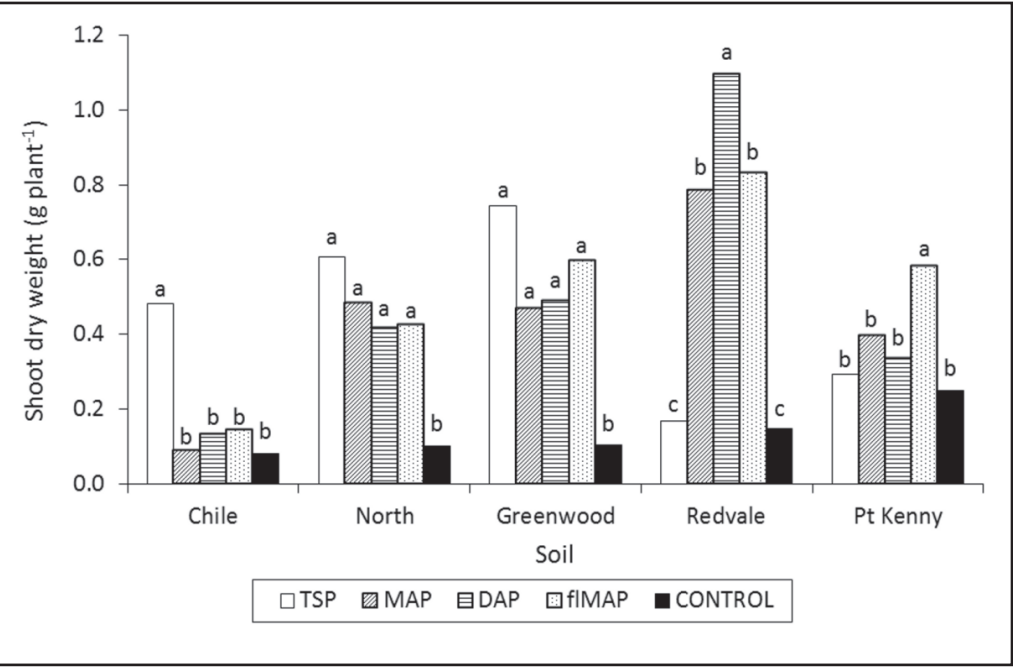


Fig. 1. Shoot dry matter yield (g plant⁻¹) for wheat grown in soils with granular (TSP, MAP, DAP) or fluid (fMAP) fertilizer. A control treatment (nil P) was included for each soil. Bars appended with different letters are statistically different at P ≤ 0.05.

with the fertilizer (TSP, 15% Ca). In this soil exchangeable Ca (1.5 cmolc kg⁻¹) was very close to the minimum level (1 cmolc, kg⁻¹) recommended for adequate plant growth. In this experiment, Ca was not added in the basal fertilization to avoid opportunities of Ca-P precipitation that could hinder the results.

In the Redvale soil, TSP performed much worse than the ammoniated sources. In our previous study, we found that significantly less P remained labile when calcium phosphate fertilizers were applied in the Redvale soil. We hypothesized that the lower P availability may be due to Ca-P precipitation at the relatively high pH of this soil.

P effect. In the Andisols and Oxisols the addition of P fertilizer significantly increased tissue P concentration with respect to the control (Figure 2). However, the concentration of P in the shoots was still deficient in many of the amended treatments where the measured shoot P concentrations were below the critical level of 3 mg g⁻¹. In the calcareous Port Kenny soil, P concentration did not statistically differ between the control and the fertilizer treatments.

The seed P contribution needs to be taken into account to distinguish between uptake from soil and fertilizer applied P. Several studies have used the assumption of 50 percent of total seed P translocation to the shoots. However, the uptake of P in the control treatments of the Oxisols and Andisols was very low and in some cases even less than 50 percent of total seed P. Hydroponic experiments were conducted with labeled P to determine the seed P contribution and showed that the translocation of seed P to the shoot increased with increasing P supply.

Most literature studies have shown good correspondence between E and L values, except for some species known to mobilize P (e.g. white lupin). Therefore, to estimate the seed contribution, we assumed the E values that were previously determined (data not shown) equaled the L values:

L value =
$$\frac{R}{33P_{shoot} - P_{shoot} - P_{dseed}}$$

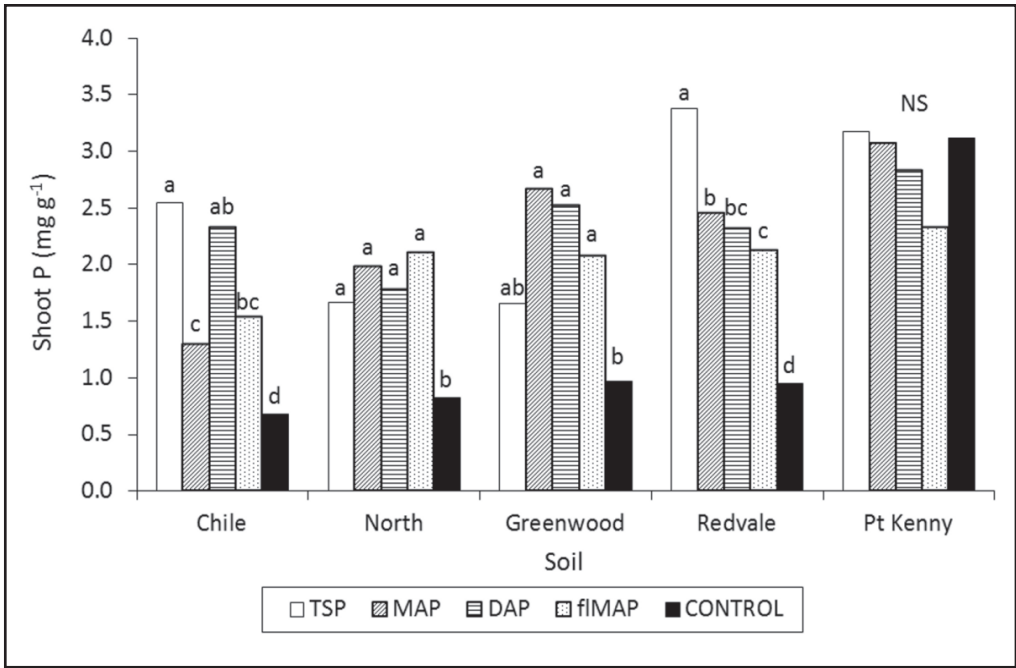


Fig. 2. Shoot P concentration (mg g⁻¹) for wheat grown in soils with granular (TSP, MAP, DAP) or fluid (fMAP) fertilizer. A control treatment (nil P) was included for each soil. Bars appended with different letters are statistically different at P ≤ 0.05.

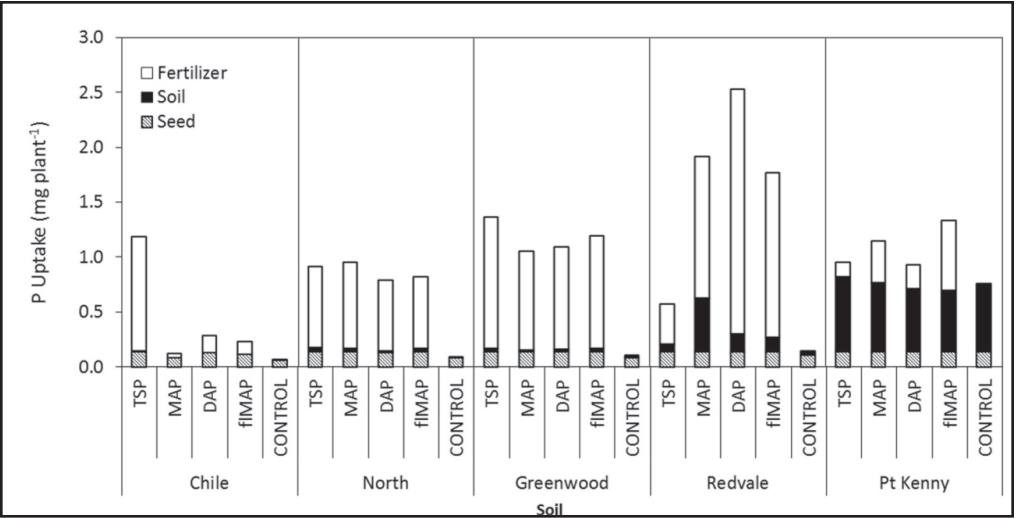


Fig. 3. Distribution of P in the plant shoots derived from fertilizer, soil, and seed. Granular fertilizers (TSP, MAP, and DAP), fluid fertilizer (fMAP), and control (nil P).

R (above) is the applied 33P dose. This allowed estimating the P seed contribution for all control treatment replicates. Translocation of seed P to shoot increased with increasing P uptake in the shoot and the relation could be well described with an exponential equation:

$$P_{dseed} = A \times (1 - \exp(B \times P_{shoot}))$$

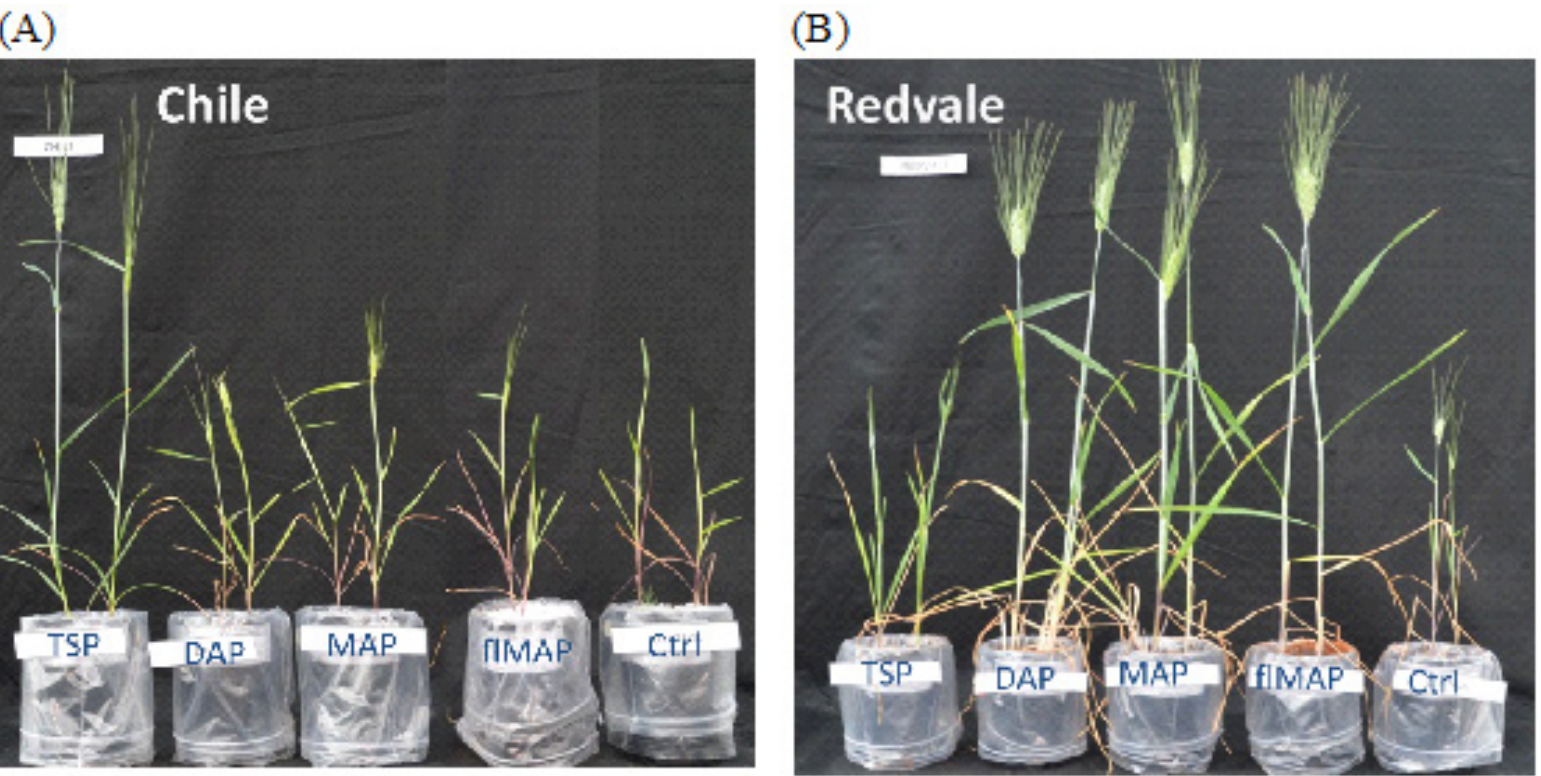
A and B are fitted parameters. This equation was used to estimate the seed P contribution in the fertilizer treatments. Note that the estimate of seed P contribution was less crucial for the fertilizer treatments, as the relative

contribution of seed P to shoot P uptake was smaller.

The contribution of P from the fertilizer, soil, and seed to the total P uptake of the plants is shown in Figure 3. For the Andisols and Oxisols, the highest

“Fluid P fertilizers were highly effective in calcareous soils.”

contribution to P uptake came from the fertilizers with an average value of 75 percent (average of all treatments). In



Plant response to fertilizer sources: wheat plants grown for 6 weeks in Andisol, Chile (A) and Oxisol, Redvale (B).

these soils, the contribution of P from the soil was minimal due to the low P availability. For the calcareous soil, the contribution of P from the fertilizer ranged from 15 percent for TSP to 48 percent for fMAP. The greater TSP efficiency in the Chile soil may be due to an effect of Ca nutrition. In the Redvale soil the TSP appears to be the worst fertilizer option.

Summing up

This study demonstrates that in acidic and oxide-rich soils where the availability of P is restricted by strong adsorption reactions, fluid P fertilizer did not provide any additional advantage over granular

sources to plant growth.

In contrast, the fluid P fertilizer was highly effective in the calcareous soil, in agreement with previous studies.

The chemical properties of the soils need to be considered prior to the selection of P fertilizers as they play a vital role in the fate of P in soils. The management of P nutrition in soils that strongly adsorb P is very challenging because a very high P rate is needed in order to obtain adequate yields, but care should be taken to minimize the negative impacts that over-fertilization can cause to the environment.

Dr. Daniela Montalvo is Postdoctoral Research Fellow at University of Adelaide, Dr. Fien Degryse is Senior Research Fellow in Soil Science at the University of Adelaide and Dr. Mike J. McLaughlin is a Research fellow at CSIRO Land and Water, and Professor in Soil Science, at the University of Adelaide, Australia.

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