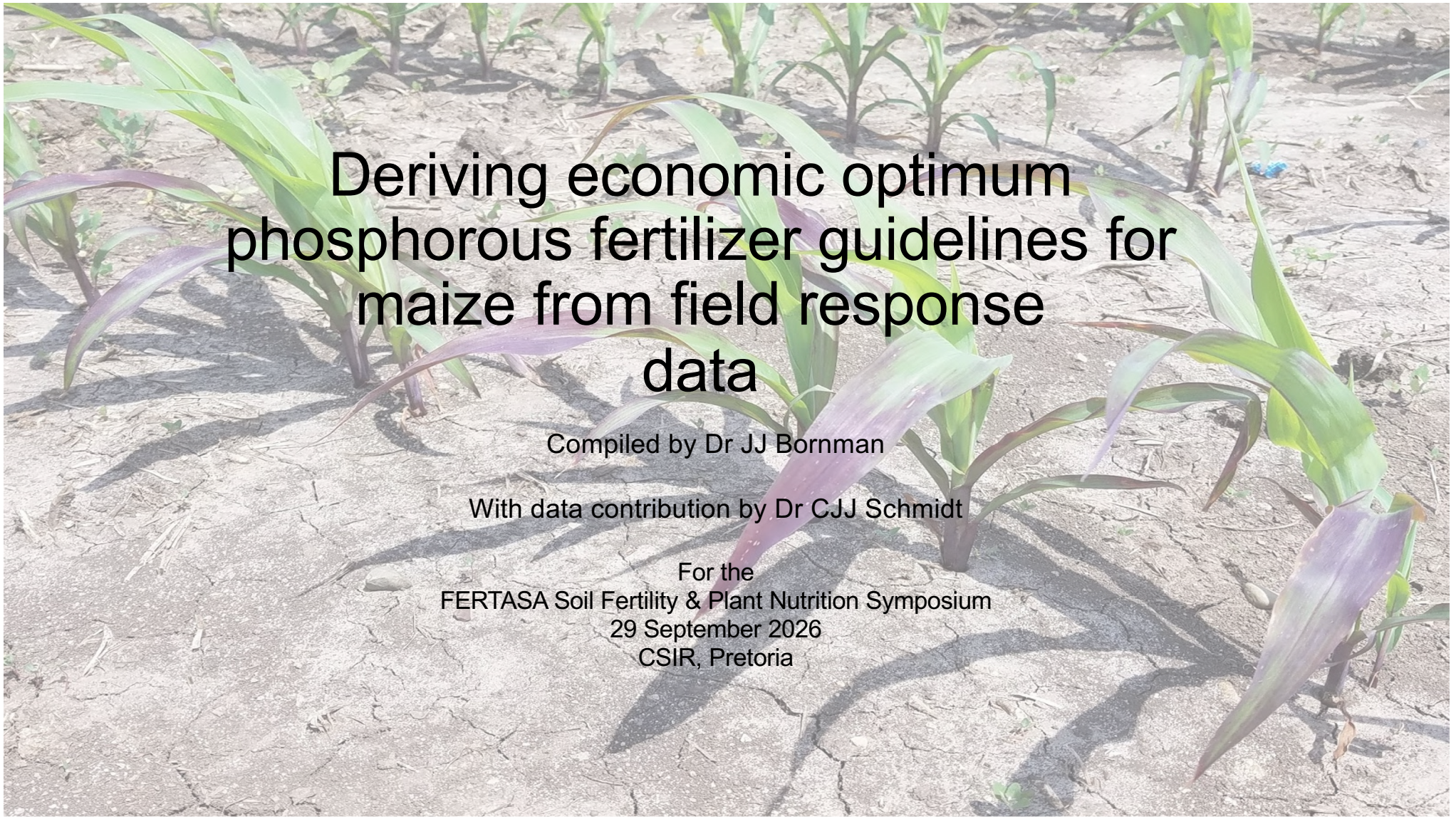


Deriving economic optimum phosphorous fertilizer guidelines for maize from field response data

Compiled by Dr JJ Bornman

With data contribution by Dr CJJ Schmidt

For the
FERTASA Soil Fertility & Plant Nutrition Symposium
29 September 2026
CSIR, Pretoria

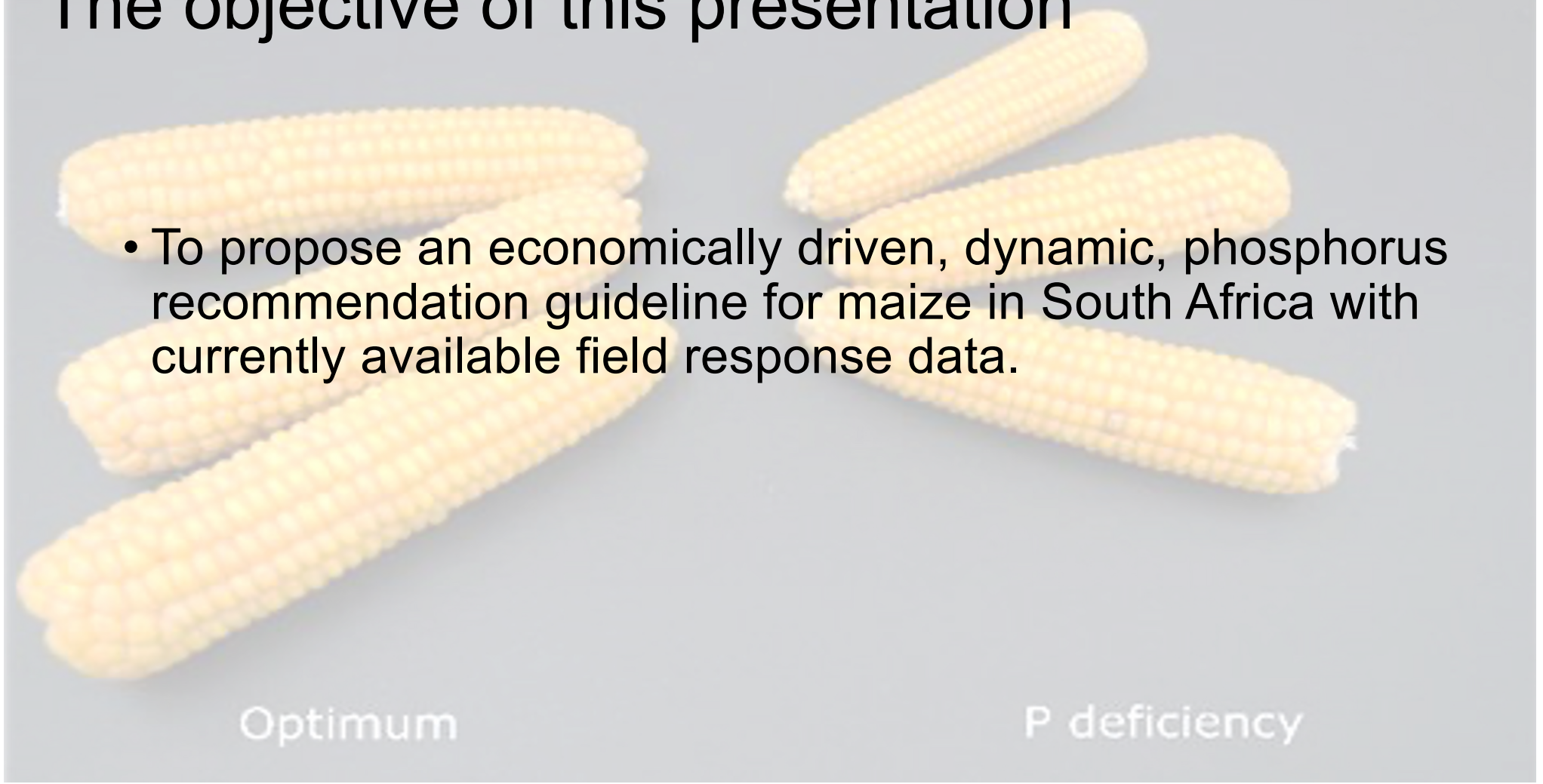
Content

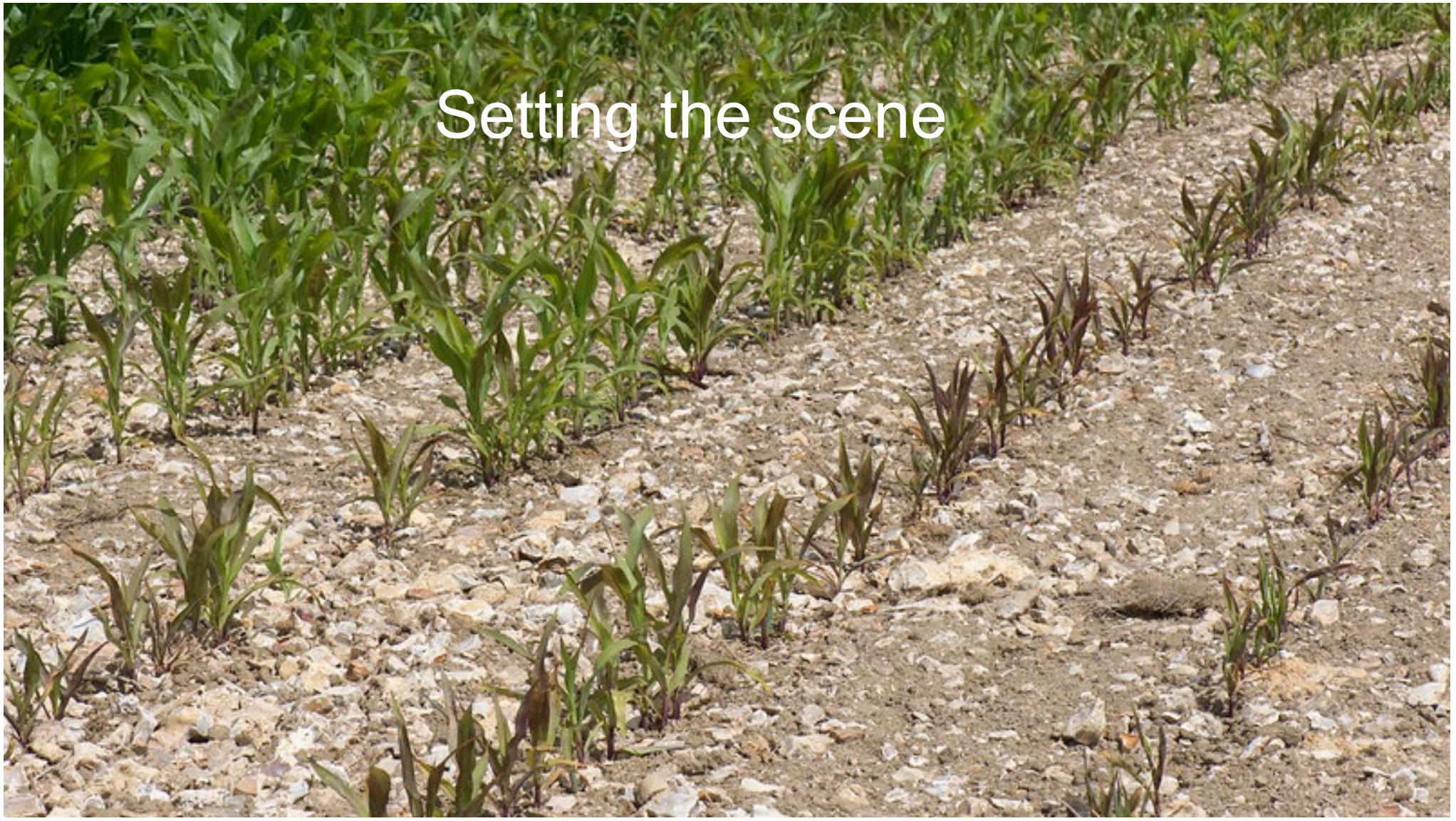
- Setting the scene
  - Increasing price ratios
  - Specificity of phosphorus (P) nutrition of grain crops
- Identifying a critical level for soil P for optimum maize production
- Economic considerations
  - The need of a production function and price ratio
- From field data to a response function
  - Data set used
  - Developing a representative response function
- From response function to production function
- Calculation of economic optima and the importance of soil P
- Recommended economic optimum guidelines from the dynamic model with the current price ratio
- Cross checks with current and historical RSA and Southern USA guidelines



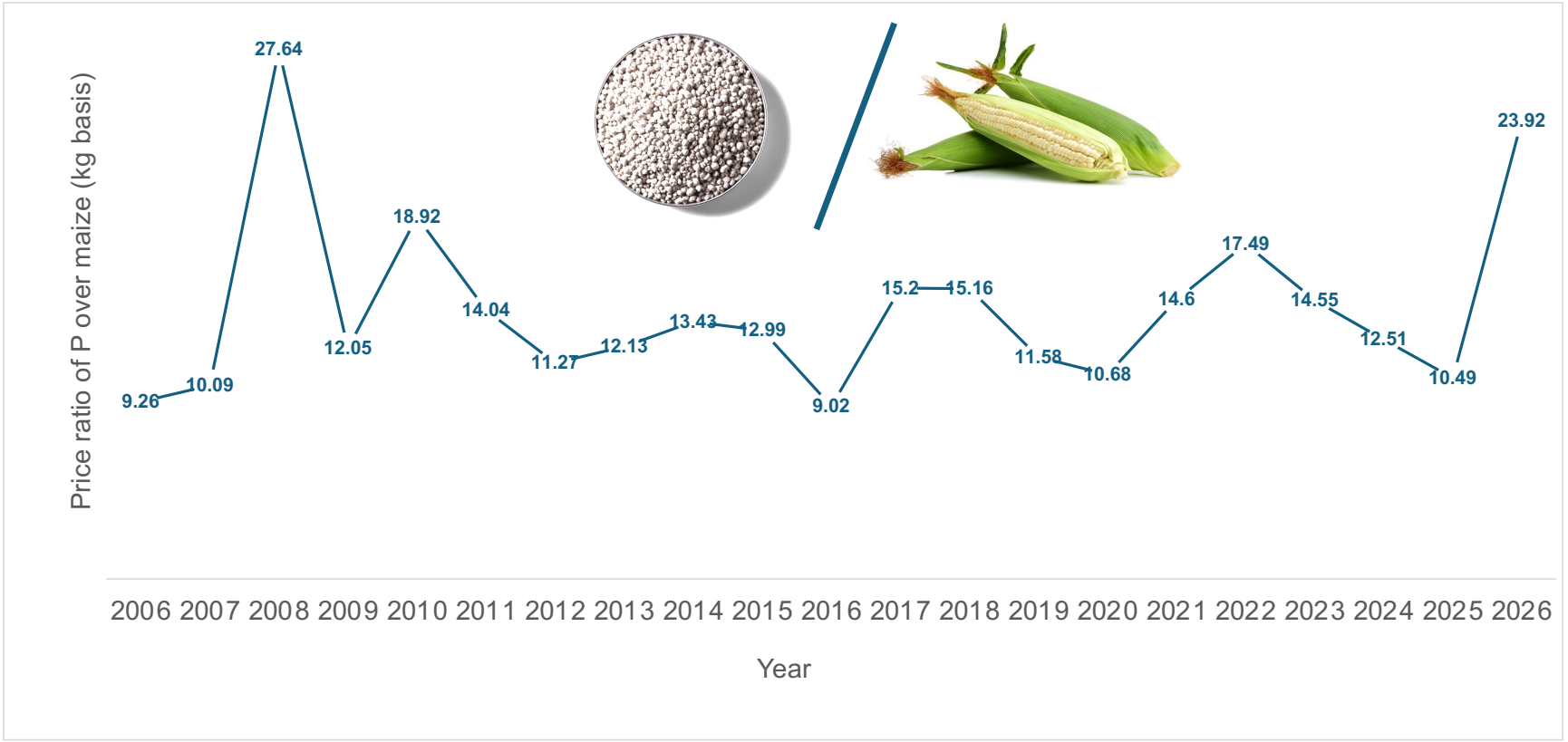
The objective of this presentation

- To propose an economically driven, dynamic, phosphorus recommendation guideline for maize in South Africa with currently available field response data.



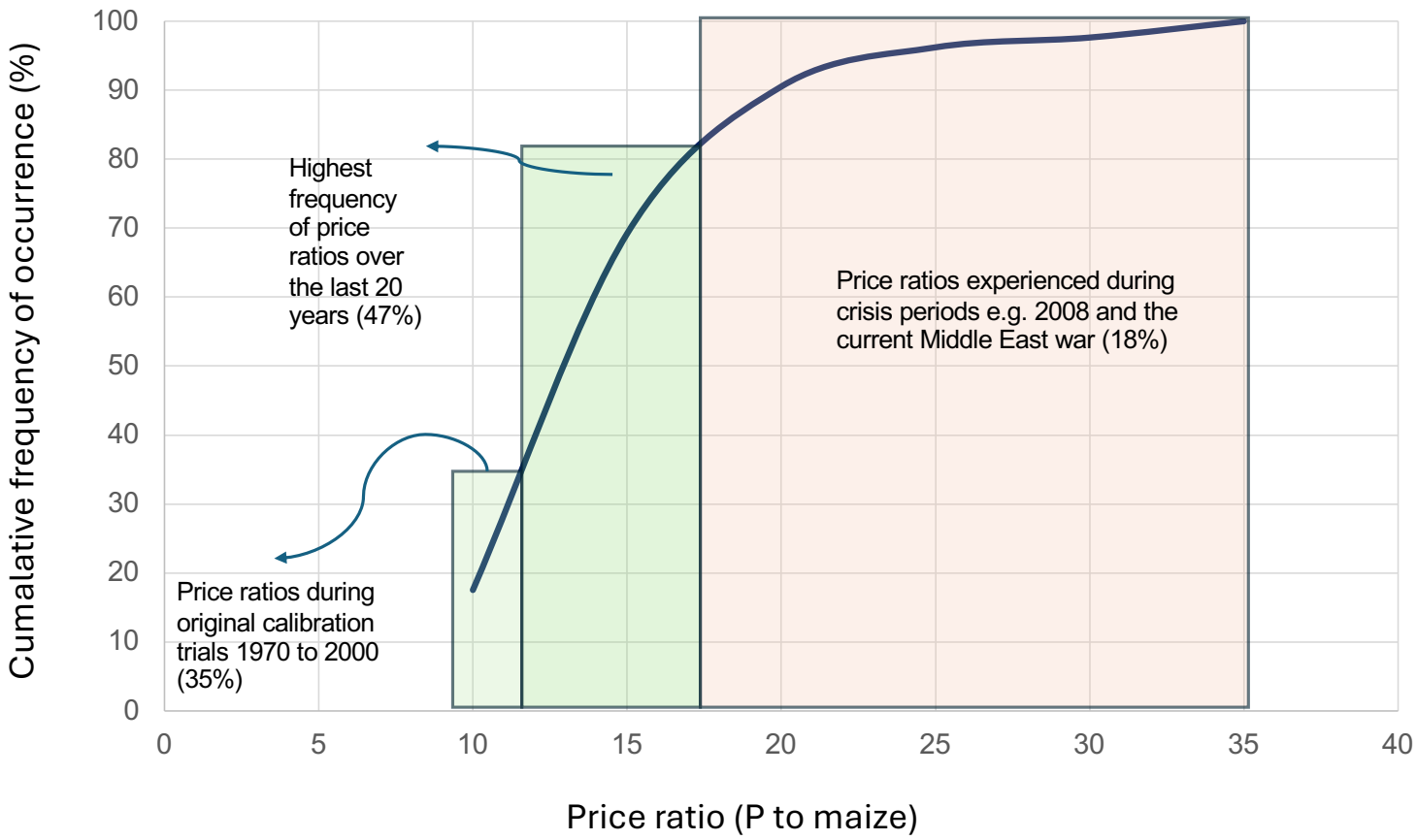

Setting the scene

The trend of phosphorus to maize price ratio from 2006 to present.



Data primarily from Grain SA and fertilizer company price lists

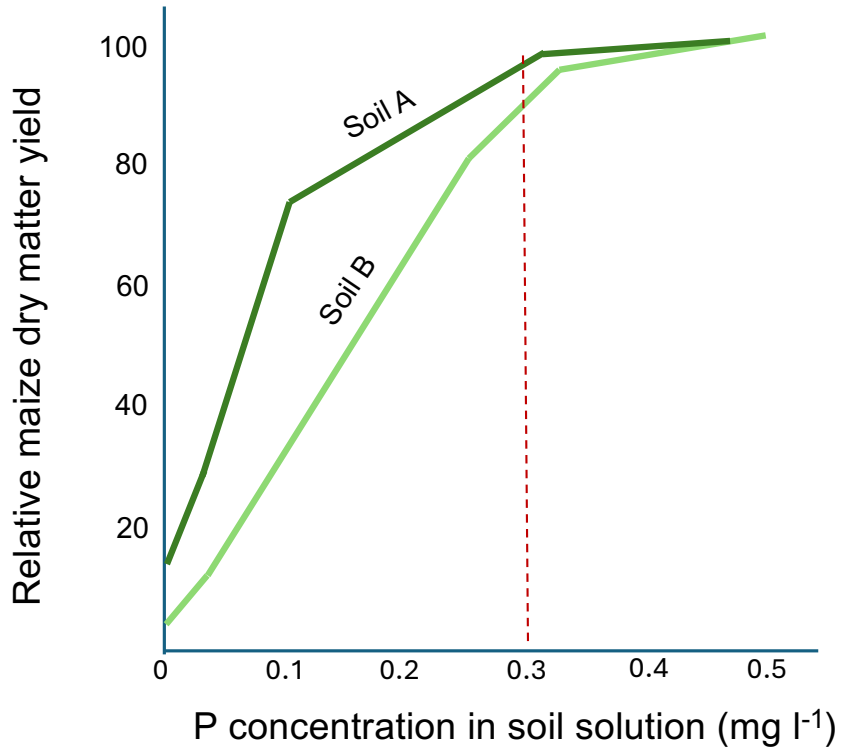
Frequency analysis of phosphorus to maize price ratio from 2006 to present (monthly data)





Phosphorus (P) nutrition of grain crops is specific

Response of maize to soil solution P concentration.



Redrawn from Chaudhary et al, 2013

Results of a meta-analysis by ChatGPT (vs 5.6) by OpenAI to a query on **quantity intensity** relations of phosphorus in soil and soil solution, specifically for the adequate feeding of high yielding maize. Primary references were from A.N. Sharpley, J.K. Syers, P.E Fixen, IPNI, P.H.T. Beckett, N.J. Barrow, R.L. Fox and E.J. Kamprath (1960 -1980)

Please note; the table is illustrative. There are no universal conversion factors between quantity and intensity (concentration). The relations are highly dependant on the soil buffer capacity.

Soil solution P (mg l^{-1}) or kg P per ha^{-1} in brackets (assuming 250 mm water in the root zone)	**Bray 1 P (mg kg^{-1})**	**Kg P ha^{-1} equivalent at 150 mm depth for a soil with a density of 1.5 g cm^{-3}**	**Expected maize response**
<0.05 (<0.13)	<10	< 22	Severe deficiency
0.05–0.10 (0.13 – 0.25)	10–20	22-44	Moderate deficiency
0.10–0.20 (0.25 – 0.50)	**20–35**	**44-77**	Near optimum for high yields
0.20–0.30 (0.50 – 0.75)	35–60	77-132	Little additional response
>0.30 (>0.75)	>60	> 132	Excessive for most situations.

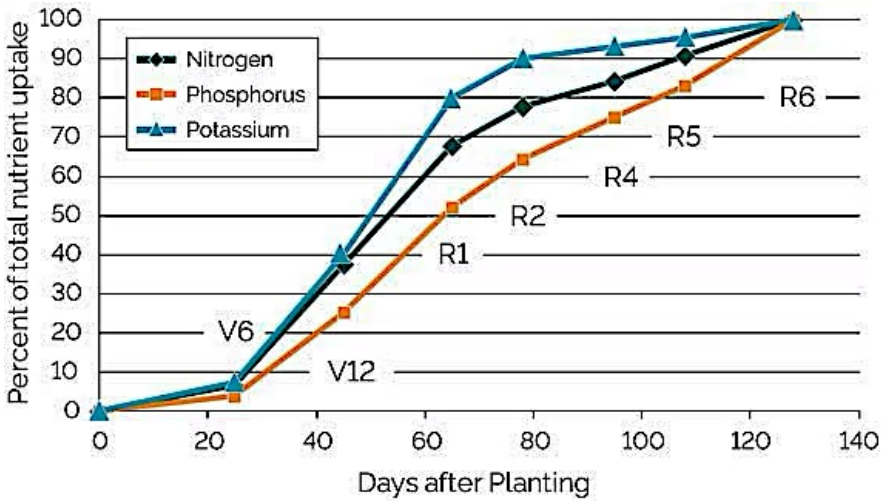
Calculating soil P quantity (kg ha^{-1}) from soil P concentration (mg kg^{-1}) as from a Bray 1 extractant analysis value reported as a concentration of P (mg kg^{-1})

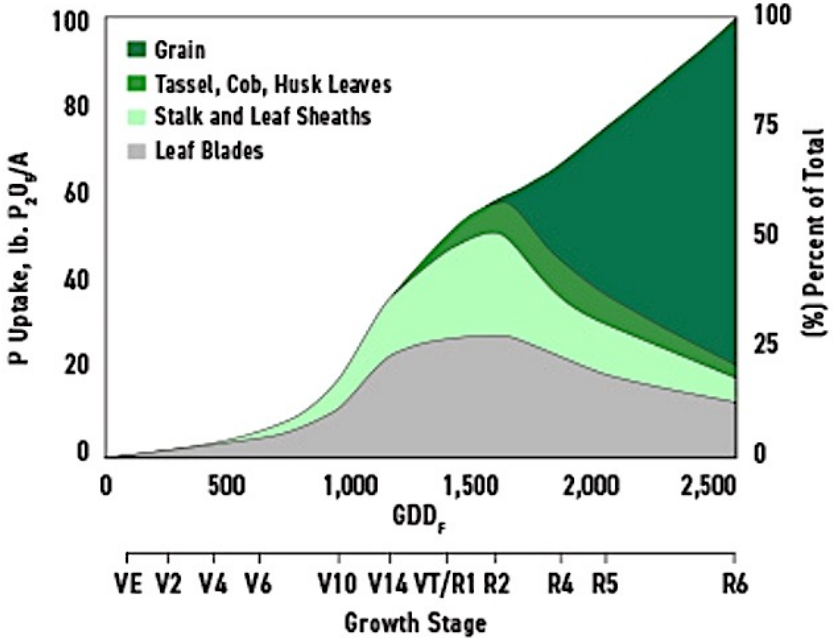
$$\frac{\text{Bray 1 value (mg kg}^{-1}\text{) x soil depth (mm) x soil density (g cm}^{-3}\text{)}}{100}$$

Stone fraction should be taken into account if applicable

kg P ha^{-1} value multiplied with percentage soil i.e. (1 – stone percentage/100)

Phosphorus peak uptake by maize is later in the season





Nitrogen and potassium – more than 67% **before** VT/R1

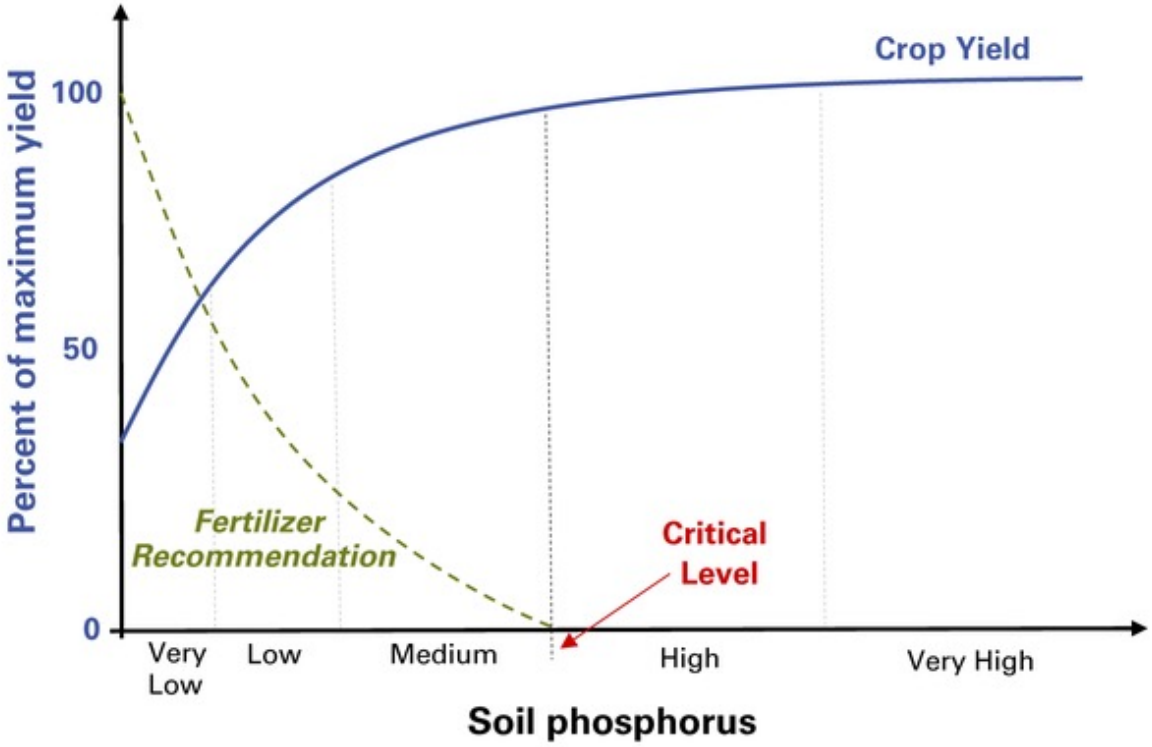
*Phosphorus and sulphur – more than 60% **after** VT/R1*

Bender, Haegele, Ruffo, & Below, 2013, Skinner, 2023

(https://www.beckshybrids.com/resources/croptalk-newsletter/managing-phosphorus-nutrient-availability-in-corn-and-soybeans)

https://assets.vylor.com/is/image/pioneer/n-p-k-uptake-sm?ts=1778511013261

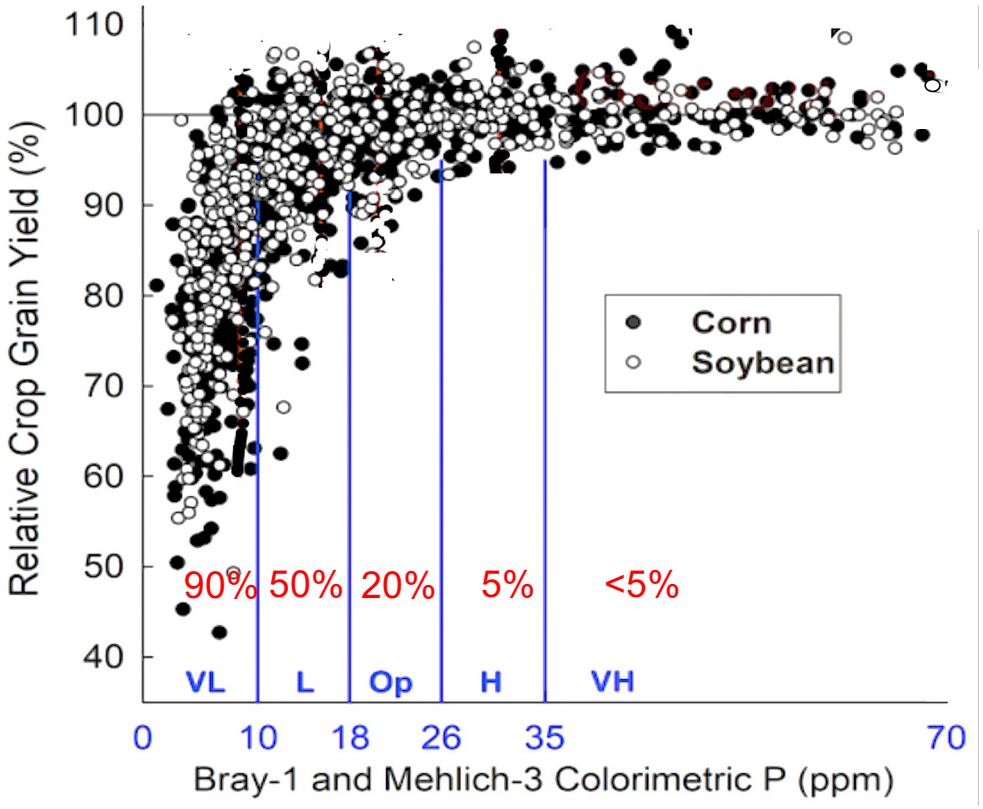
The classic approach to identify critical levels of soil P for grain crops



From Gatiboni et al, 2021.

https://content.ces.ncsu.edu/changes-in-phosphorus-fertilizer-recommendations-for-corn-soybean-and-small-grains

Relative yield vs Soil P test is often used to quantify norms for guidelines.
The example is from Iowa State University extension (USA), (Mallarino, 2023).



https://crops.extension.iastate.edu/cropnews/2023/02/newly-updated-phosphorus-and-potassium-guidelines

Data represents more than 200 trials conducted at 5 experimental farms in Iowa since 2013.

Numbers in red represents probability of response

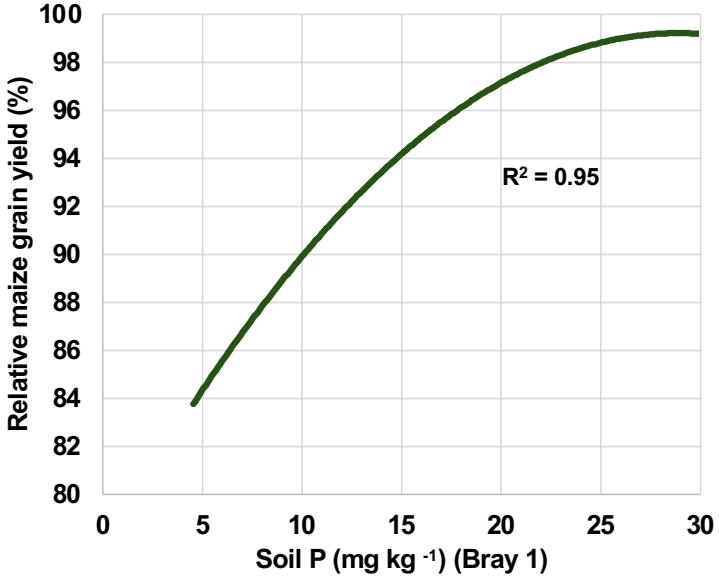
The question

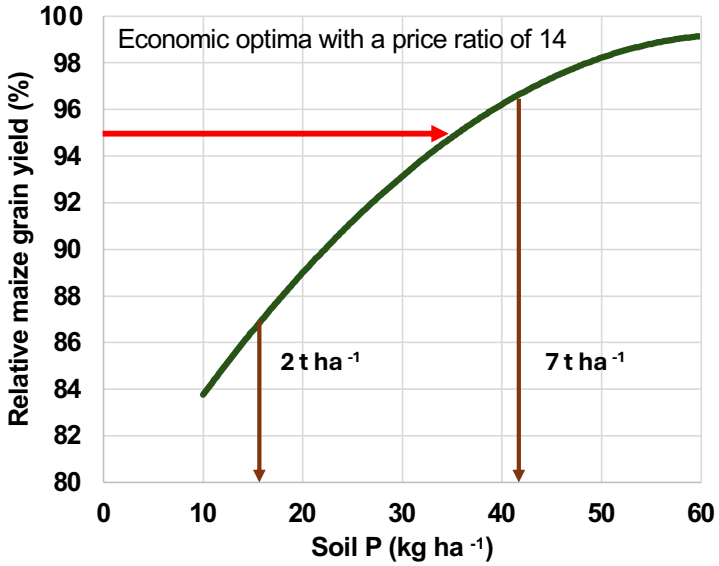
How should critical levels of soil P be reached and maintained under economically challenging conditions?



To regard a P application to reach 95% relative yield, as the economic optimum, is questionable.

Wesselsbron; Soil P originally 3 mg kg $^{-1}$ Bray 1, pH (KCl) – 4.8, 6% clay.





Data from AECI Agronomy Research project M/178/93/W


Economic considerations should dictate, with the application of classic principles

Basic economics;
The neoclassical production function

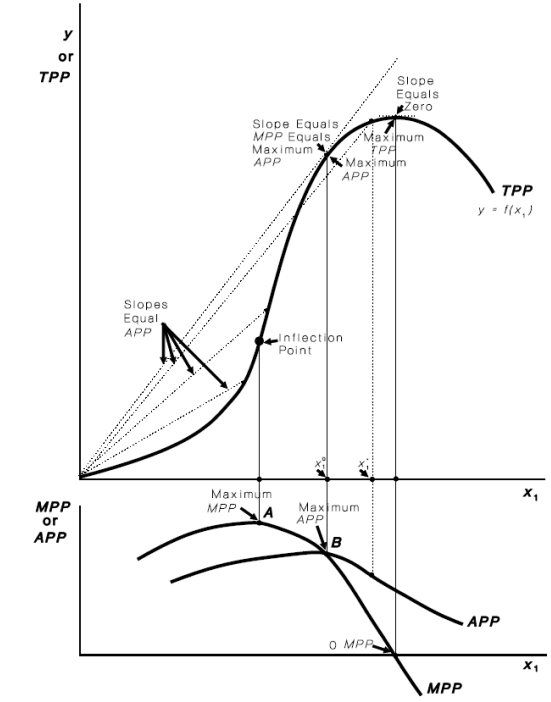


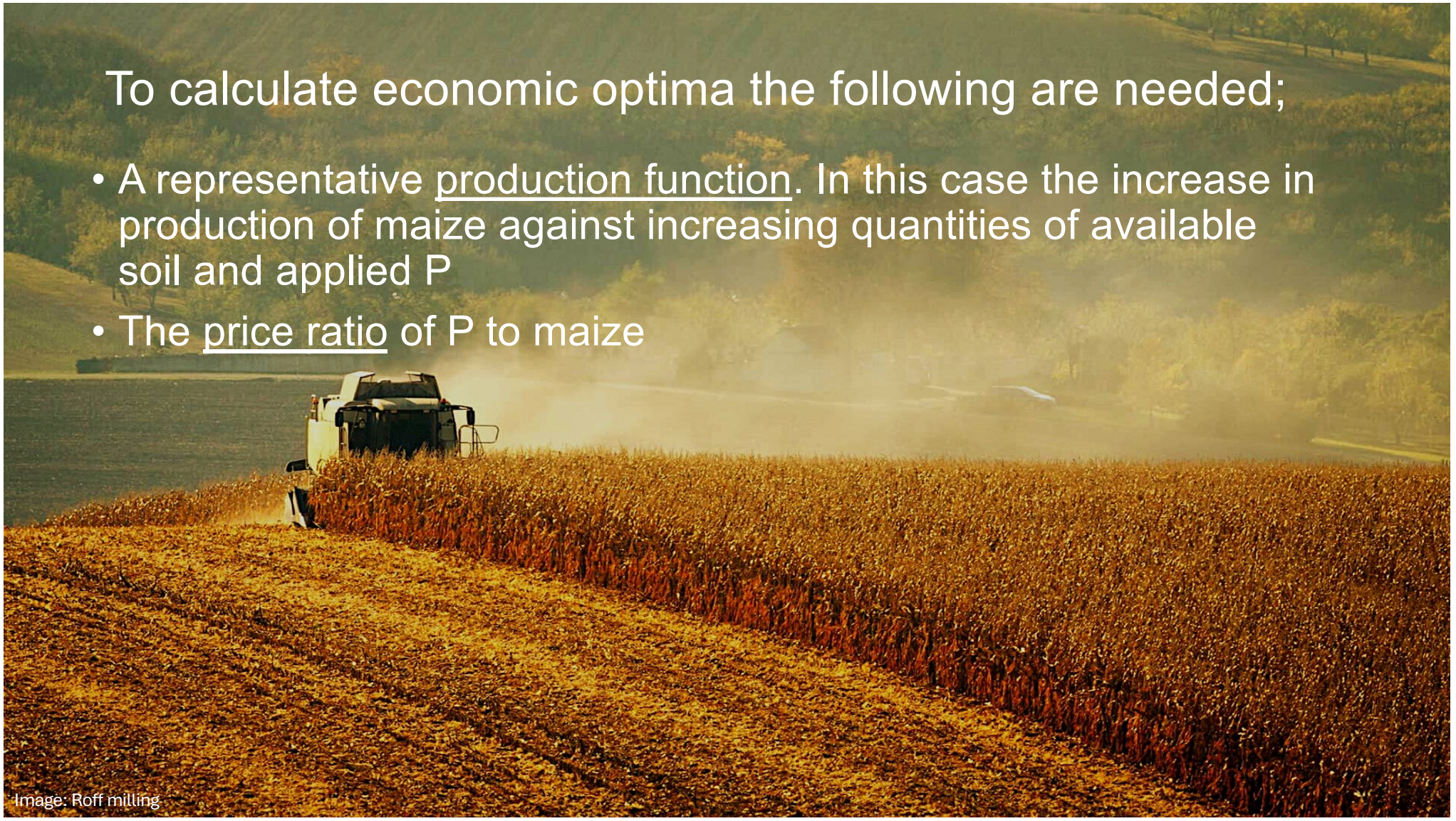
Figure 1: The neoclassical production function. Source: Debertin (2012)

TPP: total produced product

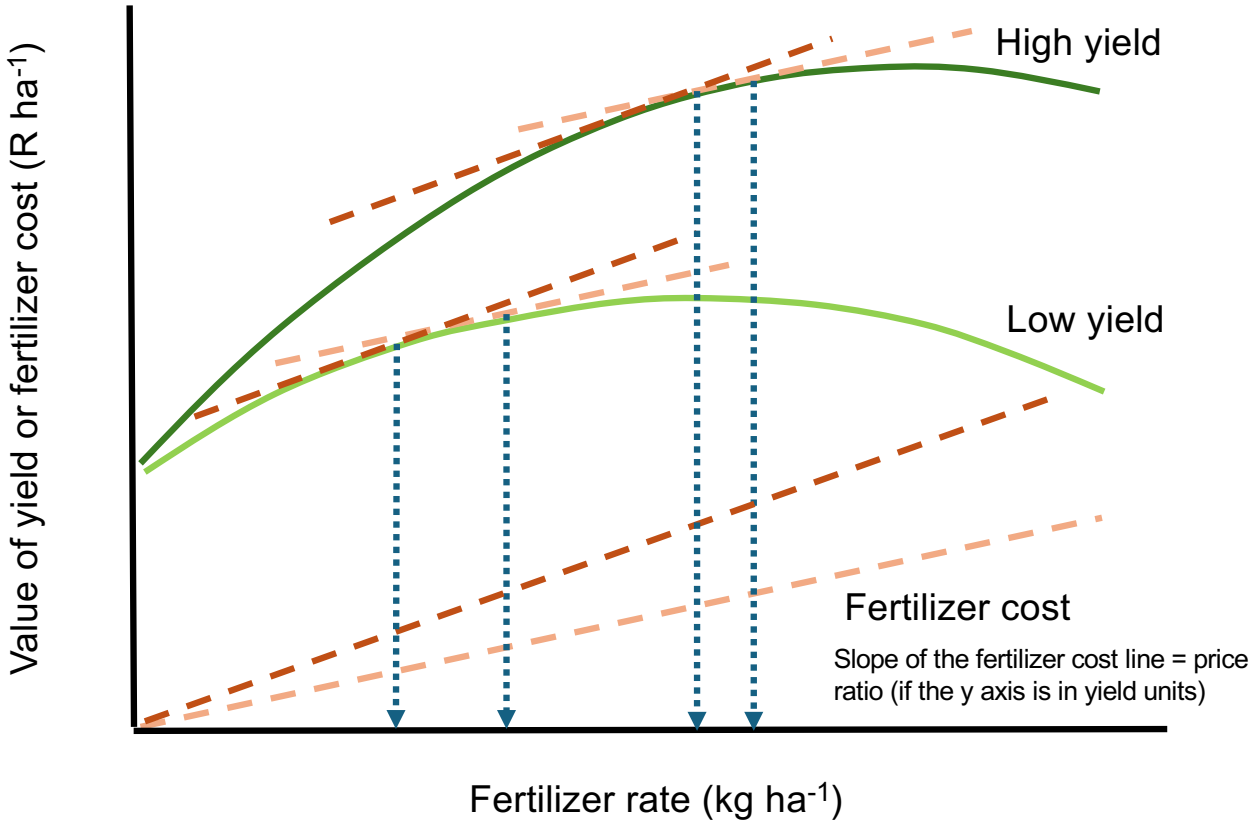
APP: average produced product
MPP: marginal produced product



https://rstudio-pubs-static.s3.amazonaws.com/585783_7394468bd1b64816af3fb430d39d3f00.html


To calculate economic optima the following are needed;
• A representative production function. In this case the increase in production of maize against increasing quantities of available soil and applied P
• The price ratio of P to maize
Image: Roff milling

Economic optimum fertilizer application at different price ratios and yield response



Rate for maximum profit (margin)

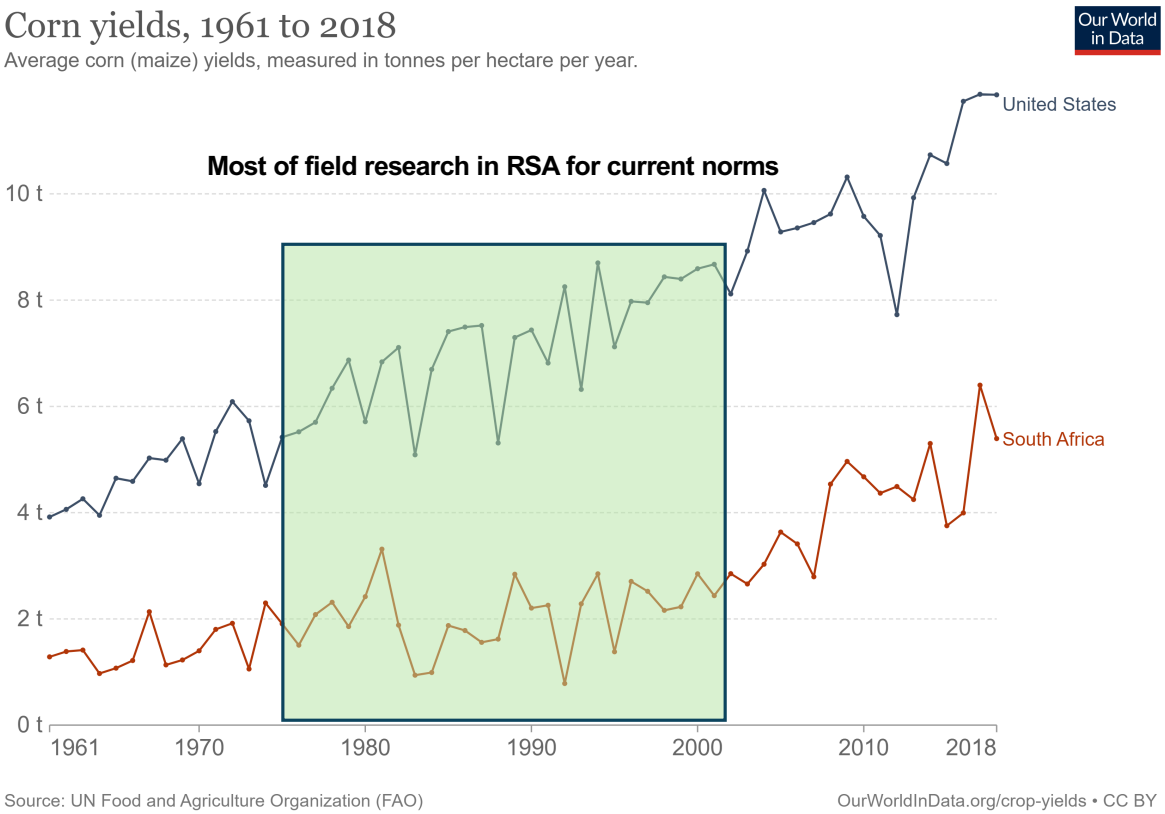
Diagram representing fertilizer economics associated with high and low yield levels. Fertilizer rate for maximum yield occurs where the slope of the response curve is equal to 0 or is parallel with the x-axis. Fertilizer rate for maximum profit occurs where the slope of the response curve is parallel to the fertilizer cost line.

Adapted from Havlin et al, 2017. Chapter 11



Image: Flanders Research Institute

Average maize yields over time



The data set and methodology



The data set used

Locality	Clay%	West (W) or East (E)
Argent	12	E
Heidelberg (2)	17	E
Nigel	24	E
Dirkiesdorp	44	E
Wesselsbron	6	W
Viljoenskroon	8	W
Wolmeranstad	12	W
Ventersdorp	14	W
Stilfontein	18	W
Koppies (2)	47	W

The original maize relative yield response data to soil phosphorus levels (kg ha^{-1}) from the research by Schmidt (2003) for a PhD thesis were used.

Additional and similar data (from four localities) as documented in formal research reports and publications from research done by AECI Agronomy Research from 1980 to 2000 were made available by Bornman (2024).

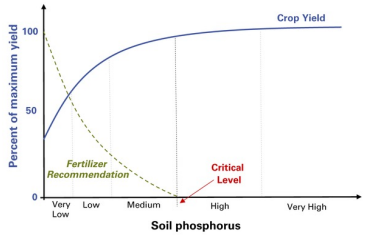
Each response function from the data set is representative of between 2 to twelve seasons per locality. Each data point used represents a mean of 4 to 16 observations. The twelve localities represent more than 50 site years of data.

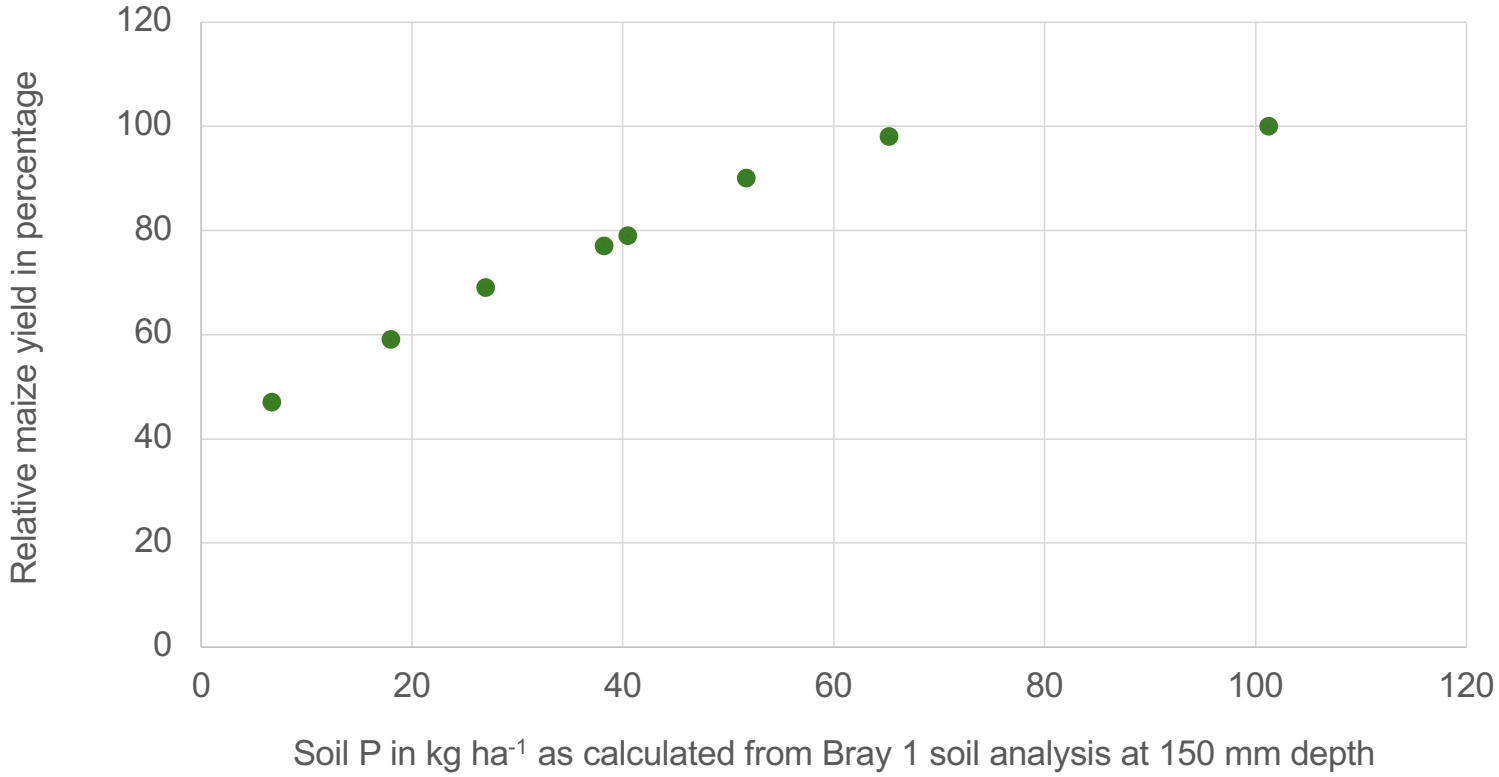
The data set and methodology



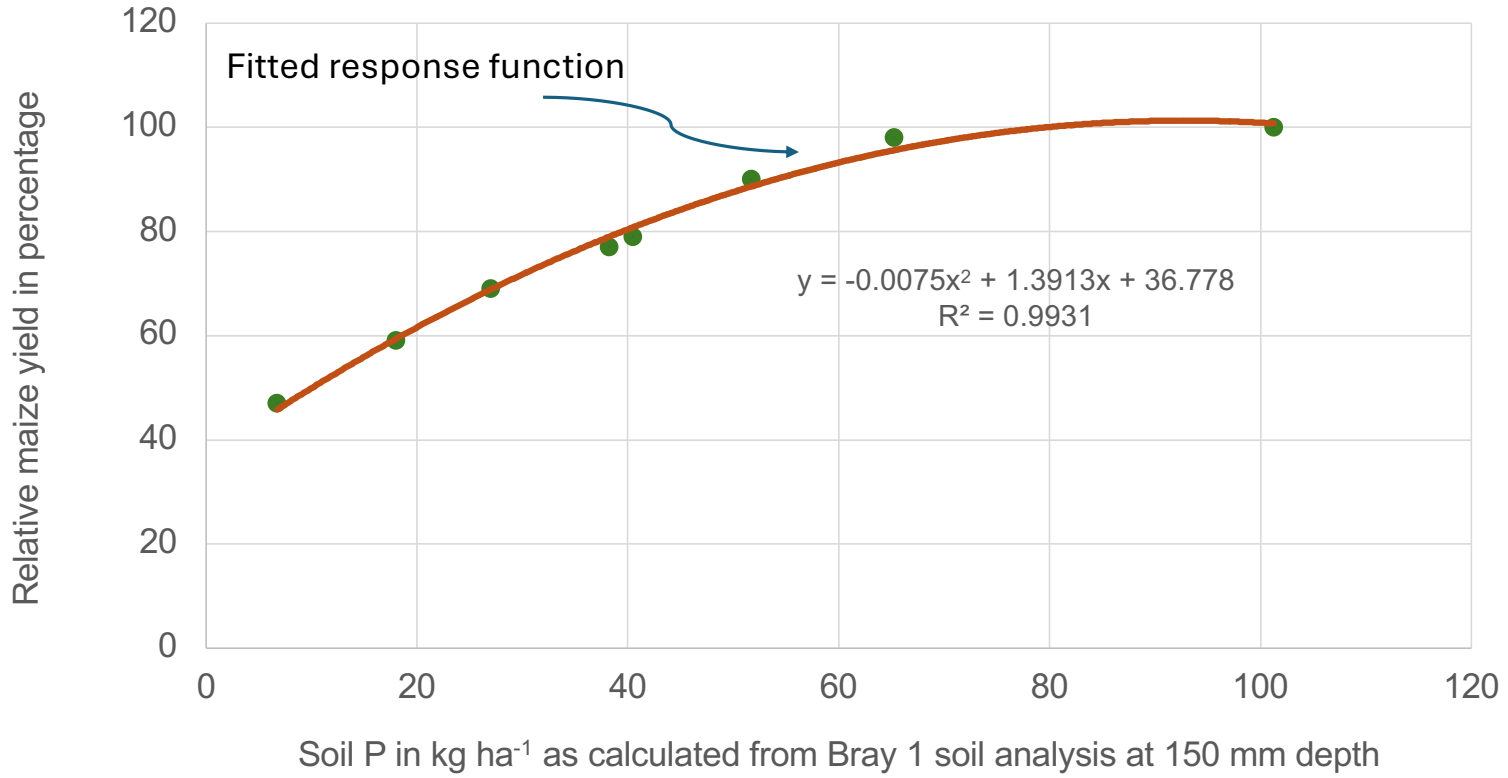
Relative yield vs soil P (as kg ha^{-1})

For two seasons at Argent (near Delmas).
Yields of 4.5 and 5.9 t ha^{-1})

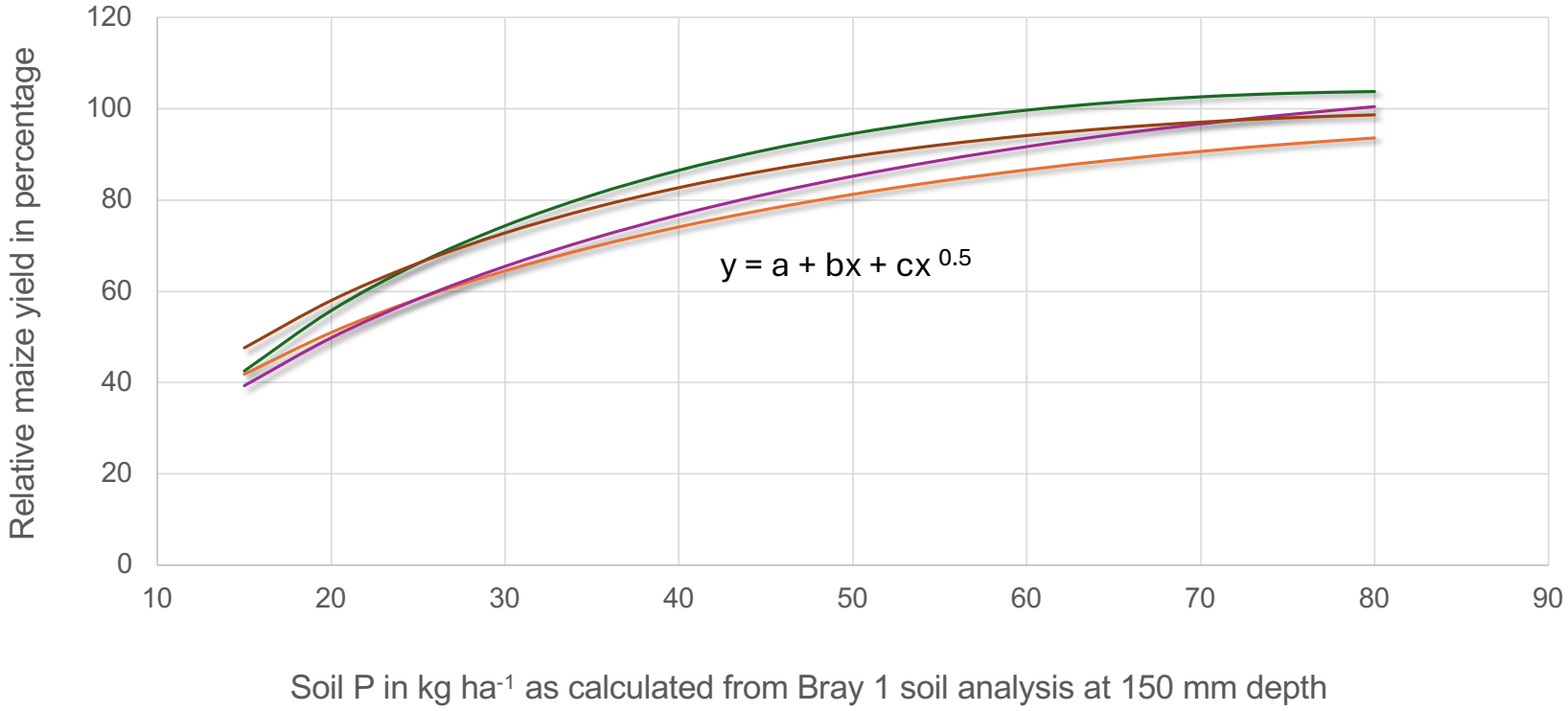




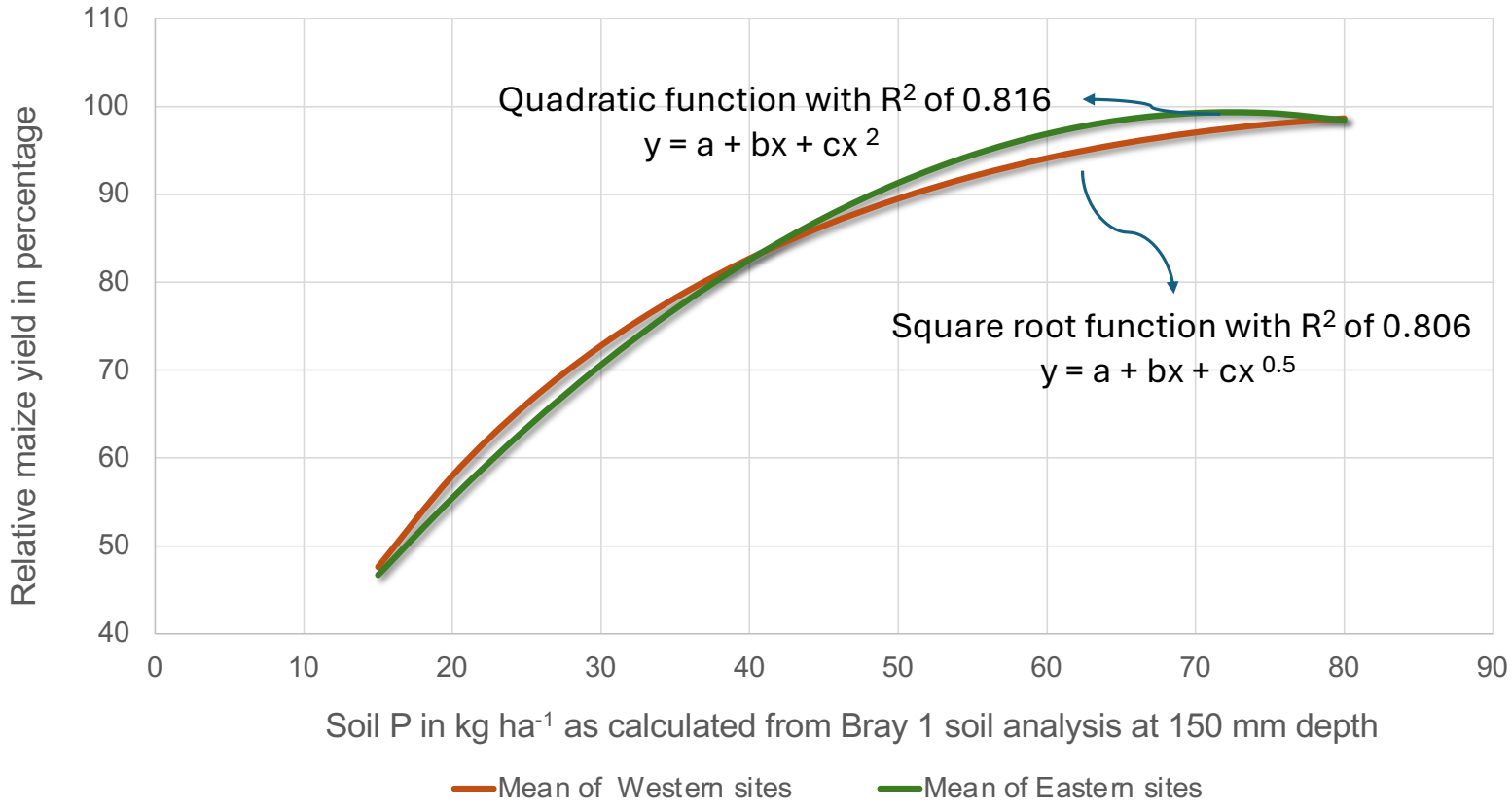
A fitted response function to relative yield vs soil P (as kg ha^{-1}) for two seasons at Argent



An example of a group of response functions for sites in the western maize producing area (square root functions)

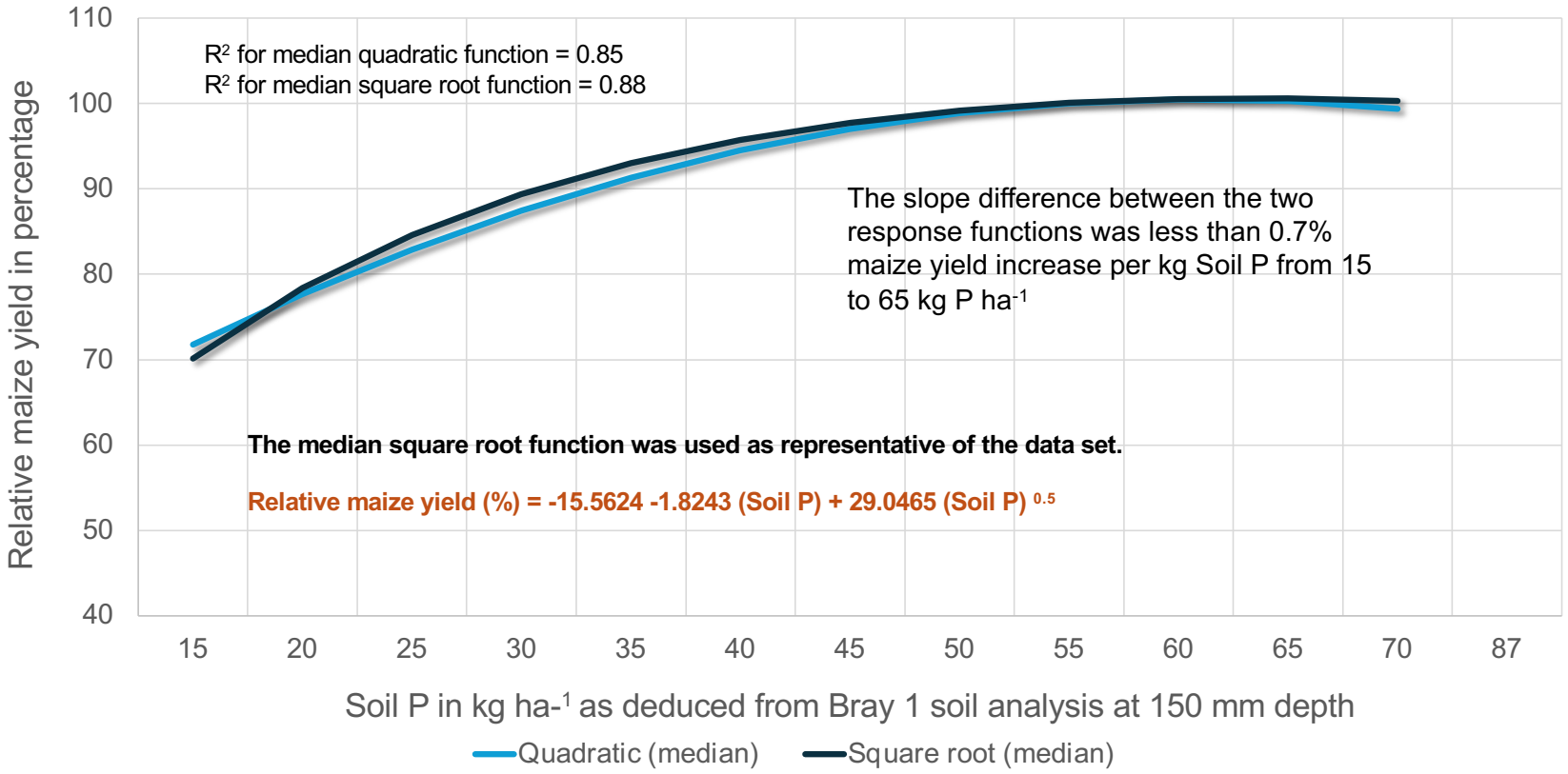


Mean response functions of the eastern and western producing areas

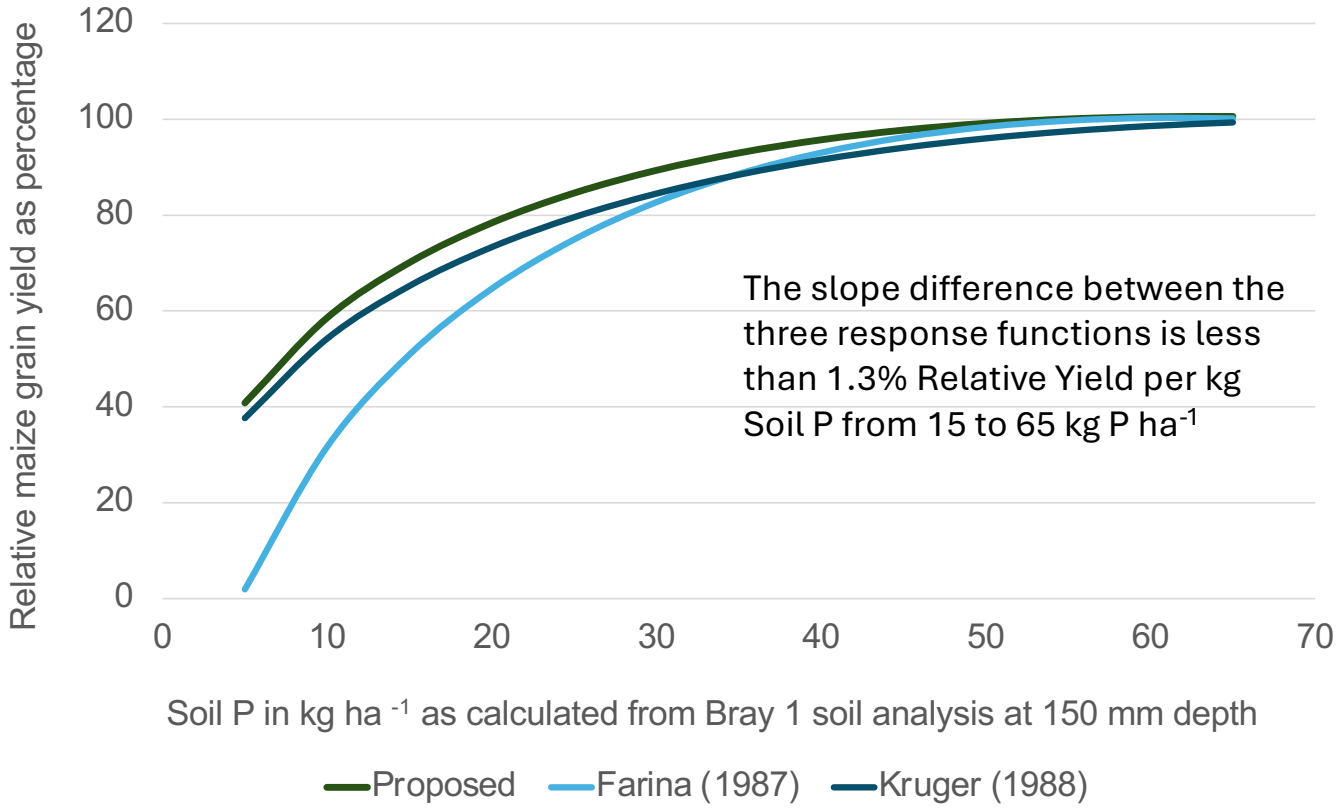


The best fit for the western response data was square root (80%) while the best fit for the eastern response data was quadratic (72%)

Median response functions of all sites



The representative function compares well with published KZN response data



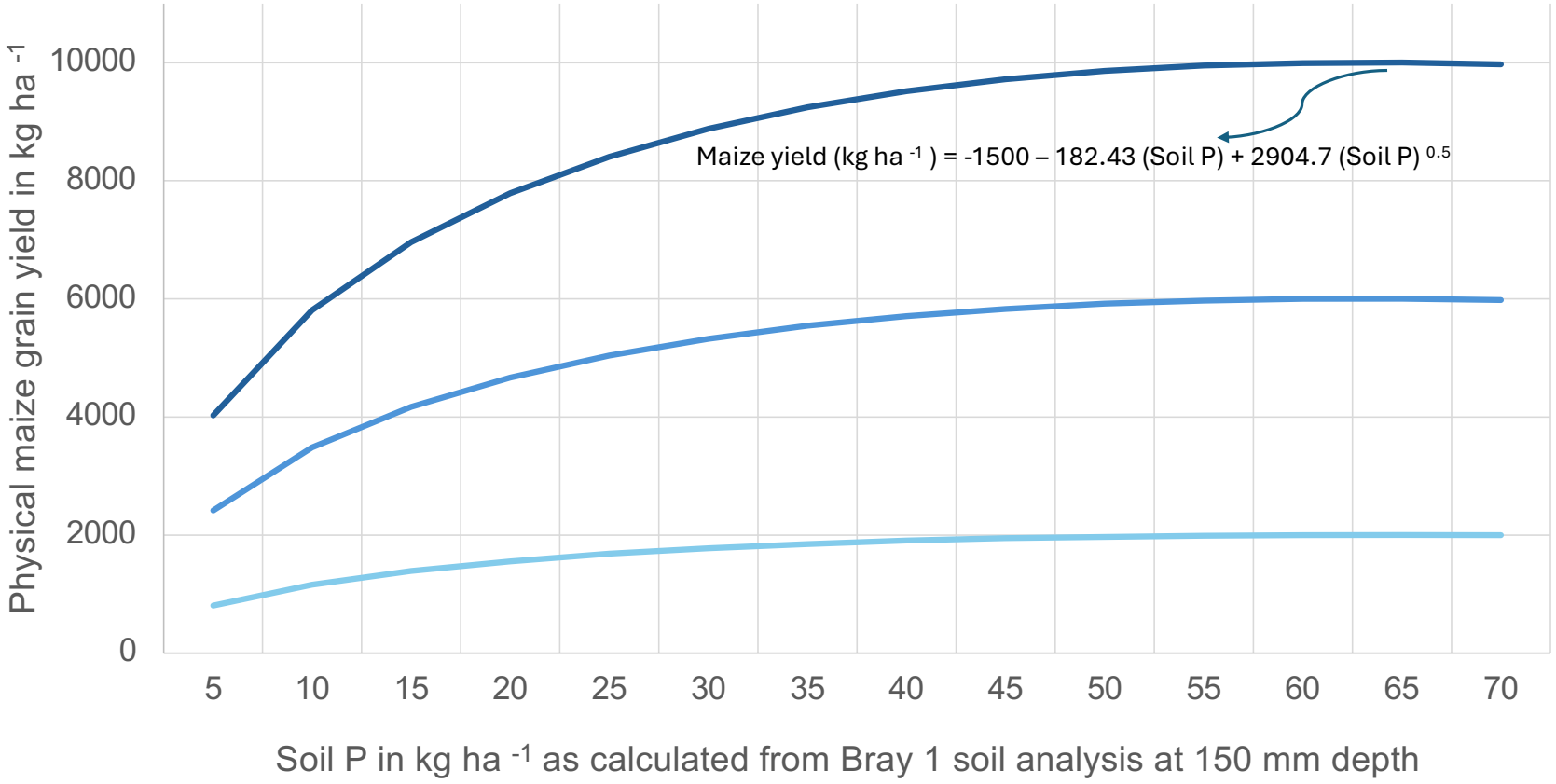
Natal trial sites are Normandien, Dundee and Greytown.

Clay percentages varied from 10%, to 61%.

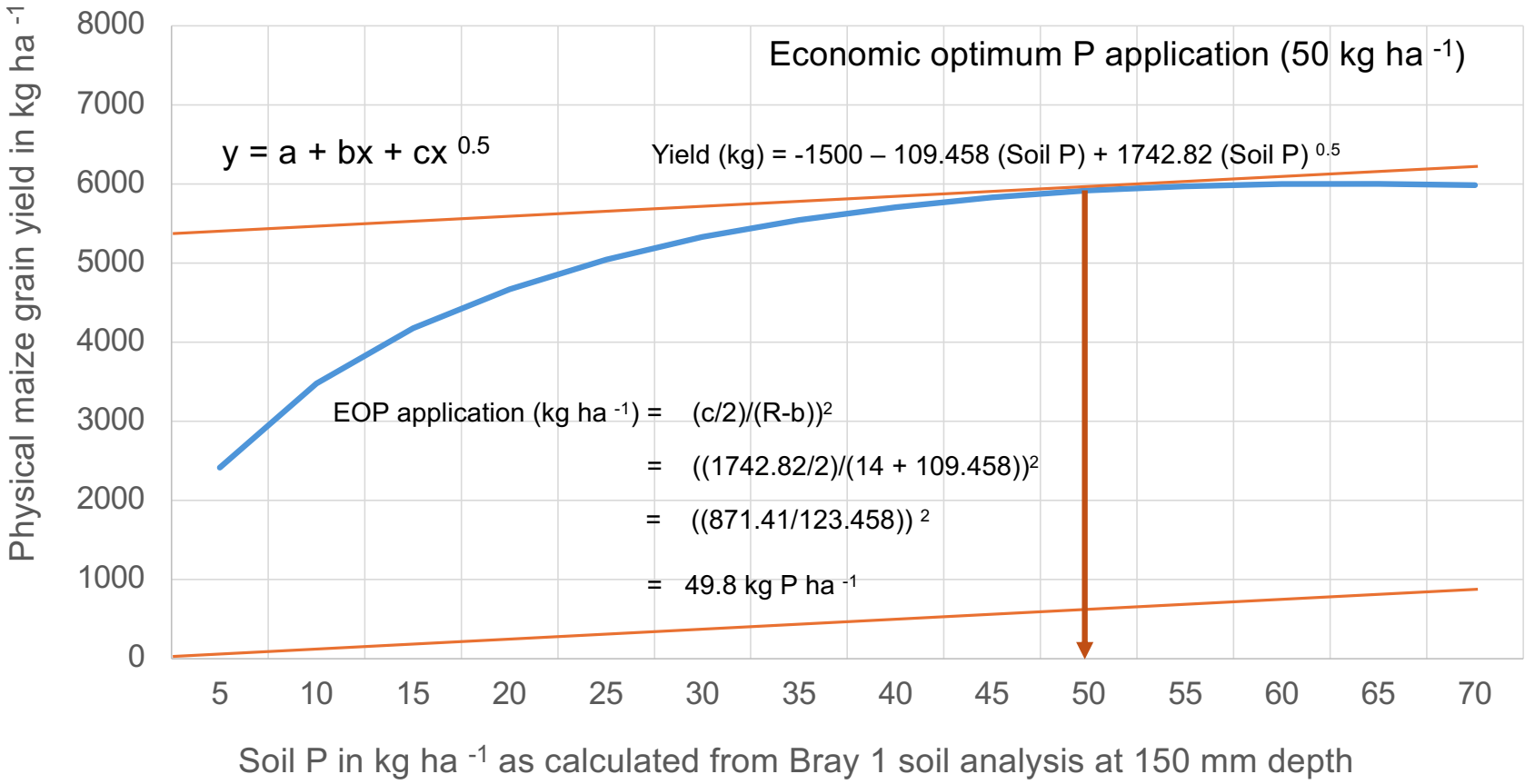
Yields varied between 3 and 7.5 t ha $^{-1}$

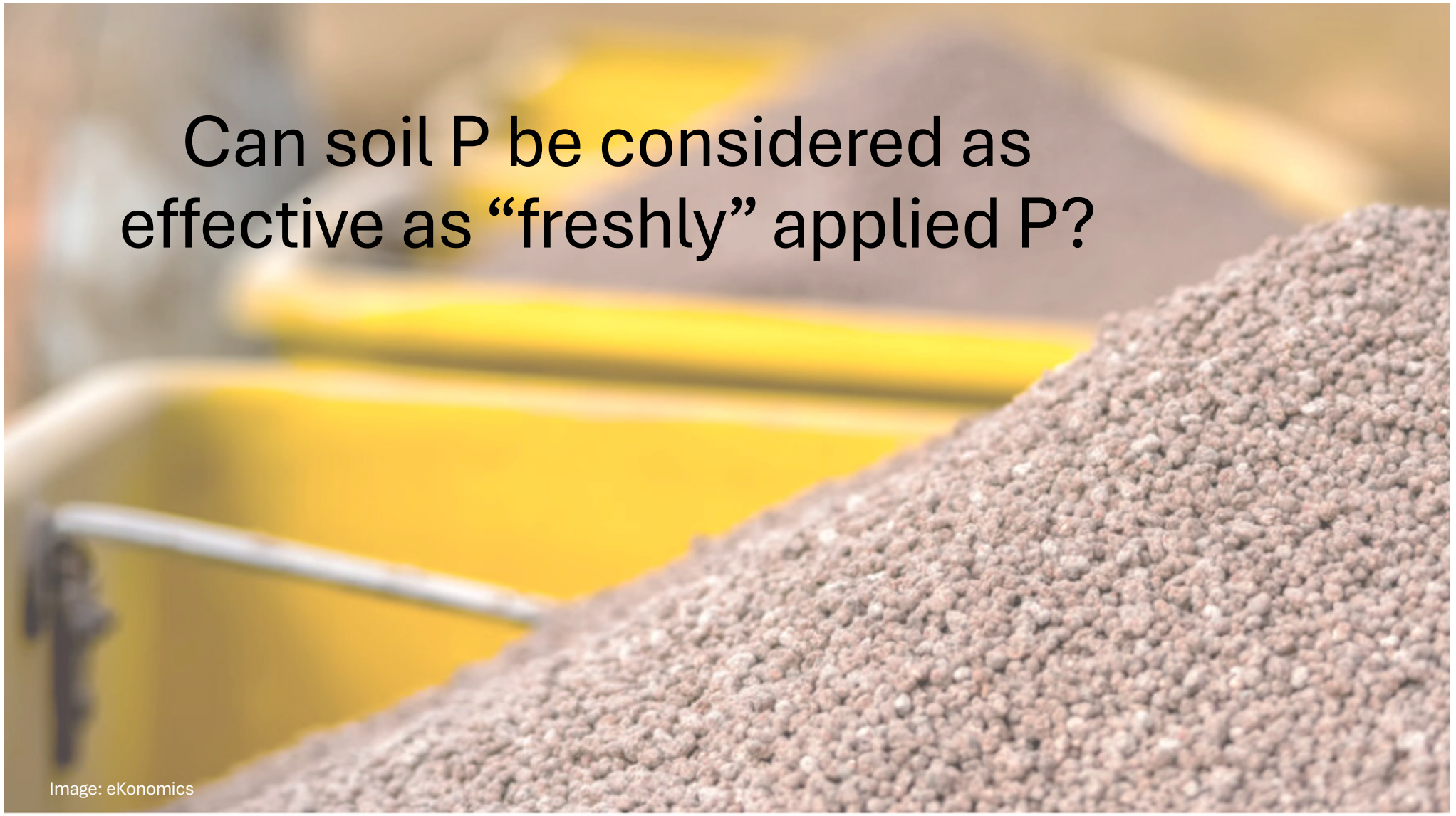
Five site years of data were used

It is possible to calculate production functions for different physical yield levels from the representative relative yield response function



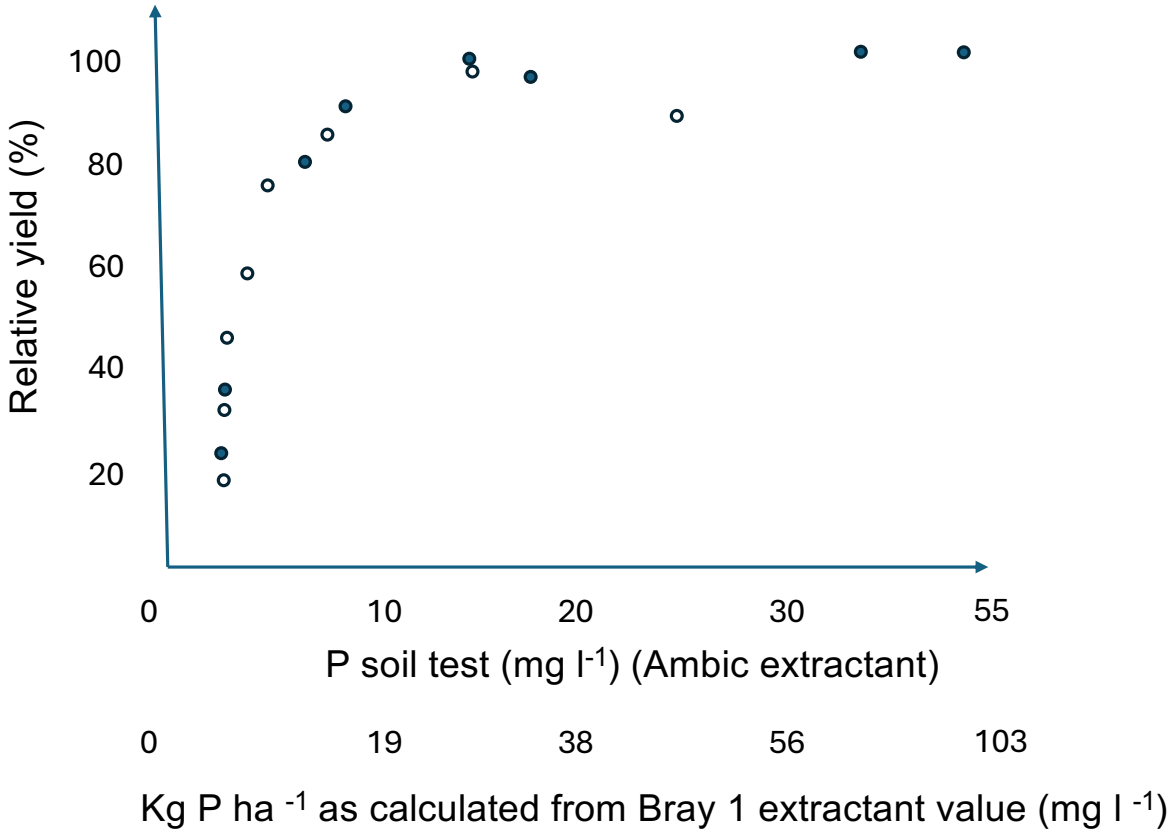
Example calculation; using the 6t ha $^{-1}$ production function and a price ratio of 14




Can soil P be considered as effective as “freshly” applied P?
Image: eKonomics

Response of maize to residual and “fresh” P

Redrawn from the publication of Farina & Channon, 1987.



Normandien clay loam (Plinthic Paleudult) near Newcastle, Natal. The topsoil is 48% clay, 17% silt and 35% sand and contains 1,76% organic C as determined by the Walkley-Black procedure (Allison, 1965). According to the standard suggested by Sanchez & Uehara (1980) it would be **described as having a high P-flxing capacity.**

Relationship between relative maize yield and Ambic soil P over two seasons.

Solid symbols are for fresh P and **open symbols for residual P**.

Each point represents the mean of 16 subplots.

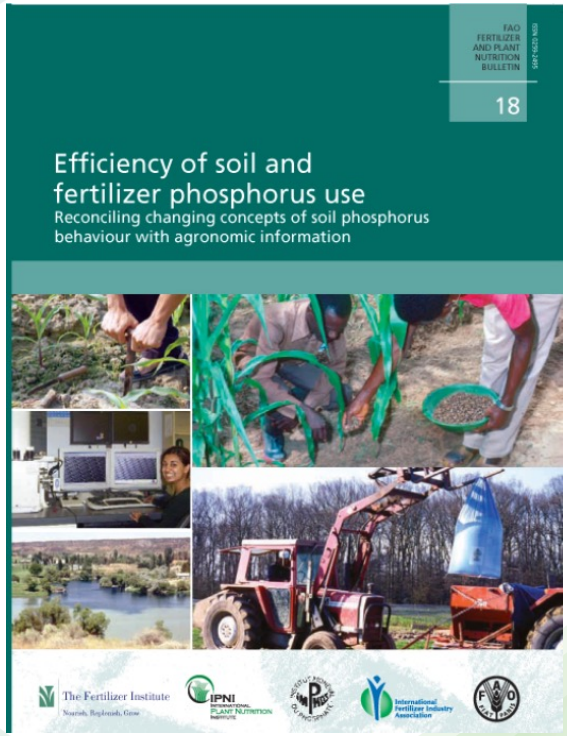
Conclusion from a paper of Farina and Channon, 1987

“The relationship between yield and soil test was identical for residual P subplots and those which received annual applications of fertilizer P”.

Farina, M.P.W., and Channon, P., 1987. Season and phosphorus age effects on the relationship between maize yield and phosphorus soil test on a highly weathered soil. S. Afr. J. Plant Soil 1987, 4(1)

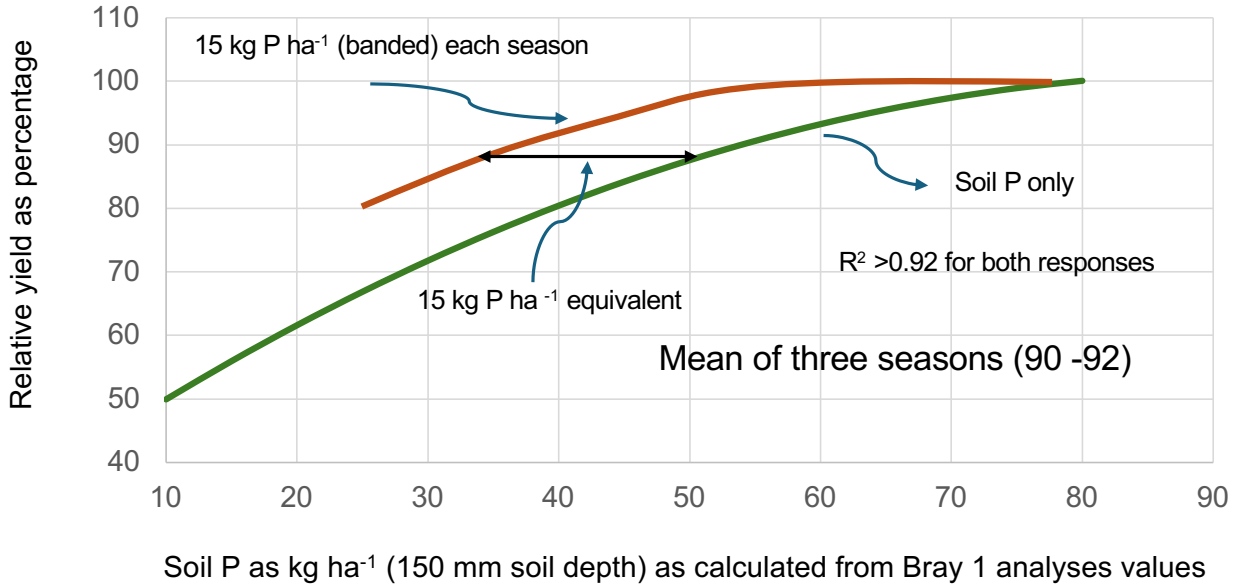
Reliable soil extractants may “define” or indeed *quantify* readily available soil P

Routine soil tests measure P that is in the soil solution and in the readily plant available soil pool. Provided that there is a strong relationship between the amount of P extracted and the response of a crop to an application of P fertilizer, then this fraction of soil P can be thought of as being reasonably well defined (*Syers, Johnston and Curtin, 2008)



*Syers, J.K., Johnston, A.E. & Curtin, D. 2008. Efficiency of soil and fertilizer phosphorus use. FAO fertilizer and plant nutrition bulletin no 18. 110 pages

Freshly applied P have the same efficiency as soil P. Argent, Eastern Highveld (Clay – 12%)



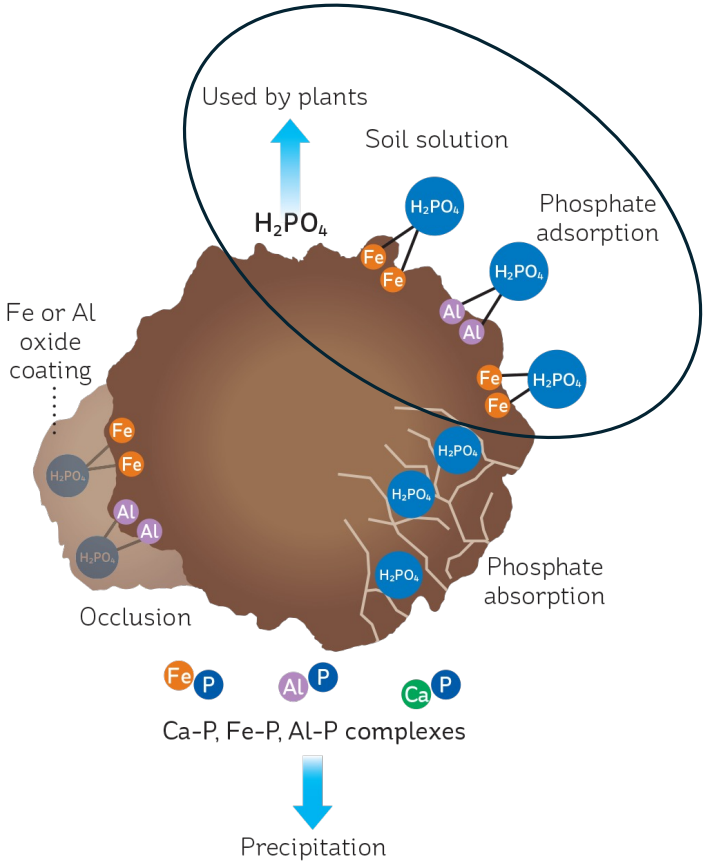
Data from AECI Agronomy Research Project reports M/2/90/N (12 seasons)
Bornman, 1991 a, b, c, d.

If it is accepted that;

1. readily available soil P has the same value as applied P

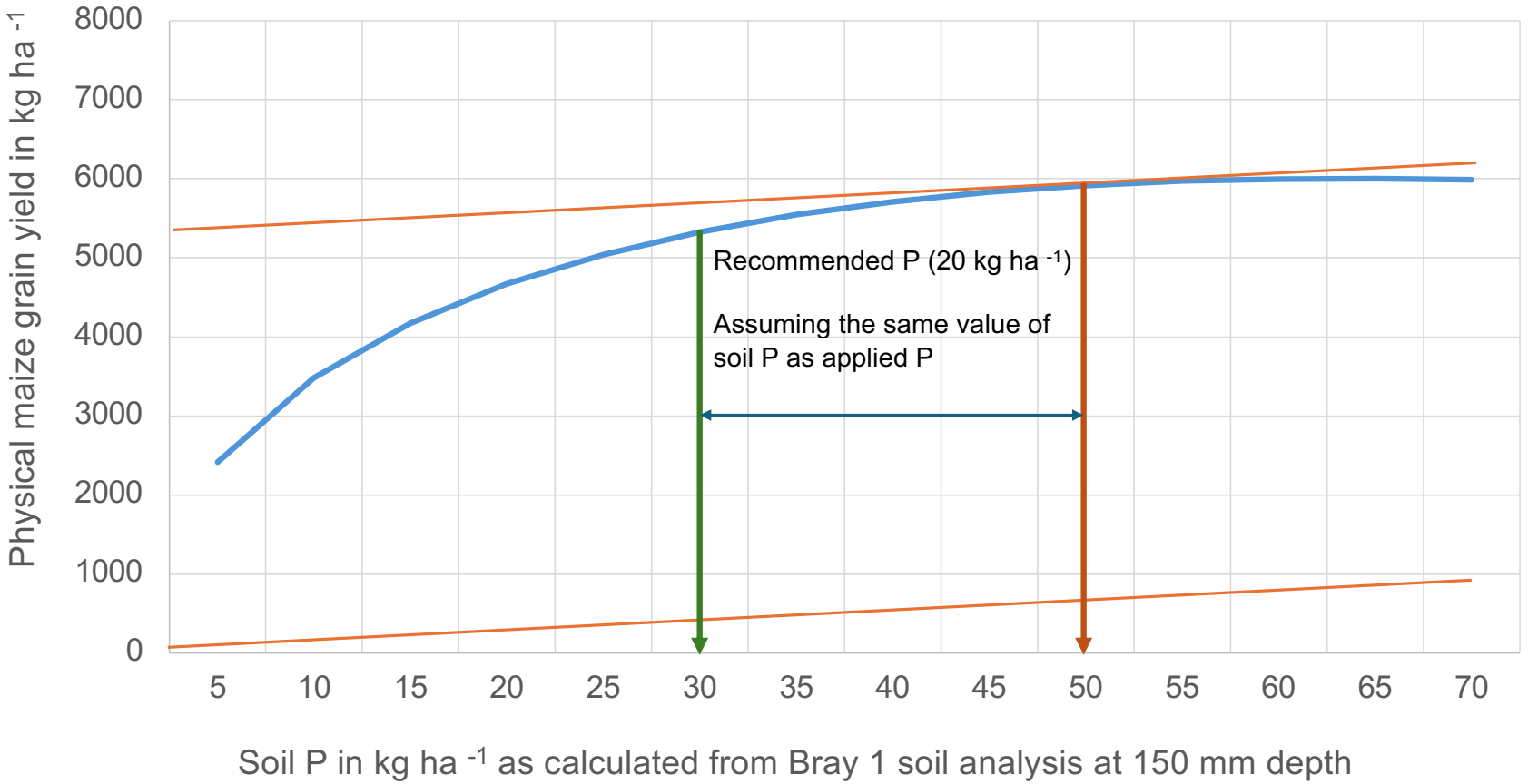
2. and it has the same efficiency as freshly applied P,

Then the calculation on the following slide may be made….



https://ballance.co.nz/advice/phosphorus/availability-in-soil

Example calculation; using the 6 t ha $^{-1}$ production function and a price ratio of 14, with 30 kg ha $^{-1}$ inherent soil P present



The data set and methodology



Guideline from the proposed, dynamic, economically based, model with a price ratio of 14

	Soil phosphorus level (kg ha^{-1}) as calculated from Bray 1 analysis (soil depth 150 mm)						
Maize yield ton ha^{-1}	5	15	25	35	45	55	65
2	33	18	8	*	*	*	*
4	45	30	20	10	*	*	*
6	50	35	25	15	5	*	*
8	53	38	28	18	8	*	*
10	55	40	30	20	10	*	*
12	56	41	31	21	11	1	*

* Theoretically zero P would be recommended from the model, but a minimum quantity would always be recommended to be band placed as financial circumstance dictates e.g. a “Pop Up” or “Starter”

Deviation from the FERTASA 2016 guideline (average over different soil densities)

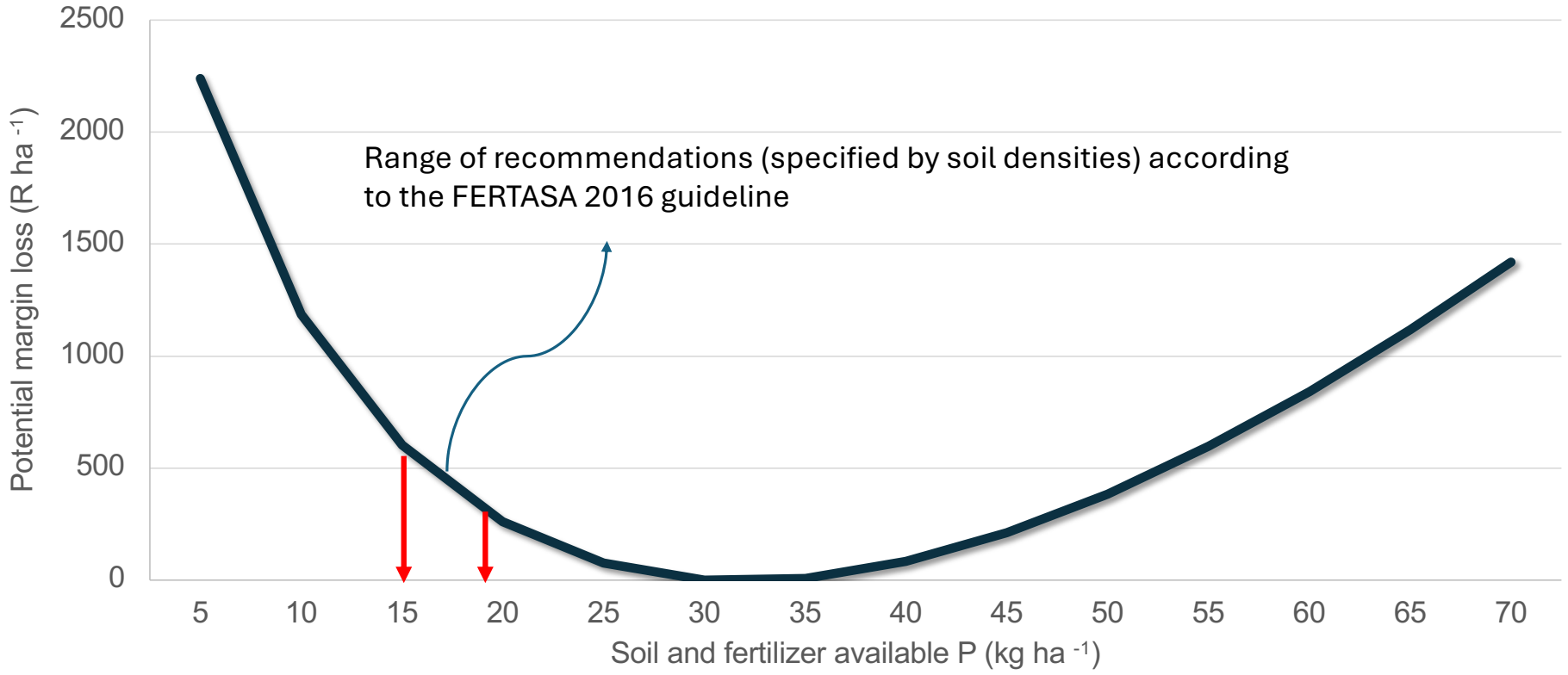
With a price ratio of 14

Fertilizer Handbook Table 5.4.4.6 page 314-315

	Soil phosphorus level (kg ha^{-1}) as calculated from Bray 1 analysis (soil depth 150 mm)						
Maize yield ton ha^{-1}	5	15	25	35	45	55	65
2	14	1	-6	-12	-10	-10	-9
4	18	10	-3	-11	-18	-18	-17
6	15	2	-6	-13	-21	-26	-25
8	10	-3	-11	-18	-26	-34	-33
10	4	-9	-17	-25	-32	-42	-41
12	-3	-16	-23	-31	-39	-49	-49

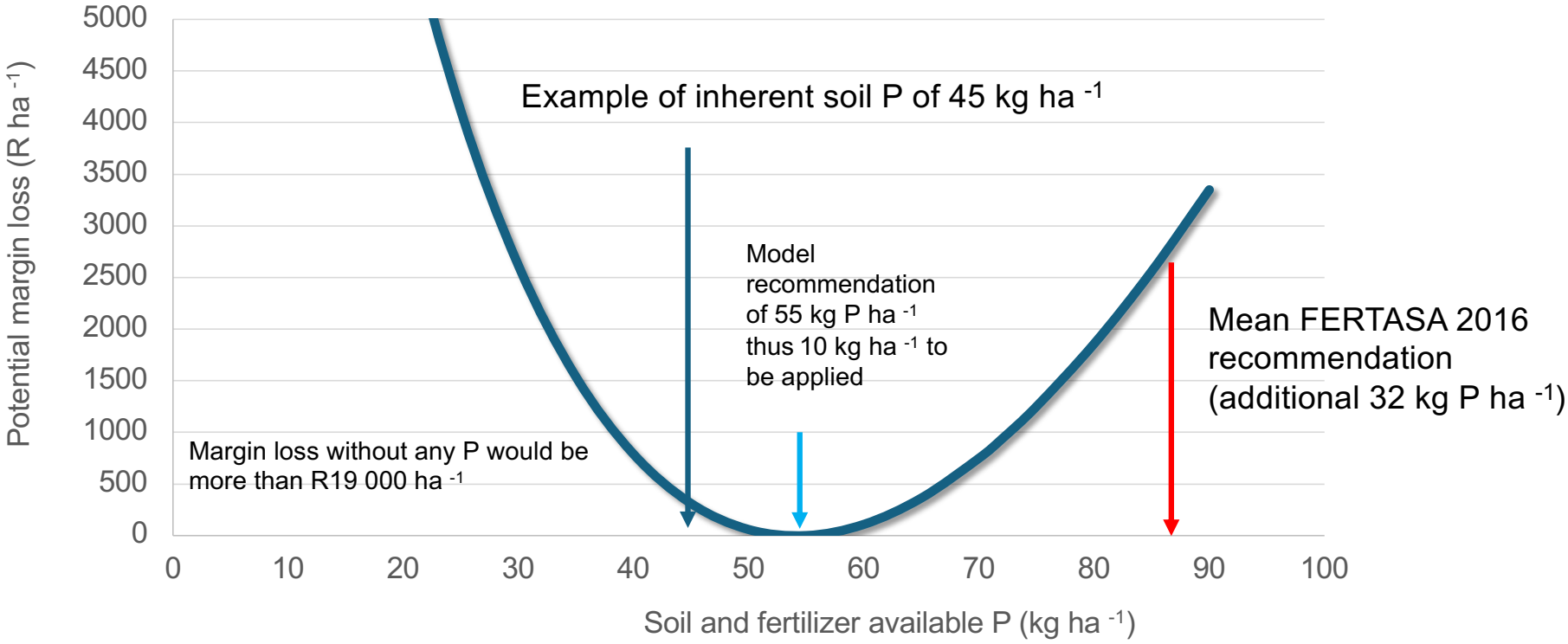
Potential margin loss according to the proposed model for a yield of 2t ha^{-1} and a price ratio of 14.

5 kg ha^{-1} soil P available



Potential margin loss according to the proposed model for a yield of 10t ha^{-1} and a price ratio of 14

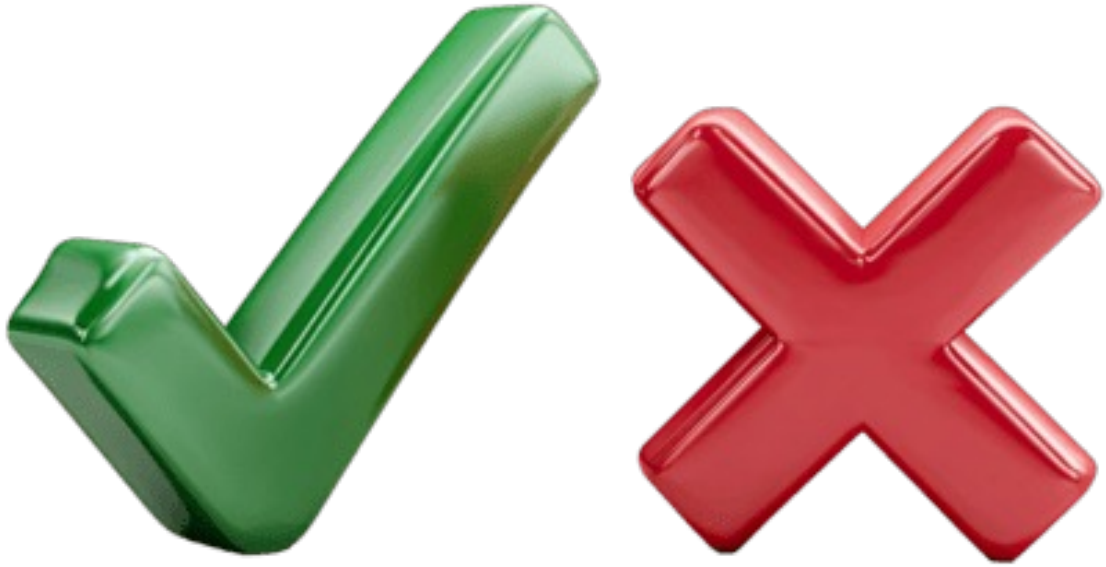
45 kg ha^{-1} soil P available



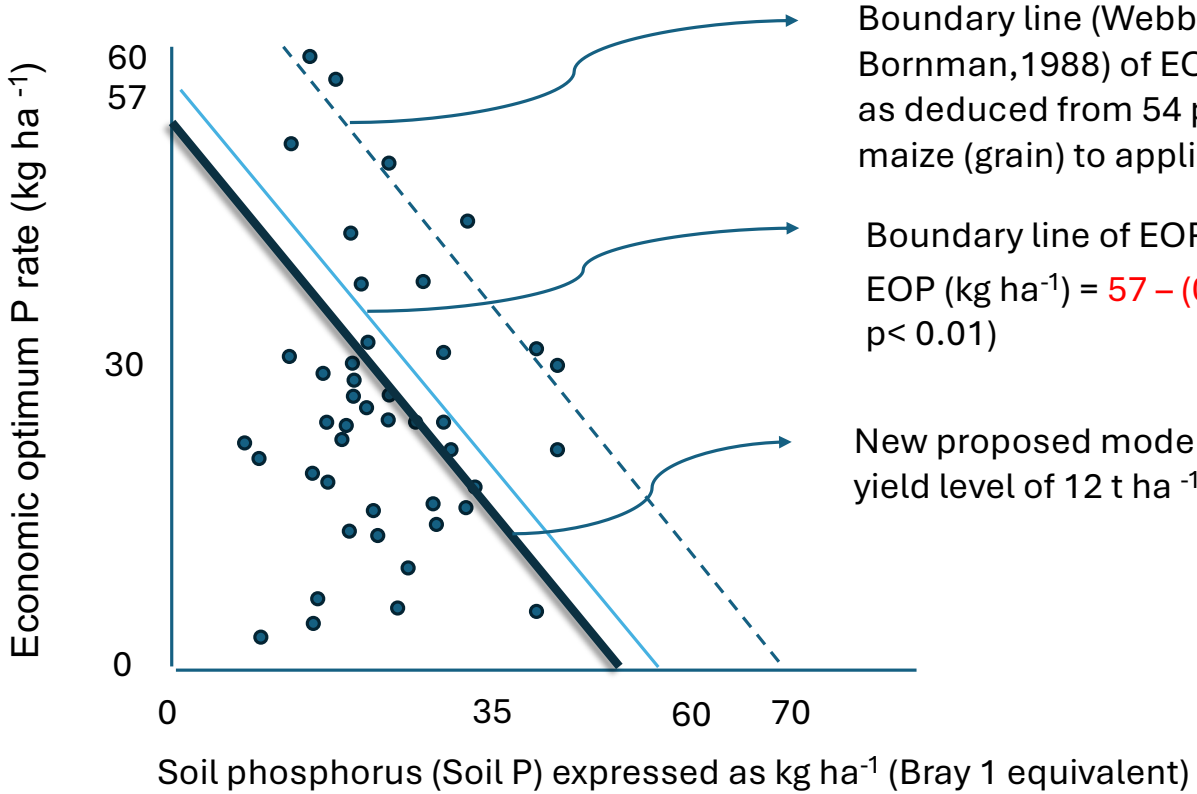
The data set and methodology



Cross checks



Taken from a paper by Bornman, J.J & Venter, G.C.H., 1988. Application of different techniques in the evaluation of P response data in maize. Proceedings Phosphorus Symposium by FSSA, Pretoria. 195-197.



Boundary line (Webb,1972, Sumner, 1987, Bornman,1988) of EOP (at a price ratio of 8.5 as deduced from 54 production functions of maize (grain) to applied P (banded).

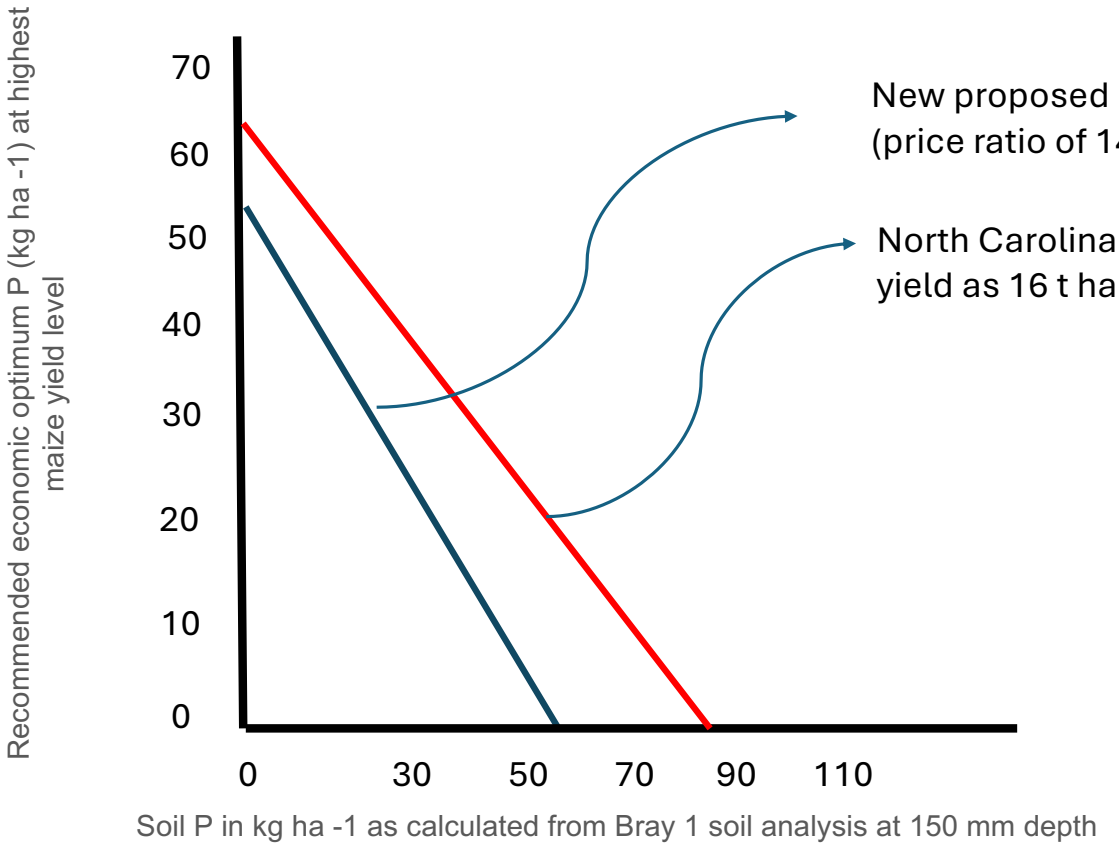
Boundary line of EOP (at a price ratio of 12)

EOP (kg ha^{-1}) = 57 – (0.92 x Soil P) (R^2 = 93.6%, $p < 0.01$)

New proposed model (at a price ratio of 14 and yield level of 12 t ha^{-1}) 55 – (1.1 x Soil P)

Factorial banded NPK trials. P main effect evaluated. Over maize producing areas, except KZN. Yields varied from 2 to 9 tons of maize grain per hectare.

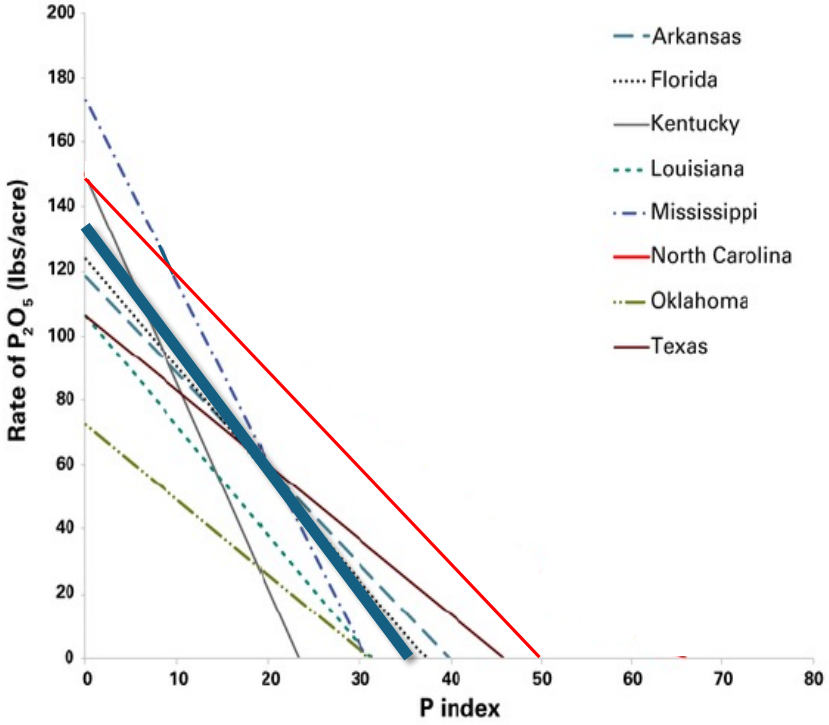
Comparison of proposed guideline with those of North Carolina university extension services following a similar economic approach



Gatiboni et al, 2021.

https://content.ces.ncsu.edu/changes-in-phosphorus-fertilizer-recommendations-for-corn-soybean-and-small-grains

Comparison of guidelines. New proposed economic optimum P guideline (line in dark blue) vs some USA (Southern States) guidelines



Gatiboni et al, 2021.

https://content.ces.ncsu.edu/changes-in-phosphorus-fertilizer-recommendations-for-corn-soybean-and-small-grains

Summary

- An economically based model was developed from currently available field response data, which could serve as a P application guideline for maize producers under financially constrained conditions.
- The model is dynamic, with reference to the price ratio used.
- It is comparable with international guidelines.
- The model could easily be adapted as more field data becomes available.



End