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Further insights into why potassium fertility is a paradox

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Abstract

For many years, crop potassium (K) availability has been estimated by soil testing the plow layer for exchangeable K, in conjunction with potassium chloride fertilization widely promoted as an essential prerequisite for ensuring crop yield and quality. As rigorously documented in our paper, both components of chemical-based K management are seriously flawed by the lack of a scientific basis. Under the pretext of providing economic benefit for the producer and a healthy food supply for the public at large, the real purpose is to generate revenue for the fertilizer industry.

Key words: soil K testing, KCl, potash fertilizer, profitability, Cd bioaccumulation

Introduction

We welcome the comments of Bar-Yosef et al.[1] regarding our recent paper[2], which challenges the current paradigm of intensive potassium chloride (KCl) fertilization without regard to the economic importance of yield response and the long-term implications for soil fertility, crop production and human health. That challenge rests upon a very solid foundation consisting of: (1) rigorous field and laboratory evaluations of soil potassium (K) testing; and (2) an extensive survey of peer-reviewed and university publications from field trials that compare crop yield and/or quality with and without KCl fertilization. In both cases, the evidence clearly revealed that chemical-based K management for industrialized agriculture serves the sole purpose of promoting KCl consumption.

The K-testing Paradox

Numerous flaws inherent to soil testing for exchangeable K (Exch-K) have been thoroughly documented on pages 6–11 of our paper[2], and leave no doubt that such testing is of no interpretive value for evaluating soil K buildup/depletion or as a basis for fertilizer K recommendations. This view could hardly be avoided considering that: (1) soil K test levels were extremely variable when assessed by a fixed protocol that involved 4 years of biweekly sampling, and increased substantially during this period despite the absence of fertilization (see figure 1 of our paper[2]); (2) a far greater increase occurred for the Morrow Plots following 51 years of continuous corn (*Zea mays* L.) that removed almost 900 kg K ha^{-1} without K fertilization (see table 1 of our paper[2]); and (3) Exch-K was not sensitive to K addition or removal in 68 field trials throughout the world involving seven soil orders, 20 cropping systems and a wide range of ecological conditions (see table 2 of our paper[2]). Bar-Yosef et al.[1] agree that 'an increase in Exch-K over time under zero K fertilization occurred', cite further evidence in support of our interpretation and recognize the need to improve estimation of plant-available K by utilizing intensity and capacity factors. Regardless, they cling to the belief that 'measurement of Exch-K is an essential and valuable tool and its use should be continued'. Such resistance to scientific reality surely qualifies as a paradox.

The Paradox of KCl Fertilization

If crop K uptake originates from huge K reserves throughout the soil profile, the question naturally arises as to whether producers can expect a profitable return from annual or biennial applications of KCl. The answer is a resounding NO, according to table S4 in the online supplement of our paper that compares yield data for NP and NPK treatments (P and PK for legumes) in more than 2100 short-term university field trials mostly

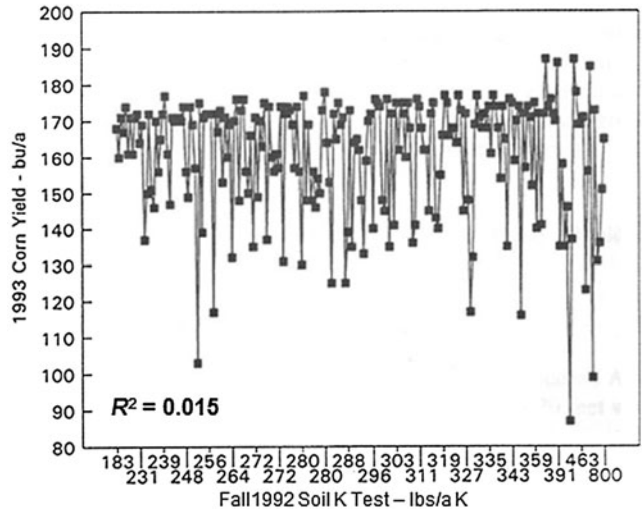

Figure 1. Relation of 1993 corn yield with K test, as reported by Peck[12] for a 40-acre (16-ha) field systematically sampled for both parameters using a 16 × 16 grid.

conducted since fertilizer KCl became widely available in the early 1960s. The vast majority of these trials showed no profitable yield gain from KCl fertilization, and this was even more striking for grain production in North America, in which case KCl was of no agronomic value for 93% of 774 trials surveyed and more often led to yield loss than gain.

In our survey of fertilizer K response, considerable care was taken to avoid data sets confounded by growth-limiting factors such as diseases or drought, but apparently Bar-Yosef et al.[1] are unwilling to face the prospect that KCl is often of no value to agricultural producers, and instead have resorted to obfuscation for justifying the intensive use of this fertilizer. Two long-term studies with K fertilization are cited to strengthen their case, one in England by Johnston et al.[3] and another in Australia by Li et al.[4]. In contrast to the survey reported in our paper, such studies are of no relevance to fields in a production setting, as yield differences between fertilized and unfertilized treatments reflect nutrient depletion that intensifies over time. Examination of figure 1 in Johnston et al.[3] does not substantiate the interpretation of Bar-Yosef et al.[1], that 'wheat and barley responded by enhanced grain yield to K application of 70 kg K ha^{-1} in starved soils, but not on previously K-enriched plots'. In fact, Johnston et al.[3] reported for both the Rothamsted Exhaustion Land study and the Woburn study that 'the responses to new K fertilizer were too small and the yields on starved and enriched soils were too variable'. Interestingly, Bar-Yosef et al.[1] neglected to mention that the K source for both sites had always been K_2SO_4, not KCl.

The study by Li et al.[4] is no more useful than that of Johnston et al.[3] for defending the value of soil testing for Exch-K and the need for K fertilization. We note, for example, that Exch-K was estimated by Li et al.[4] using 0.1 M $BaCl_2$–0.1 M NH_4Cl rather than 1 M $NH_4C_2H_3O_2$, which has implications for extraction efficiency. More importantly, Li et al.[4] were unable to establish a critical level in relating soil test K to dry matter or grain production by wheat (*Triticum aestivum* L.) in a mixed pasture, nor was there any meaningful relationship between plant K concentration and pasture yield despite soil K-supplying power inherently limited by a sodic subsoil in a semi-arid region where K fertilization is not generally recommended for cereal crops. Bar-Yosef et al.[1] have misinterpreted both findings.

In their attempt to avoid the obvious evidence in supplementary table S4 that KCl is often ineffective for yield response, Bar-Yosef et al.[1] are discounting a global database of more than 2100 field studies that encompass diverse cropping systems, tropical to semi-arid climates and a wide array of soils representing Mollisols (525 site-years), Alfisols (423 site-years), Ultisols (403 site-years), Inceptisols (261 site-years), Entisols (177 site-years), Spodosols (53 site-years), Oxisols (50 site-years), Aridisols (23 site-years), Vertisols (23 site-years) and Histosols (3 site-years). Instead, they prefer empirical modeling by Mueller et al.[5] that predicted the need for a 35% increase in K_2O usage to close the yield gap in underachieving areas; however, Bar-Yosef et al.[1] failed to mention a major concern that the model was insensitive to soil and slope parameters[5]. This is an important limitation, because yield responses to K fertilization predominately occur on soils inherently low in K-supplying power, as discussed on page 11 of our paper.

In discounting the adverse effects of intensive KCl fertilization on soil properties, Bar-Yosef et al.[1] focus on hydraulic conductivity and aggregate stability without addressing the loss of cation-exchange capacity (CEC) as documented on page 18 of our paper in regard to cumulative KCl usage over decades. As justification, they cite short-term data from a pot study by Chen et al.[6] and a column study by Levy and Torrento[7]. The latter publication, and several others that could have been cited[8–10], actually show a decrease in hydraulic conductivity rather than the benefits broadly claimed by Bar-Yosef et al.[1] in concluding that 'there is no possibility that KCl application adversely affects soil structure'. Critical examination of figure 1 in Chen et al.[6] clearly refutes this conclusion, because Bar-Yosef et al.[1] neglected to mention a marked decrease in hydraulic conductivity that occurred with one of the three soils studied. More importantly, data reported by Chen et al.[6] show that the three soils decreased 4–13% in CEC as K saturation increased.

Despite extensive coverage given to the consequences of KCl fertilization for crop quality in a global survey of more than 1000 field studies (see pages 15–17 and table S5 of the online supplement), Bar-Yosef et al.[1] consider this no more than 'scant evidence' and instead declare that there is 'no evidence of a detrimental effect of potassium chloride (KCl) on crop yield or quality'.

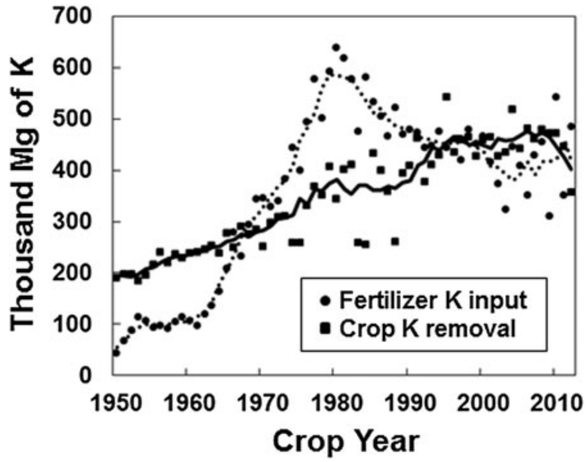

Figure 2. Illinois data for fertilizer K input[13,14] and K removal in corn, soybean (*Glycine max* L. Merr.), wheat, oats (*Avena sativa* L.), barley (*Hordeum vulgare* L.), rye (*Secale cereale* L.) and hay, plotted with lines that represent a 5-yr moving average. Crop K removal was estimated using composition data[15,16] in conjunction with online production records[17,18].

This claim cannot be reconciled with the references they cite to document the antagonistic effect of K on plant uptake of Ca and Mg, which has important ramifications for human and animal health. Bar-Yosef et al.[1] consider Cl an essential nutrient for controlling plant diseases, while avoiding considerable evidence that Cl enhances bioaccumulation of Cd in food and feed.

Seven Decades of the K Paradox

Soil K testing and commercial K fertilization originated from work in the 1940s by Dr Roger Bray at the University of Illinois[11], utilizing static plot trials with and without K fertilization for up to four decades. Even after this prolonged period of soil K depletion, Bray[11] was unable to establish a direct relationship between the Exch-K test level and corn yield, and the same reality was apparent five decades later in a 1993 study by Peck[12] (Fig. 1). The latter finding exposes the futility of current K management, considering that: (1) crop K removal reflected much higher yields in 1993 than in the 1940s; (2) more than half of the test values were below 300 lb per acre (336 kg ha^{-1}), which is supposed to be the critical threshold for yield reduction[13]; and (3) no KCl had been applied in the previous 6 years. The reality represented by Figure 1 is consistent with the overwhelming majority of K response trials we surveyed for North America, and is further substantiated by Figure 2, which shows no evidence of a relationship between annual K fertilizer consumption and crop K removal (estimated from yield data) in Illinois since 1950. This disparity is reflected in fertilizer K inputs that have exceeded crop K removal by almost 60,000 Mg yr^{-1} on average for the past 40 years, representing an unsound investment at current prices of US$60 million per year in the purchase of KCl by Illinois producers. In reality, the annual loss would easily total several hundred million dollars, considering both direct and indirect costs and the widespread lack of K response cited previously for grain crops in North America.

As documented by our supplementary table S4, KCl consumption can often be decreased without sacrificing yield, but this opportunity has not been realized because of buildup–maintenance recommendations that intensify fertilizer consumption at the expense of agronomic uptake efficiency and thus accentuate the economic interests of the fertilizer industry over those of the producer. These recommendations have been effectively presented through ergonomic diagrams such as figure 8.8 in the *Illinois Agronomy Handbook*[13], and are widely publicized by the extension community as a best management practice. Thus continues the K paradox.

Conclusion

We stand by our two principal contentions that: (1) soil testing for Exch-K is of no use for predicting crop K availability or assessing soil K buildup/depletion; and (2) KCl fertilization is often superfluous for increasing crop yield and quality and can have a detrimental effect on soil productivity and human health. Both these points are strongly supported by the extensive literature citations in our paper[2], covering peer-reviewed publications from field and laboratory research. Bar-Yosef et al.[1] have attempted to defend the status quo of soil testing for Exch-K and intensive KCl usage, but their arguments are speculative in nature, self-contradictory and misrepresent some of the scientific literature cited. The prevailing approach to K management is invariably advocated under the pretext of providing economic benefit for the producer and a healthy food supply for the public at large, but the real purpose is to generate revenue for the fertilizer industry. This is the essence of a paradox, not a dilemma.

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