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Cotton yield response to soil applied potassium across the U. S. Cotton Belt

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Abstract

Across the U.S. Cotton Belt, potassium (K) deficiency symptoms in cotton (*Gossypium hirsutum* L.) have become more common over the past decade. In 2015–2017, an experiment was conducted in Alabama, Arkansas, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, two regions in Texas, and Virginia for a total of 23 site-years. The objectives were (a) to quantify soil K levels at-depth in representative soils where cotton is commonly grown in major cotton production regions with observed K deficiencies; and (b) to evaluate the effects of application method and K rates on cotton lint yield, loan value, and return on fertilizer investment. Granular and liquid potassium chloride were broadcast or injected, respectively, 2–4 wk prior to planting at 0, 45, 90, 135, and 180 kg K_2O ha^{-1}. Locations other than Texas and Oklahoma generally had soil K levels <less than 150 mg kg^{-1}, the Mehlich III critical K level, and thus, a yield response to applied K fertilizer was expected. However, among the 23 site-years, a treatment effect was determined at 5 site-years. Two of those, Williamson County, Texas, and Virginia endured severe moisture stress and resulted in low yields (<526 kg lint ha^{-1}). A positive lint yield response to knife-injected 0–0–15 was determined in 2015 at the Lubbock County, Texas, location—a location with high yield (>1,653 kg lint ha^{-1}). Inconsistent yield responses among locations indicate that K dynamics in the soil–cotton plant system are not well understood and deserve continued investigation.

1 | INTRODUCTION

Even with supplemental fertilization, observations of mid-season potassium (K) deficiencies have become more common across the U.S. Cotton Belt over the past two decades (Oosterhuis et al., 2013). Improved cultivars and pest management have increased yields an average of 9 kg ha^{-1} each year between 1985 and 2018, with a total increase of 41% in yields over the period (USDA-NASS, 2018). The USDA Economic Research Service reported nitrogen (N) usage increased 12% from 1980 to 2011 and was positively correlated to the national yield trend. However, actual K applied decreased over this same period by 20% (USDA-ERS, 2011). Producer reports of K deficiency symptoms in cotton (*Gossypium hirsutum* L.) are becoming more frequent, and the occurrences are appearing over a broader geographic area. With greater

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Abbreviations: DS-TX, Dawson County, Texas; HVI, high volume instrument; ICP, inductively coupled plasma; KMO, Kaiser-Meyer-Olkin; PCA, principle component analysis; ROI, return on investment; WM-TX, Williamson County, Texas.

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yields, more K may be taken up by plants and removed as cotton seed, such that not enough nutrient is returned through K applications (Nutrient Use Geographic Information System, 2018; Pabuayon et al., 2020).

Potassium plays several key roles in the plant, including fiber growth, photosynthesis, osmotic adjustment, and enzyme activation (White & Karly, 2010). Many of the processes associated with K deficiency are interrelated and cause direct and indirect effects on the plant (Bednarz & Oosterhuis, 1999; Marschner, 1995). Adequate K content in cotton increases water-use efficiency (Pervez et al., 2004). The regulation of cytosol pH by K is also a necessity for proper activation of enzymes, which K directly and indirectly affects. Potassium also has an important role within the cell. It accumulates in the vacuole where it lowers osmotic potential in the vacuole, thereby increasing turgor pressure (Mengel et al., 2001). Photosynthesis and translocation of assimilates are also decreased in K-deficient environments (Bednarz & Oosterhuis, 1999). Potassium is also necessary for leaf expansion and elongation of pollen tubes (Pettigrew, 2008).

Potassium deficiencies can cause a premature abscission of leaves, decreased plant growth and vigor, and a reduced boll load (Pettigrew & Meredith, 1997). Each of these deficiency symptoms can contribute to yield reductions in cotton. Two types of potassium deficiency can be observed. The first is full-season and severe (Davis, 1996), and the second is transient during boll fill with effects not being well characterized (Oosterhuis, 2002). The second type of K deficiency occurs in the upper canopy during flowering, boll formation, and boll filling. These effects are likely caused by an inadequate supply of K to the plant, which may be caused by low concentrations of plant-available soil K, drought, soil compaction, nematode pressure, or increased demand by early-maturing cultivars (Stewart et al., 2009). The developing fruit are a large K sink; therefore, K tends to be removed from leaves in the upper canopy, which are the most metabolically active, and then remobilized to the fruit (Mengel & Arneke, 1982).

Cotton has peak K uptake 50–80 d after planting, a period corresponding with first-to-peak bloom (Mullins & Burmester, 1991; Pabuayon et al., 2020). Whole plants of high-yielding crop, producing 2,250 kg lint ha^{-1}, can accumulate 312 kg K ha^{-1} (Rochester et al., 2012). More recently, Pabuayon et al. (2020) reported, at most, 134 kg K ha^{-1} taken up to produce 1,709 kg lint ha^{-1}. Of the K taken up, approximately 30 kg K ha^{-1} was removed in seed. Thus, a relatively large amount of K must be supplied to meet the demand of modern high-yielding cotton cultivar.

The soils in some parts of the Cotton Belt are dominated by minerology that restricts the availability and mobility of K within the soil profile (Barré et al., 2007; USDA-NRCS, 2006). Soil K pools are dynamic, and transfer between soil solution K, exchangeable K, slowly exchangeable K, and mineral K takes place continuously. Potassium in soil solution is readily plant available if roots are proximate, but this form of K is generally very low in most soils (Sparks & Huang, 1985). Exchangeable K consists of K^+ ions sorbed to clay mineral, amorphous mineral, or organic matter surfaces and can readily move into solution (Barré et al., 2007). Slowly exchangeable forms of K are often termed fixed K; such K is held in the interlayer spaces of 2:1 clays (Sparks, 1987). Slowly available K can become available, but weathering of the clays, or wetting and drying, must take place for the K to be released (Eberl et al., 1986). In hydrated smectitic clays, the interlayer space will allow K to enter, but upon drying, voids will collapse and temporarily fix K, causing it to be unavailable (Havlin et al., 1985). The largest portion of K is in the mineral state in feldspar minerals and the interlayer spaces of clay micas, which account for approximately 90% of the total and are not plant available (Hinsinger, 2002).

Core Ideas

- Mehlich III K ranged 30–400 mg kg^{-1} across cotton regions reporting K deficiency.
- Over half of site-years reported soil K levels less than the Mehlich III critical level.
- A lint yield response to soil-applied K fertilizer was determined at 5 of the 23 site-years.
- Inconsistent results indicated K dynamics in the soil–plant system need further investigation.

Soil K chemistry coupled with soil and environmental conditions creates K management challenges for growers. This research was aimed at gaining better understanding of K dynamics and developing optimized management strategies across the U.S. Cotton Belt. The objectives of this research were to (a) quantify soil K levels, at depth (0-to-15-, 15-to-30-, and 30-to-60-cm), from several major cotton production regions across the Cotton Belt experiencing visual K deficiency symptomology and (b) evaluate the impact of application method and K rate on cotton lint yield, loan values, and return on investment (ROI) of fertilizer.

2 | MATERIALS AND METHODS

2.1 | Experimental sites, treatments, and crop management

Research trials were conducted from 2015 to 2017 across the U.S. Cotton Belt in the following states: Alabama, Arkansas, Louisiana, Mississippi, North Carolina, Oklahoma, Texas, and Virginia (Table 1). There were two research locations in Texas including Dawson (DS-TX) and Williamson (WM-TX)

TABLE 1 Description of research locations from 2015 to 2017

Experimental site				Soil classification		Mehlich III elements (0-to-15-cm depth)				
Site	**Year**	**County, State**	**Irrigation**	**Series**	**Texture**	**P**	**Ca**	**Mg**	**S**	**Na**
						——————mg kg^{-1}——————				
1	2015	Macon, AL	Sprinkler	Compass	Loamy sand	93	398	82	3	2
2	2015	Desha, AR	Furrow	Herbert	Silt loam	59	1,220	171	11	9
3	2015	Rapides Parish, LA	Rainfed	Coushatta	Silt loam	37	3,119	290	7	12
4	2015	Dawson, TX	SDI	Amarillo	Fine sandy loam	28	1,404	261	5	7
5	2015	Williamson, TX	Rainfed	Burleson	Clay	47	3,076	449	8	25
6	2015	Suffolk, VA	Rainfed	Eunola/Kenansville	Loamy fine sand/loamy sand	84	278	29	7	4
7	2016	Macon, AL	Sprinkler	Compass	Loamy sand	72	447	77	9	5
8	2016	Desha, AR	Furrow	Herbert	Silt loam	63	1,701	343	9	37
9	2016	Rapides Parish, LA	Rainfed	Coushatta	Silt loam	26	4,362	332	10	14
10	2016	Jackson, OK	Furrow	Hollister	Silty clay loam	14	2,406	672	32	100
11	2016	Edgecombe, NC	Rainfed	Norfolk	Loamy sand	82	446	70	10	5
12	2016	Dawson, TX	SDI	Amarillo	Fine sandy loam	25	963	251	3	1
13	2016	Williamson, TX	Rainfed	Burleson	Clay	28	3,363	427	8	9
14	2016	Southampton, VA	Rainfed	Uchee	Loamy sand	103	317	41	12	36
15	2017	Macon, AL	Rainfed	Marvyn	Sandy loam	88	422	80	12	1
16	2017	Desha, AR	Furrow	Herbert	Silt loam	47	2,085	481	12	46
17	2017	Rapides Parish, LA	Rainfed	Coushatta	Silt loam	19	4,274	414	16	34
18	2017	Edgecombe, NC	Rainfed	Norfolk	Loamy sand	77	480	100	17	1
19	2017	Jackson, OK	Furrow	Hollister	Silty clay loam	20	3,501	769	183	171
20	2017	Leflore, MS	Furrow	Dubbs	Loam	47	1,394	141	8	7
21	2017	Dawson, TX	SDI	Amarillo	Fine sandy loam	79	1,401	275	6	4
22	2017	Williamson, TX	Rainfed	Branyon	Clay	10	10,907	106	6	8
23	2017	Sussex, VA	Rainfed	Roanoke	Loam	97	365	68	12	0

Note. SDI, subsurface drip irrigation.

Counties. In 2015, cotton was not harvested in North Carolina and Oklahoma due to herbicide injury, and in 2017, a Mississippi location was added to the trial. In total, there were 23 site-years from 2015 to 2017. Location information including county, irrigation method, and soil series are presented in Table 1.

Potassium fertilizer treatments were applied as a combination of methods and rates arranged in a randomized complete block design with four replications of the five fertilizer rates applied broadcast or knife-injected. Zero application rates were represented for both the injected and broadcast treatments; therefore, there were 10 plots in each replication. Potassium treatments, knife-injected and broadcast, were applied 2–4 wk prior to planting cotton at rates of 0, 45, 90, 135, and 180 kg K_2O ha^{-1}. The granular treatments (muriate of potash, potassium chloride [KCl], 600 g K_2O kg^{-1}) were broadcast applied by hand on the soil surface and mechanically incorporated to an approximate depth of 5 cm if conventional tillage was used. Liquid fertilizer K treatments (solution of KCl, 150 g K_2O kg^{-1}) were injected approximately 15 cm deep and 10 cm to the side of the seed row. Plot size varied from one location to another because of row spacing 91–101 cm but was consistently a minimum of four rows wide by 12 m in length.

Nitrogen, P, and other nutrients were applied at the recommended rate based on soil test results and state extension recommendations to ensure nutrients other than K were not limiting. The cotton cultivars planted at all locations were ‘DP 1321 B2RF’ in 2015 and ‘DP 1522 B2XF’ (Bayer Group) in 2016 and 2017. Both cultivars are listed in company literature as short season cultivars. Cotton was planted and managed for insects, the canopy growth was regulated, and the lint and seed was harvested using practices common to the location.

TABLE 2 Soil K concentrations with depth for locations from 2015 to 2017

		Mehlich III K at different soil depths					
Year	Location	0-to-15 cm	15-to-30 cm	30-to-60 cm	$P > F$	0-to-30 cm	0-to-60 cm
		mg K kg^{-1}				mg K kg^{-1}	
2016	VA	30 a	40 a	37 a	0.748	35	36
2016	AL	39 b	56 a	44 b	0.002	48	46
2017	AL	56 a	54 a	67 a	0.153	55	59
2015	AL	61 a	64 a	82 a	0.547	63	69
2017	VA	61 a	47 a	61 a	0.184	54	56
2017	NC	73 a	69 a	63 a	0.344	71	68
2016	WM-TX	83 a	77 a	86 a	0.133	80	82
2016	NC	86 a	66 b	57 b	0.007	76	70
2015	VA	92 a	99 a	93 a	0.393	95	94
2015	WM-TX	96 a	96 a	98 a	0.694	96	97
2017	MS	100 a	90 b	89 b	0.071	95	93
2017	LA	152 a	129 b	92 c	0.003	140	124
2017	AR	158 b	167 b	212 a	0.005	163	179
2015	LA	159 a	144 b	129 c	0.0004	151	144
2016	AR	168 ab	153 b	174 a	0.099	160	165
2015	AR	174 a	112 b	99 c	<0.0001	143	128
2016	LA	177 a	139 b	92 c	0.0004	158	136
2016	OK	204 a	178 b	171 c	0.0002	191	185
2017	WM-TX	207 a	216 a	180 b	0.001	211	201
2017	DS-TX	261 a	236 b	246 b	0.019	249	248
2017	OK	267 a	267 a	259 a	0.366	267	264
2016	DS-TX	277 a	265 a	244 b	0.015	271	262
2015	DS-TX	391 a	281 b	253 c	<0.0001	336	309

Note. Soil K for the 0-30 cm depth was calculated as the average of soil K concentrations at 0-to-15- and 15-to-30-cm soil depths, and soil K concentration for the 0-to-60-cm depth was the average of soil K concentrations at the 0-to-30- and 30-to-60-cm soil depths. Site-year means within a row followed by the same letter are not different at $P < .10$.

2.2 | Soil collection and analysis

Fields with a history of K deficiency symptoms were selected to conduct the trials. From these fields, soil samples were collected 4–6 wk prior to fertilizer application from each location at the 0-to-15-, 15-to-30-, and 30-to-60-cm soil depths. Subsamples were collected and composited from each plot in 2015, while in 2016 and 2017, samples were collected at the same depths but were composited for each replication. Soil samples were air-dried and sent to the Texas A&M AgriLife Extension Soil, Water and Forage Testing Laboratory (College Station, TX) for analysis of P, K, calcium (Ca), magnesium (Mg), sulfur (S), and sodium (Na). Nutrients were extracted using the Mehlich III extractant and determined by inductively coupled plasma (ICP) (Mehlich, 1978, 1984). Although some of the participating states soil testing services use other extractants, such as Mehlich I (Alabama and Virginia), the Mehlich III extractant was chosen because it is the most used test method across the Cotton Belt (Texas, Louisiana, North Carolina, and Arkansas). Soil K concentrations at the 0-to-30 and 0-to-60cm depths were calculated by averaging the 0-to-15- and 15-to-30-cm depth and the 0-to-15-, 15-to-30-, and 30-to-60-cm depths, respectively. These values were used in the principal component analysis (PCA).

2.3 | Leaf K, lint yield, fiber quality, and economics

In-season plant measurements included stand counts, plant height, total nodes, and leaf samples for K determination, which were collected 4 wk after first flower. Leaf K was determined by ICP analysis of a nitric acid digest (Havlin & Soltanpour, 1989; Isaac & Johnson, 1975). Cotton was mechanically harvested using equipment (picker or stripper) common for each region. Subsamples of seed cotton were collected and ginned to calculate lint turnout and lint yield. Cotton lint was sent to Cotton Incorporated (Cary, NC) for fiber

TABLE 3 Leaf K as affected by fertilizer K rates from 2015 to 2017

		Soil K	Broadcast K (kg K_2O ha^{-1})						Injected K (kg K_2O ha^{-1})					
Year	Location	0-to-15 cm	0	45	90	135	180	$P > F$	0	45	90	135	180	$P > F$
		mg kg^{-1}	leaf tissue K (g kg^{-1})						leaf tissue K (g kg^{-1})					
2016	VA	30	7.43	10.1	8.92	12.0	11.4	0.121	9.25	9.38	10.0	11.0	11.9	0.462
2016	AL	39	12.7	17.4[a]	19.4[a]	20.1[a]	19.3[a]	0.001	16.8	17.2	16.0	15.4	15.4	0.564
2017	AL	56	—	—	—	—	—	—	—	—	—	—	—	—
2015	AL	61	20.6	20.4	24.0	21.3	22.6	0.435	22.5	20.2	23.3	20.9	28.2	0.631
2017	VA	61	—	—	—	—	—	—	—	—	—	—	—	—
2017	NC	73	11.9	10.2	9.6	10.6	10.5	0.186	10.0	10.5	10.1	10.7	10.9	0.663
2016	WM-TX	83	6.32	7.07	7.01	6.10	7.13	0.271	6.05	6.76	6.94	7.37[a]	7.49[a]	0.007
2016	NC	86	14.8	13.0	13.6	13.8	13.7	0.455	13.7	15.7	14.5	16.1	17.2	0.327
2015	VA	92	15.5	16.0	16.3	16.0	17.2	0.183	16.4	16.8	16.8	16.7	16.3	0.748
2015	WM-TX	96	7.29	7.24	8.08	8.93[a]	9.70[a]	0.007	7.41	8.34	9.15[a]	8.92[a]	9.76[a]	0.0003
2017	MS	100	10.4	11.5	11.1	10.3	10.3	0.735	10.9	10.1	10.0	10.6	11.2	0.690
2017	LA	152	13.2	11.7	12.7	11.8	11.5	0.001	12.3	12.3	12.3	12.4	11.8	0.745
2017	AR	158	13.8	14.1	14.6	12.7	14.8	0.614	13.2	14.8	14.0	13.1	14.3	0.411
2015	LA	159	13.5	13.0	13.6	14.1	13.0	0.822	13.8	13.6	14.2	14.0	14.1	0.758
2016	AR	168	16.2	15.8	16.2	16.2	16.5	0.955	—	—	—	—	—	—
2015	AR	174	10.9	10.7	10.4	12.5	11.7	0.566	11.1	11.3	11.6	10.1	10.4	0.589
2016	LA	177	12.3	13.7	13.1	12.4	14.0	0.153	13.1	13.9	15.1	14.2	14.5	0.115
2016	OK	204	12.3	12.2	12.8	12.5	12.9	0.430	12.9	12.5	12.9	12.9	12.9	0.845
2017	WM-TX	207	10.3	10.1	8.95	9.46	9.41	0.028	8.20	8.18	7.81	6.83	7.26	0.098
2017	DS-TX	261	21.3	20.4	21.0	20.2	21.2	0.654	20.5	21.1	20.3	20.5	21.6	0.716
2017	OK	267	11.8	12.1	12.3	12.8	12.2	0.231	11.9	12.6	11.9	12.5	11.9	0.535
2016	DS-TX	277	22.5	23.1	23.0	22.0	21.4	0.796	22.8	22.5	22.0	22.6	22.0	0.533
2015	DS-TX	391	16.9	17.1	16.9	16.5	17.2	0.927	16.7	16.9	17.3	17.0	18.1	0.134

[a] Indicates leaf K content greater than the untreated check (0 kg K_2O ha^{-1}) within application method at responsive sites at a significance level of $\alpha = 0.1$.

analysis using high volume instrument (HVI) analysis. Loan values of lint were calculated based on HVI results for each year using the Cotton Incorporated Loan Value Calculator. Return on investment of fertilizer was calculated by multiplying loan value and lint produced, and then subtracting the cost of the fertilizer. The cost of the fertilizer was calculated by multiplying the amount of fertilizer applied by the cost (\$0.469 kg^{-1} K_2O applied).

2.4 | Statistical analysis

Mehlich III soil K, leaf mineral K, and cotton lint yield were analyzed using the GLIMMIX procedure in SAS 9.4 (SAS Inst.). Site-year was significant for soil K ($p < .0001$) and lint yield ($p < .0001$); therefore, these parameters were evaluated within site-year. For each location, fixed effects included soil depth for soil K concentration and fertilizer K rate for lint yield, loan value, and ROI. Replication was considered a random effect. Fisher's protected LSD means separation was used to determine soil K concentration differences among depths ($p < .10$). To classify each site as responsive or unresponsive to fertilizer K, a single degree-of-freedom contrast was performed at a significance level of $\alpha = .10$ by comparing the yield, loan value, and ROI of cotton receiving no K to the yield of cotton receiving K within application method (Clover & Mallarino, 2013; Slaton et al., 2010). The cost of fertilizer used to calculate ROI was \$0.468 kg^{-1} K_2O applied. Fisher's protected LSD at $\alpha = .10$ was used to determine the minimum K rate needed for maximum lint yield at responsive sites.

Principal component analyses were used to determine the relationship between soil and leaf K, yield, and loan value within year (2015, 2016, and 2017) among the research sites and within each research site among years using the PRINCOMP procedure in SAS 9.4. The input variables to the multivariate model were assessed using the Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy (Kaiser, 1958). Variables were considered adequate if the respective KMO value was greater than 0.5. The PCA extracts a part of the variance from the original data with the greatest amount of variance for the first PCA, followed by as much of the remaining

TABLE 4 Lint yield as affected by K fertilizer rates within application method at 23 sites from 2015 to 2017

		Soil K	Broadcast K (kg K_2O ha^{-1})						Injected K (kg K_2O ha^{-1})					
Year	Location	0-to-15 cm	0	45	90	135	180	$P > F$	0	45	90	135	180	$P > F$
		mg kg^{-1}	lint yield (kg ha^{-1})						lint yield (kg ha^{-1})					
2016	VA	30	87	264[a]	478[a]	456[a]	360[a]	0.002	128	358[a]	511[a]	332[a]	526[a]	0.004
2016	AL	39	1,259	1,255	1,225	1,307	1,286	0.888	1,267	1,319	1,266	1,299	1,247	0.652
2017	AL	56	1,993	1,759	1,804	1,711	1,740	0.034	1,858	1,553	1,669	1,775	1,681	0.428
2015	AL	61	1,549	1,681	1,578	1,715	1,496	0.630	1,562	1,602	1,629	1,721	1,815	0.174
2017	VA	61	1,505	1,830[a]	2,209[a]	2,094[a]	1,791	0.005	2,025	2,166	1,780	1,836	1,895	0.541
2017	NC	73	1,582	1,678	1,598	1,653	1,657	0.515	1,506	1,597	1,702[a]	1,603	1,718[a]	0.067
2016	WM-TX	83	245	275	244	343[a]	355[a]	0.094	207	234	288[a]	273[a]	346[a]	0.031
2016	NC	86	741	661	727	832	713	0.924	703	733	735	682	700	0.956
2015	VA	92	1,386	1,363	1,377	1,367	1,384	0.850	1,413	1,356	1,315	1,372	1,438	0.762
2015	WM-TX	96	356	385	466[a]	431[a]	439[a]	0.032	334	423[a]	487[a]	406[a]	472[a]	0.001
2017	MS	100	673	567	568	592	602	0.228	609	611	594	629	573	0.926
2017	LA	152	1,013	1,011	944	1,058	998	0.899	1,068	993	1,066	976	919	0.357
2017	AR	158	1,319	1,231	1,380	1,236	1,202	0.691	1,350	1,460	1,374	1,409	1,268	0.838
2015	LA	159	1,736	1,630	1,641	1,467	1,519	0.281	1,482	1,533	1,454	1,739	1,741	0.374
2016	AR	168	1,269	1,238	1,220	1,250	1,304	0.909	1,228	1,278	1,283	1,452	1,420	0.375
2015	AR	174	1,549	1,571	1,506	1,506	1,471	0.772	1,504	1,527	1,426	1,497	1,607	0.928
2016	LA	177	1,541	1,678	1,651	1,658	1,678	0.152	1,706	1,691	1,667	1,643	1,710	0.752
2016	OK	204	1,827	2,004[a]	1,995[a]	2,005[a]	2,122[a]	0.002	1,981	2,074	2,082	1,982	2,088	0.279
2017	WM-TX	207	897	981	822	846	883	0.881	909	864	786	886	913	0.500
2017	DS-TX	261	1,900	1,796	1,793	2,070	1,987	0.922	1,971	2,097	2,094	1,725	2,091	0.856
2017	OK	267	1,852	1,881	1,801	1,889	1,827	0.975	1,920	1,931	1,942	1,906	1,763	0.516
2016	DS-TX	277	1,932	1,965	2,132	1,848	1,826	0.945	1,653	1,900	2,033[a]	1,994	2,005	0.032
2015	DS-TX	391	2,006	1,838	1,949	1,892	1,861	0.119	1,872	1,954	1,981	1,985	2,094[a]	0.033

Note. VA, Virginia; AL, Alabama; NC, North Carolina; WM-TX, Williamson County, Texas; MS, Mississippi; LA, Louisiana; AR, Arkansas; OK, Oklahoma; DS-TX, Dawson County, Texas.

[a]Indicates yield greater than the untreated check (0 kg K_2O ha^{-1}) within application method at responsive sites at a significance level of $\alpha = 0.1$.

variability possible into each subsequent PCA until there is no remaining variability. Within a PCA, a loading angle less than 90° indicates a positive correlation, whereas an angle greater than 90° indicates a negative correlation. An angle equal to 90° indicates no correlation between variables. All PCA figures were made using SigmaPlot 13.0 (Systat Software).

3 | RESULTS AND DISCUSSION

3.1 | Soil potassium

The research sites reflected the wide diversity of soils, textures, and management strategies used throughout the Cotton Belt. Even within the major cotton production regions, including the Southeast, Delta, and Southwest, a range of soil K levels were observed, but generally K levels increased in a westward direction. Low K levels were observed in both sandy and clay soils. The lowest levels from the 2015 sites occurred in Alabama, WM-TX, and Virginia (Table 2). At these locations, K levels were less than 150 mg kg^{-1} at the 0-to-15-cm depth, which is the Mehlich III K critical level, but also through the 60-cm-depth; this is the critical level established by the Texas A&M AgriLife Extension Soil, Water and Forage Testing Laboratory. With a yield goal of 1,075 kg ha^{-1} lint, a supplemental K fertilizer rate of 100 kg ha^{-1} was recommended for the Alabama location, which was based on recommendations established by the Texas A&M AgriLife Extension Soil, Water and Forage Testing Laboratory. At the Arkansas and Louisiana locations in 2015, K levels were slightly greater than the K threshold, 174 mg kg^{-1} and 159 mg kg^{-1}, respectively. The 2015 DS-TX location had K levels that were 2.6 times greater than the threshold in the 0-to-15-cm depth. In 2016 and 2017, the DS-TX and Oklahoma locations had K levels much less than those of 2015, but still much greater than the threshold. The site chosen for the WM-TX location in 2016 had K levels less than 100 mg kg^{-1}, but the new site used in 2017 had levels greater than 200 mg K kg^{-1}.

TABLE 5 Calculated loan values from 2015 to 2017

Year	Location	Soil K 0-to-15 cm	Broadcast K (kg K_2O ha^{-1}) 0	45	90	135	180	$P > F$	Injected K (kg K_2O ha^{-1}) 0	45	90	135	180	$P > F$
		mg kg^{-1}	——loan value (dollars kg^{-1})——						——loan value (dollars kg^{-1})——					
2016	VA	30	1.17	1.16	1.18	1.17	1.17	0.773	1.18	1.17	1.18	1.18	1.19	0.685
2016	AL	39	1.19	1.18	1.17	1.17	1.19	0.276	1.18	1.18	1.19	1.19	1.18	0.683
2017	AL	56	1.21	1.20	1.20	0.90	1.20	0.065	1.20	1.18	1.20	1.20	1.20	0.334
2015	AL	61	1.20	1.20	1.20	1.20	1.20	0.315	1.20	1.20	1.20	1.20	1.20	0.579
2017	VA	61	1.19	0.89	1.20	1.18	1.16	0.672	1.17	1.20	1.16	1.16	1.14	0.985
2017	NC	73	1.19	1.18	1.19	1.15	1.18	0.515	1.20	1.18	1.19	1.17	1.18	0.278
2016	WM-TX	83	1.12	1.13	1.11	1.13	1.13	0.634	1.14	1.12	1.15	1.10	1.12	0.276
2016	NC	86	1.15	1.09	1.13	1.13	1.16	0.227	1.16	1.12	1.16	1.11	1.16	0.454
2015	VA	92	1.18	1.15	1.15	1.15	1.14	0.203	1.20	1.15	1.18	1.17	1.14	0.007
2015	WM-TX	96	1.10	1.10	1.14	1.12	1.08	0.614	1.12	1.10	1.12	1.15	1.10	0.881
2017	MS	100	—	—	—	—	—	—	—	—	—	—	—	—
2017	LA	152	1.20	1.20	1.18	1.18	1.20	0.404	1.19	1.19	1.19	1.20	1.20	0.547
2017	AR	158	1.18	1.18	1.18	1.16	1.16	0.519	1.18	1.18	1.18	1.15	1.18	0.602
2015	LA	159	1.17	1.15	1.16	1.14	1.16	0.058	1.15	1.14	1.16	1.15	1.16	0.536
2016	AR	168	1.18	1.20	1.19	1.17	1.19	0.755	1.17	1.19	1.20	1.19	1.16	0.491
2015	AR	174	1.16	1.18	1.19	1.16	1.16	0.665	1.19	1.20	1.17	1.20	1.16	0.927
2016	LA	177	1.16	1.16	1.15	1.17	1.19	0.656	1.15	1.16	1.16	1.19	1.17	0.231
2016	OK	204	1.20	1.20	1.20	1.20	1.20	0.171	1.20	1.20	1.20	1.20	1.20	0.674
2017	WM-TX	207	1.12	1.12	1.14	1.14	1.14	0.508	1.12	1.13	1.14	1.13	1.12	0.771
2017	DS-TX	261	0.89	1.19	1.19	1.19	1.19	0.738	1.19	1.19	1.19	1.19	1.19	0.689
2017	OK	267	1.19	1.20	1.20	1.20	1.19	0.108	1.20	1.19	1.19	1.20	1.19	0.438
2016	DS-TX	277	1.19	1.19	1.19	1.19	1.19	0.928	1.19	1.19	1.19	1.19	1.19	0.315
2015	DS-TX	391	1.19	1.19	1.19	1.17	1.17	0.458	1.19	1.19	1.19	1.19	1.18	0.808

Note. VA, Virginia; AL, Alabama; NC, North Carolina; WM-TX, Williamson County, Texas; MS, Mississippi; LA, Louisiana; AR, Arkansas; OK, Oklahoma; DS-TX, Dawson County, Texas. Loan values were calculated using Cotton Incorporated's 2018 Cotton Loan Calculator.

Potassium levels in 2016 and 2017 at the Alabama, Mississippi, North Carolina, and Virginia locations were generally less than the threshold. In 2017, the Mississippi and Alabama locations were at least 50 mg K kg^{-1} less than the threshold K level at all measured depths. The Louisiana location K level was close to the threshold at 0-to-15 cm and decreased with depth to levels less than the threshold. All other locations had soil K levels greater than the threshold at each depth.

Across all site-years, K levels decreased with depth for over 50% of the research sites, while 23% had comparable K levels from the surface to the 60-cm-depth. The Louisiana sites showed the most dramatic and consistent decrease in K level with depth. These results demonstrate the dimensional diversity of soil in the major cotton production regions and the importance of quantifying soil nutrient levels within a field and with depth. Without historical soil analysis with depth, it is impossible to confirm K depletion in these cotton production fields. However, based on K nutrient deficits reported in Nutrient Use Geographic Information System (2018), depletion appears to be occurring with depth rather than by surface depletion. Ultimately, this depletion of K with depth will have implications on K recommendations and long-term management of crops.

3.2 | Leaf potassium

Out of the 18 site-years, there were two sites where broadcast and injected K resulted in greater leaf tissue K than the control (0 kg K_2O ha^{-1}) (Table 3). All rates of broadcast-applied K were greater than the control at the Alabama site in 2016. At the WM-TX site in 2015, the 135 and 180 kg K_2O ha^{-1} rates had greater leaf tissue values than the control. At the same site in 2015, the three highest rates applied as injected K resulted in greater leaf tissue K than the control. In 2016, the WM-TX site also had injected treatments that were greater than the control, which included the 135 and 180 kg K_2O ha^{-1} rates. Most all sites had less than 20 g kg^{-1} leaf K, which would be considered deficient for leaf tissue collected at early bloom

TABLE 6 Calculated fertilizer return on investment (ROI) from 2015 to 2017

Year	Location	Soil K 0-to-15 cm	Broadcast K (kg K_2O ha^{-1}) 0	45	90	135	180	$P > F$	Injected K (kg K_2O ha^{-1}) 0	45	90	135	180	$P > F$
		mg kg^{-1}	ROI (dollars ha^{-1})						ROI (dollars ha^{-1})					
2016	VA	30	101	287	522[a]	466[a]	333	0.005	152	395	560[a]	331	541[a]	0.047
2016	AL	39	1,494	1,459	1,394	1,471	1,446	0.516	1,497	1,539	1,460	1,477	1,387	0.508
2017	AL	56	2,404	2,095	2,123	1,546	2,009	0.015	2,237	2,308	1,964	2,070	1,934	0.254
2015	AL	61	1,850	1,993	1,846	1,990	1,705	0.841	1,869	1,896	1,905	2,000	2,094	0.357
2017	VA	61	1,650	1,520	2,536	2,334	1,889	0.298	2,410	2,543	2,177	1,998	2,085	0.408
2017	NC	73	1,874	1,950	1,863	1,845	1,880	0.935	1,800	1,864	1,974	1,819	1,937	0.302
2016	WM-TX	83	272	291	227	326	318	0.628	235	241	291	236	301	0.399
2016	NC	86	859	696	818	876	741	0.414	811	810	814	704	735	0.820
2015	VA	92	1,574	1,617	1,503	1,479	1,410	0.401	1,728	1,557	1,403	1,541	1,539	0.049
2015	WM-TX	96	392	402	487	418	392	0.388	374	446	500[a]	403	436	0.043
2017	MS	100	—	—	—	—	—	—	—	—	—	—	—	—
2017	LA	152	1,213	1,188	1,071	1,187	1,110	0.445	1,269	1,159	1,228	1,103	1,016	0.170
2017	AR	158	1,545	1,347	1,625	1,275	1,315	0.490	1,641	1,756	1,623	1,552	1,289	0.649
2015	LA	159	2,024	1,849	1,853	1,608	1,670	0.134	1,703	1,733	1,636	1,944	1,934	0.538
2016	AR	168	1,498	1,463	1,403	1,402	1,468	0.691	1,440	1,497	1,494	1,662	1,568	0.510
2015	AR	174	1,804	1,827	1,741	1,682	1,631	0.558	1,786	1,813	1,631	1,735	1,783	0.735
2016	LA	177	1,796	1,924	1,859	1,875	1,882	0.535	1,944	1,942	1,898	1,891	1,909	0.753
2016	OK	204	2,183	2,376[a]	2,346	2,341	2,457[a]	0.009	2,370	2,459	2,459	2,312	2,414	0.570
2017	WM-TX	207	1,007	1,073	898	905	920	0.608	1,020	953	855	941	938	0.265
2017	DS-TX	261	1,746	2,115	2,094	2,395	2,273	0.496	2,341	2,472	2,449	1,987	2,404	0.947
2017	OK	267	2,206	2,229	2,113	2,194	2,095	0.508	2,295	2,286	2,270	2,216	2,020	0.139
2016	DS-TX	277	2,297	2,317	2,494	2,137	2,084	0.830	1,967	2,236	2,376[a]	2,307	2,298	0.061
2015	DS-TX	391	2,386	2,164	2,275	2,145	2,099	0.044	2,226	2,301	2,314	2,298	2,396	0.158

[a] Indicates ROI greater than the untreated check (0 kg K_2O ha^{-1}) within application method at responsive sites at a significance level of $\alpha = .1$. ROI was calculated using lint only and did not include seed cotton price. The estimated fertilizer price used was 0.469 dollars kg^{-1} K_2O applied.

TABLE 7 Pearson correlation (r) matrix determined from principal components analysis for all sites in 2015, 2016, and 2017 growing seasons

Variable	Soil K			Leaf K	Yield	Loan value
	0-to-15 cm	15-to-30 cm	30-to-60 cm			
	2015					
Soil K, 0-to-15 cm	1.000					
Soil K, 15-to-30 cm	0.959	1.000				
Soil K, 30-to-60 cm	0.931	0.962	1.000			
Leaf K	0.019	0.040	0.113	1.000		
Yield	0.501	0.458	0.443	0.590	1.000	
Loan value	0.218	0.138	0.160	0.566	0.659	1.000
	2016					
Soil K, 0-to-15 cm	1.000					
Soil K, 15-to-30 cm	0.967	1.000				
Soil K, 30-to-60 cm	0.920	0.945	1.000			
Leaf K	0.497	0.549	0.519	1.000		
Yield	0.774	0.758	0.684	0.581	1.000	
Loan value	0.332	0.355	0.379	0.345	0.500	1.000
	2017					
Soil K, 0-to-15 cm	1.000					
Soil K, 15-to-30 cm	0.959	1.000				
Soil K, 30-to-60 cm	0.892	0.922	1.000			
Leaf K	0.446	0.326	0.464	1.000		
Yield	0.307	0.263	0.406	0.540	1.000	
Loan value	−0.056	−0.065	−0.040	0.003	0.130	1.000

(Oosterhuis et al., 2014). The lack of leaf tissue K response to both broadcast and injected K fertilizer corresponds to the minimal yield response across the 23 sites.

3.3 | Cotton lint yield and economics

In 2015, a good range of lint yield potentials was identified from 334 to as high as 2,580 kg ha^{-1}. The Alabama, Arkansas, Louisiana, and Virginia sites, for both methods of K fertilizer application, were high yielding and averaged over 1,500 kg ha^{-1}. Despite these sites having near- or below-threshold levels of K down to 60 cm, none of these locations were responsive to K rate or application method (Tables 2 and 4). At the southwestern location of WM-TX, significant drought stress was observed in the trial, and yields were around 50% of normal yields for the area. However, under these drought stress conditions, a significant yield response was observed for both K application methods, and yields were 25 and 33% (broadcast and knife-injected, respectively) greater than the untreated check. When K was applied preplant via broadcast application, the 90 kg ha^{-1} rate was required to observe a significant yield response, compared with the 45 kg ha^{-1} rate for the injected application method. At the DS-TX location with nearly 400 mg kg^{-1} of soil K, a significant yield response occurred with the 160 kg K_2O ha^{-1} application rate for the injected application method, but the broadcast method was nonresponsive (Tables 2 and 4).

In 2016, soil K concentrations at the Alabama, North Carolina, WM-TX, and Virginia locations were less than the threshold of 150 mg K kg^{-1} at all depths, and as such, a yield response was expected at these locations (Table 2). Of these locations, a positive yield response was observed with increasing K rates applied using either method at the two drought-stressed, low-yielding sites, WM-TX and Virginia (Table 4). At WM-TX, greater fertilizer K was required with the broadcast application method (135 kg K_2O ha^{-1}) compared with the injection method (90 kg K_2O ha^{-1}) to increase lint yield greater than the untreated check. The 45 kg K_2O ha^{-1} rate applied using either method at the Virginia site was the lowest rate required to increase lint yield compared with the check. The Alabama and North Carolina sites were moderate- and low-yielding environments, respectively, but neither responded to K application.

Soil K concentrations at the other sites in 2016 exceeded 150 mg K kg^{-1} at all depths except at the 15-to-30- and 30-to-60-cm depths at Louisiana, and as expected, most sites were nonresponsive (Tables 2 and 4). The two exceptions were the Oklahoma and DS-TX locations. At Oklahoma, the broadcast-applied 45 kg ha^{-1} rate was required to increase lint yield

TABLE 8 Pearson correlation (r) matrix determined from principal components analysis for each research site across 2015, 2016, and 2017 growing seasons

Variable	Soil K			Leaf K	Yield	Loan value
	0-to-15 cm	15-to-30 cm	30-to-60 cm			
	Alabama					
Soil K, 0-to-15 cm	1.000					
Soil K, 15-to-30 cm	0.744	1.000				
Soil K, 30-to-60 cm	0.869	0.816	1.000			
Leaf K	0.502	0.472	0.612	1.000		
Yield	0.697	0.583	0.747	0.531	1.000	
Loan value	0.677	0.547	0.655	0.302	0.587	1.000
	Arkansas					
Soil K, 0-to-15 cm	1.000					
Soil K, 15-to-30 cm	0.289	1.000				
Soil K, 30-to-60 cm	−0.009	0.824	1.000			
Leaf K	−0.129	0.435	0.595	1.000		
Yield	0.024	−0.385	−0.460	−0.400	1.000	
Loan value	0.057	−0.040	−0.076	0.129	−0.144	1.000
	Louisiana					
Soil K, 0-to-15 cm	1.000					
Soil K, 15-to-30 cm	0.22	1.000				
Soil K, 30-to-60 cm	−0.331	0.457	1.000			
Leaf K	0.114	0.146	−0.026	1.000		
Yield	0.039	0.139	−0.112	−0.023	1.000	
Loan value	0.291	−0.142	−0.302	−0.070	0.185	1.000
	Dawson County, TX					
Soil K, 0-to-15 cm	1.000					
Soil K, 15-to-30 cm	0.652	1.000				
Soil K, 30-to-60 cm	0.496	0.764	1.000			
Leaf K	−0.812	−0.234	−0.104	1.000		
Yield	0.096	0.199	0.247	0.019	1.000	
Loan value	−0.195	−0.143	−0.014	0.19	0.145	1.000
	Mississippi					
Soil K, 0-to-15 cm	1.000					
Soil K, 15-to-30 cm	0.247	1.000				
Soil K, 30-to-60 cm	0.515	0.382	1.000			
Leaf K	0.438	−0.003	0.189	1.000		
Yield	−0.250	−0.239	−0.184	0.150	1.000	
Loan value	N/A	N/A	N/A	N/A	N/A	N/A
	North Carolina					
Soil K, 0-to-15 cm	1.000					
Soil K, 15-to-30 cm	0.686	1.000				
Soil K, 30-to-60 cm	0.151	0.474	1.000			
Leaf K	0.295	0.243	0.109	1.000		
Yield	−0.297	0.021	0.162	−0.604	1.000	
Loan value	−0.063	0.122	0.438	−0.326	0.543	1.000

(Continues)

TABLE 8 (Continued)

Variable	Soil K			Leaf K	Yield	Loan value
	Oklahoma					
Soil K, 0-to-15 cm	1.000					
Soil K, 15-to-30 cm	0.968	1.000				
Soil K, 30-to-60 cm	0.951	0.992	1.000			
Leaf K	−0.373	−0.345	−0.324	1.000		
Yield	−0.507	−0.529	−0.545	0.100	1.000	
Loan value	−0.337	−0.344	−0.345	−0.064	0.340	1.000
	Virginia					
Soil K, 0-to-15 cm	1.000					
Soil K, 15-to-30 cm	0.832	1.000				
Soil K, 30-to-60 cm	0.889	0.707	1.000			
Leaf K	0.730	0.554	0.873	1.000		
Yield	0.845	0.764	0.866	0.753	1.000	
Loan value	−0.209	−0.330	−0.219	−0.151	−0.259	1.000
	Williamson County, TX					
Soil K, 0-to-15 cm	1.000					
Soil K, 15-to-30 cm	0.525	1.000				
Soil K, 30-to-60 cm	0.551	0.819	1.000			
Leaf K	0.336	0.626	0.527	1.000		
Yield	0.360	0.527	0.542	0.648	1.000	
Loan value	−0.180	−0.156	−0.001	−0.057	−0.124	1.000

greater than the untreated check. At the DS-TX location, 90 kg K_2O ha^{-1} applied using the injection method was the lowest K fertilizer rate that increased yields greater than that of the untreated check.

In 2017, most sites were nonresponsive except for North Carolina and Virginia, which were two of the six locations with soil K levels close to the threshold (Tables 2 and 4). Using the injection method at the North Carolina location, the 90 kg K_2O ha^{-1} rate resulted in lint yield greater than the check (Table 4), whereas at the Virginia location, 45 kg K_2O ha^{-1} applied using the broadcast method was required to increase lint yield to greater than the check. At the DS-TX location, lint yield tended to increase (approximately 110 kg lint ha^{-1}) from 0 to 90 kg K_2O ha^{-1} for injected K but not to broadcast-applied K. At Mississippi, Louisiana, and Arkansas, lint yields ranged from 560 (Mississippi) to 1,400 kg K ha^{-1} (Arkansas), but differences among K_2O rates were not observed.

Calculated loan values of lint ranged from \$0.89 to 1.21 kg^{-1} lint; however, no treatments at any of the 23 site-years resulted in increased lint value compared with the untreated check (Table 5). Differences were determined among treatments for fertilizer ROI for four site-years with only Virginia demonstrating differences within broadcast and injected fertilizer K (Table 6). At Virginia in 2016, broadcast-applied K at 90 and 135 kg K_2O ha^{-1} resulted in a greater ROI compared with the control, and with 90 and 180 kg K_2O ha^{-1} applied as injected K, there was a greater ROI. In 2015 at the WM-TX site, 90 kg K_2O ha^{-1} injected K resulted in a greater ROI compared with the control despite this location having significant yield responses in both 2015 and 2016. This was also the case in 2016 at the DS-TX site, where the minimum amount of K_2O needed to achieve maximum ROI at these sites was 90 kg ha^{-1}. However, at the Oklahoma site in 2016, the minimum amount of K_2O required to reach maximum ROI was 45 kg ha^{-1} (broadcast-applied).

3.4 | Relationship between soil K, leaf K, yield, and loan value

Principal component analysis accounted for 87.0, 83.5, and 75.2% of the variability in 2015, 2016, and 2017, respectively (Figure 1). In each year, there was a positive correlation between soil test K regardless of sampling depth across the Cotton Belt. Although correlated with each other, soil test K was not correlated with leaf K, yield, or loan value in 2015 or 2017. In 2016, there was a positive correlation between all parameters except loan value. The inconsistent results are likely the result of environmental variability among the research sites.

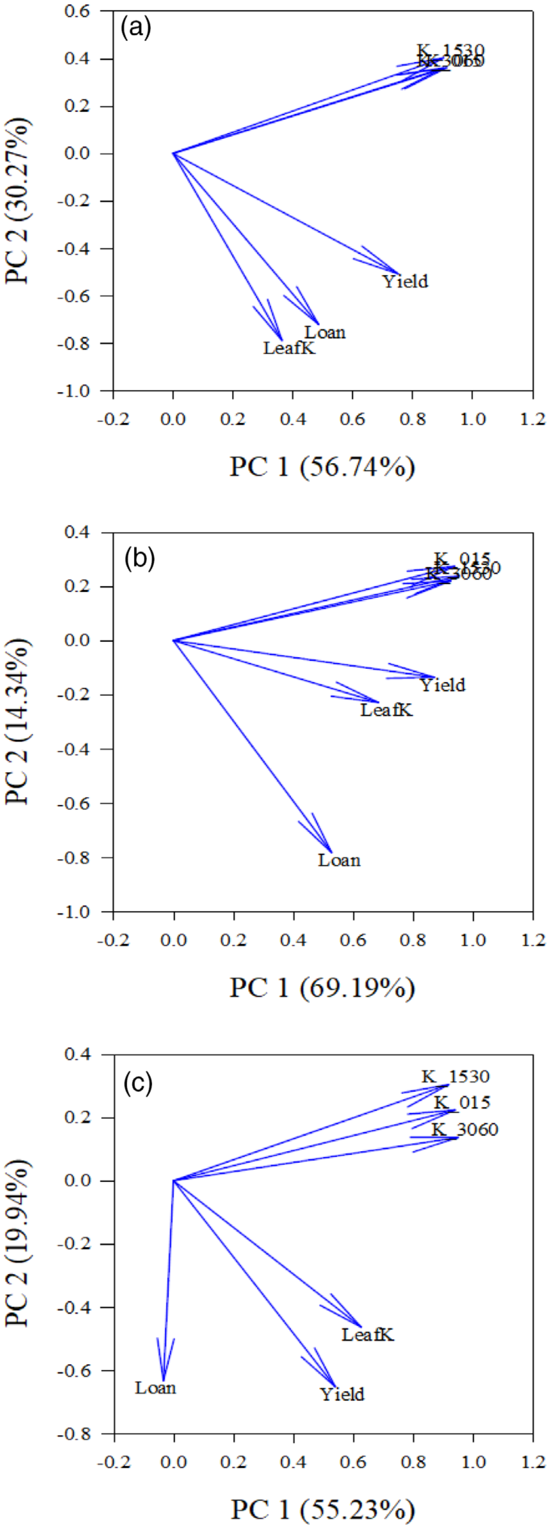

FIGURE 1 Principal component analysis (PCA) for soil and leaf K, yield, and loan value in (a) 2015, (b) 2016, and (c) 2017. Potassium at soil depths were reported as: K_015, soil K at 0-to-15-cm depth; K_1530, soil K at 15-to-30cm depth; K_3060, soil K at 30-to-60-cm depth; Leaf K, leaf tissue K; Yield, lint yield; Loan, refers to loan value; PC, principal component

Notably, there was a poor relationship between soil test K and leaf K concentration (Table 7). This is likely due to the differences in timing between annual soil testing and actual plant uptake of K. Generally, soil samples are collected in the fall or spring prior to planting to allow ample time for analysis and nutrient applications. However, plant uptake of K occurs at the greatest rate during flowering (Bassett et al., 1970). Recent evidence suggests modern cotton cultivars take up nutrients earlier in the growing season compared with historically grown cultivars (Pabuayon et al., 2020). These earlier-maturing varieties are likely the reason for reports of K deficiency in cotton regardless of adequate soil test K. Soil K is likely being taken up by the plant at a faster rate than the exchangeable K can replenish soil solution K. Regardless of year, the relationship between cotton lint yield and leaf K was consistent ($r = .59$, .58, and .54 in 2015, 2016, and 2017, respectively; Table 7). This evidence suggests that leaf tissue K is an adequate predictor of yield; however, K deficiencies determined through leaf tissue testing may or may not be remedied in-season (Coker et al., 2009; Howard, et al., 1998a, 1998b; Pettigrew, 2003).

As previously discussed, loan value is a calculation of USDA premiums and discounts based on HVI classing data and helps producers determine their ROI. In essence, loan value is the combined measure of fiber quality. Consistently, loan value did not correlate with any other evaluated parameter except leaf tissue K and yield in 2015 ($r = .57$ and .66, respectively). In 2017, loan value had no correlation with any parameter and was likely due to environmental factors such as growing degree day units and rainfall, which are more likely to impact fiber quality than K availability (Luo et al., 2016).

Principal component analysis for each site accounted for between 52 and 86% of the variability with principal component (PC) 1 and PC 2 (Figure 2). Louisiana showed the least amount of accountability, which was also evident in the poor relationship between all variables (Table 8). Similarly, Mississippi had a poor relationship between all variables with the PCA, although the analysis represented 66% of the total variability. The poor relationship between measured variables at the Louisiana and Mississippi sites are likely due to environmental conditions, which were not captured in the study.

Soil test K was correlated between depths at five of the nine experimental sites, including Alabama, DS-TX, Oklahoma, Virginia, and WM-TX. These soils are likely more homogenous across soil depths. However, soil test K only correlated to other measured variables at the Alabama and Virginia sites. Potassium availability in soils is closely related to clay mineralogy and the quantity of mica feldspars in the silt and sand fractions of coarser soils (Mengel et al., 1998; Sharpley, 1990; Wulff et al., 1998). Because our study encompasses the Beltwide Cotton Region with a wide range of soils over several years, it is not surprising to see a lack of repeatability

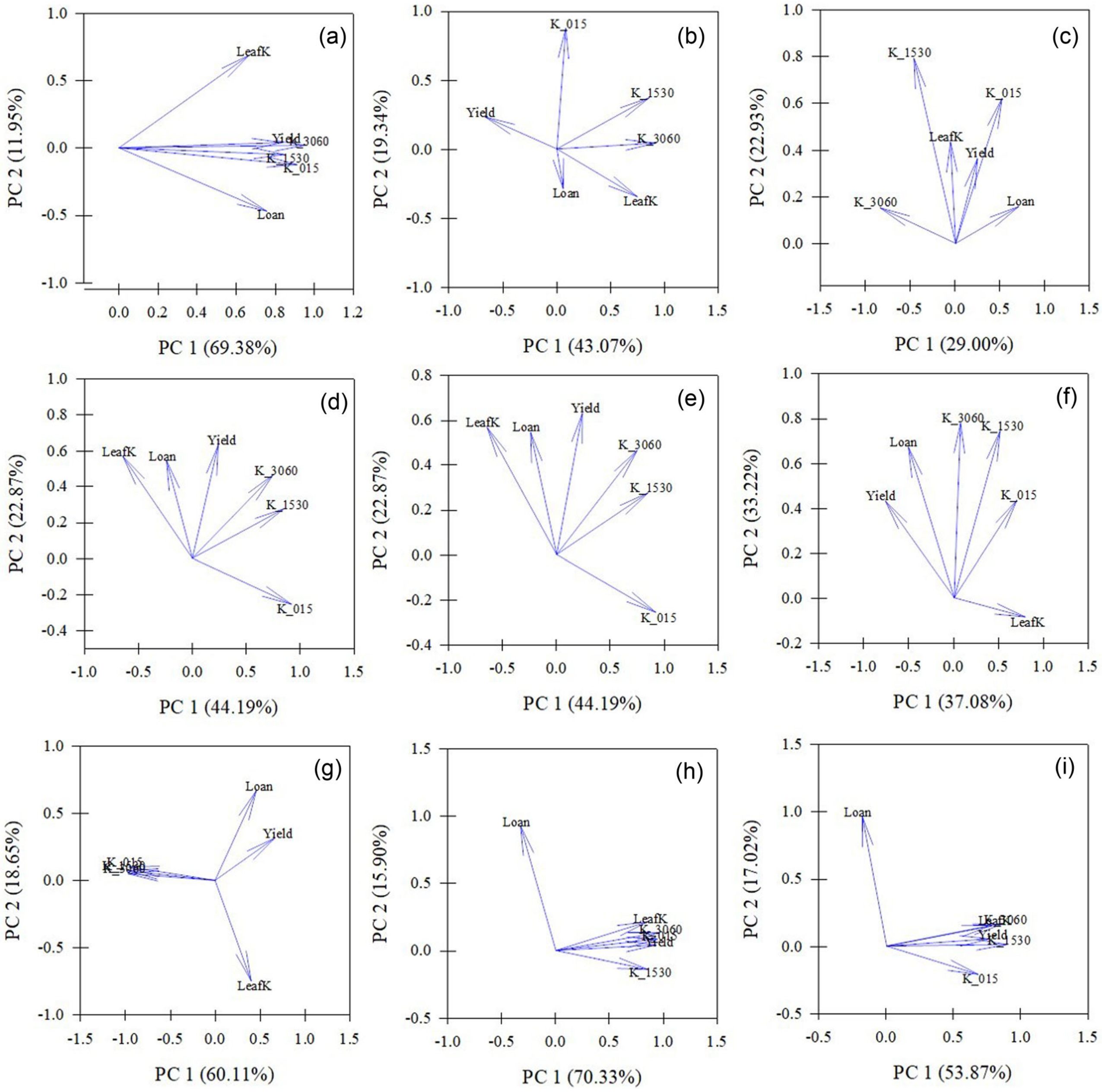

FIGURE 2 Principal component analysis (PCA) for soil and leaf K, yield, and loan value in Alabama (a), Arkansas (b), Louisiana (c), Dawson County, TX (d), Mississippi (e), North Carolina (f), Oklahoma (g), Virginia (h), and Williamson County, TX (i) sites. PC, principal component; K_015, soil K at 0-to-15-cm depth; K_1530, soil K at 15-to-30-cm depth; K_3060, soil K at 30-to-60-cm depth; LeafK, leaf tissue K; Yield, lint yield; Loan, loan value

between research sites and all measured variables. Differences in mineralogy between the surface and subsurface soils may lead to variability in soil test K results and poor correlations between depths.

In general, leaf tissue K was poorly related to other measured variables except at the Alabama, Virginia, and WM-TX sites, where it was positively correlated with nearly all measured variables except loan value. Cotton uptake of K is highly dependent on water availability, and wide ranges in tissue K concentration exist between irrigated and dryland cotton production (Mullins & Burmester, 1991; Unruh & Silvertooth, 1996).

Cotton lint yield was positively correlated with other measured variables at the Alabama, Virginia, and WM-TX sites and was negatively correlated with other measured variables at the Oklahoma site. Lint yield was not correlated with other measured variables at the remaining five research sites. Many abiotic and biotic factors influence yield; therefore, it is not surprising to see only a handful of sites with correlations to other measured variables (Mauney, 1984).

4 | CONCLUSIONS

Much remains unclear about plant available K in cotton and the plants response to application of fertilizer K. Being a perennial plant, cotton fruits over a 45-d period and modifies its fruit load according to growing conditions. Additionally, luxury uptake of K during the vegetative stages of cotton growth is common, and cotton can repartition this K to developing bolls later in the season. This dynamic relationship between crop growth stage and K increases the difficulty in quantifying plant growth and yield response. A response to supplemental K was observed more often at locations with lower yield potentials, likely due to limited in-season moisture and subsequent K absorption, but also at high-yielding locations with soil K levels greater than the Mehlich III K threshold of 150 mg kg^{-1}. At locations where K fertilizer would have been recommended because soil K levels were below the critical level established for the Texas laboratory, a response to added K was rarely determined. Before growers can fully trust soil test K recommendations, future studies should focus more specifically on determining what mechanisms are limiting K uptake by the plant.

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AUTHOR CONTRIBUTIONS

Katie Lewis: Data curation; Formal analysis; Investigation; Writing-original draft. Gaylon Morgan: Conceptualization; Data curation; Funding acquisition; Investigation; Project administration; Writing-review & editing. William Hunter Frame: Investigation. Daniel Fromme: Investigation. Darrin M. Dodds: Investigation. Keith L. Edmisten: Investigation. Bill Robertson: Investigation. Randy Boman: Investigation. Trey Cutts: Investigation. Dennis P. Delaney: Investigation. Joseph Alan Burke: Data curation; Investigation; Writing-review & editing. Robert L Nichols: Conceptualization; Data curation; Funding acquisition; Methodology; Project administration; Supervision; Visualization; Writing-review & editing.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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