Fertilization Principals for Grain Production

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FERTASA Workshop

25 August 2022

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The result of fertilization inefficiency and poor management practices

- Nearly two thirds of applied nitrogen are not used by crops, and more than half of applied phosphorus is lost to the environment (Richie, 2021)

- Suggestion of phosphorus contamination of RSA waterways by agriculture (Griffin, 2017)

- Water tables in the central area of RSA are contaminated with nitrates (Beukes, 2022)

- Soil acidity, especially subsoil acidity is deteriorating at a concerning rate (Fourie & Bornman, 2015; van Zyl and Bornman, 2019)

What are the most important factors affecting crop yield other than climate?

In order of importance (most likely response to treatment and highest return on investment)

1	Drainage (soil moisture & stresses)
2	Crop Variety (disease resistance, root systems, ability to adapt to extreme conditions)
3	Insect/weed problems (nematodes, etc.)
4	Crop rotation (synergistic effect)
5	Tillage (type, timing, wet/dry soil)
6	Compaction
7	**pH (liming) (extreme pH variability (<5.5, >7.3))**
8	Herbicides (misapplication and drift)
9	Subsoil condition (acid or alkaline subsoil, clay layer, etc.)
10	**Fertility placement (ridge-till, no-till, etc.)**
11	**Fertility**
12	Plant population (most fields have a narrow optimum population)

Mark Flock also stated, "This is dynamic, not a static listing."

Flock, 1997

Fertilization principles

Some documents accessed relating to fertilization principles (excluding 4R primary documents)

- Below, F. 2018 The seven wonders of the corn yield world. Internet publication of the Crop Physiology Laboratory at the University of Illinois.
- Bornman J.J., 1989. Bemestingsbeplanning van mielies. Fertilizer Society of South Africa document.
- Botha, L. 2019. Fertilisation: Principals that each farmer should know. Farmers Weekly July. Interviews with Dr Hugo Opperman and Dr Pieter Haumann. Internet accessed 2022.
- Boychyn, J., 2021. Fertilizer planning considerations. Alberta Wheat and Barley internet site. December. Accessed July 2022.
- Hochmuth, G. & Hanlon, E. 2022. Principals of sound fertilizer recommendations. University of Florida Extension. Publication SS527. Internet accessed July 2022.
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- Hoeft, R.G., Nafzinger, E.D., Johnson, R.R. & Aldrich, S.R. 2000. Modern corn and soybean production First edition. MCSP publications. Champaign, Illinois.
- Indrajit, 2022. Twelve main principles for applying fertilizer to soil. Soil management India internet site. Document 1425. Internet accessed August 2022.
- Macnack, N., Chim, B.K., Amedy, B. & Arnall, B. 1914. Fertilization based on sufficiency, build-up and maintenance concept. Oklahoma Cooperative Extension Service. Oklahoma University. Document PSS-2266. Internet accessed August 2022.
- Mosaic Agrisight internet article. 2021. Four considerations to maximize fertilizer inputs. Issue 20. Internet accessed August 2022.
- Singh, A.K., 2021. Fertilizer recommendation approaches/nutrient management approaches. ResearchGate publication no 357866727. Internet accessed August 2022.
- Singh, P.H., Rajput, V.D., Kumar, M. & Singh, S., 2018. Principles and Methods of Fertilizer Application in Soil. International Journal of Trend in Research and Development, Volume 5(5), ISSN: 2394-9333
- Strub, et al, 2012. Basics of fertilizer management. Cornell University Cooperative extension. Fact sheet no 75. 1 page. Internet accessed August 2022.
- Van Biljon, J.J. 2019. Back to basics for the future: principles of fertilization. Fertasa Symposium. Internet accessed July 2022.
- Yost, R.S., Tamimi, Y.N. Silva, J.A, Hue, N.V. & Evenson, C.I. 2000.Chapter 6. How Fertilizer Recommendations Are Made in J. A. Silva and R. Uchida. Plant Nutrient Management in Hawaii’s Soils, Approaches for Tropical and Subtropical Agriculture, College of Tropical Agriculture and Human Resources, University of Hawaii at Manoa. Internet accessed August 2022.

Example from documents accessed

The Seven Wonders of the Corn Yield World
(Prof Fred Below, 2018. Dept Plant Physiology University of Illinois)
Yield target of 16.32 t ha^{-1} (260 bu $acre^{-1}$)

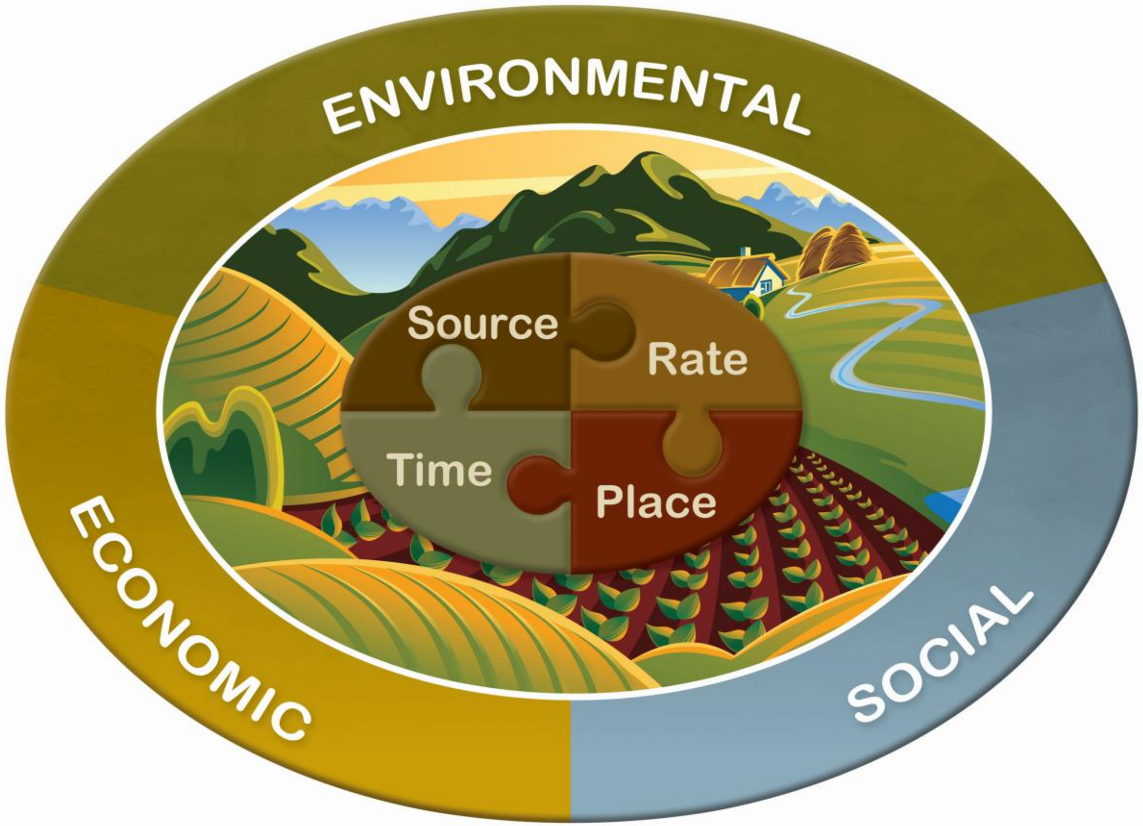
Rank	Factor	Value (contribution) as %
1	Weather	27
2	Nitrogen	26
3	Hybrid	19
4	Previous crop	10
5	Plant population	8
6	Tillage	6
7	Growth regulators	4

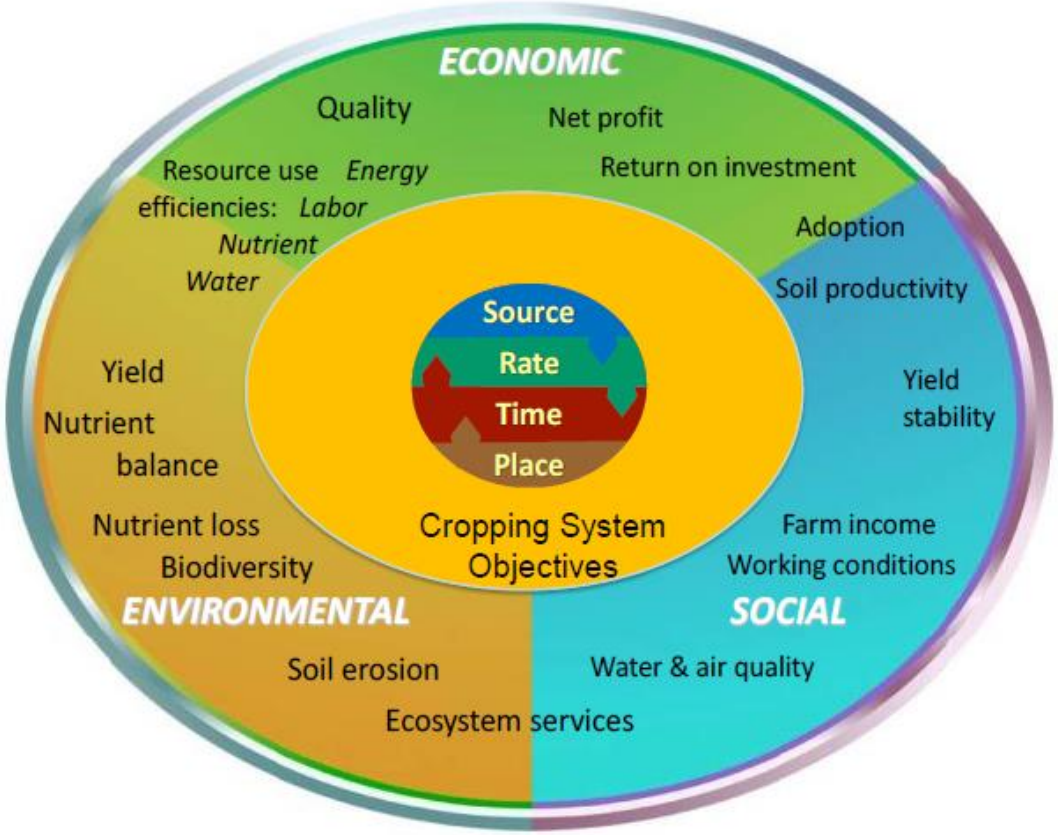
Prerequisites: Drainage, pest/weed control, adequate soil pH, P and K.
Suggests in addition – “extra P fertility” and late fungicide application.

In summary: Fertilization planning is integrated, based on a comprehensive set of site specific variables.

Integrated Plant Nutrition Management (IPNM)

The 4R concept





The objectives of the 4R approach

- Four common practical management objectives at the field or farm level are: productivity, profitability, cropping system durability and environmental health.
- System objectives vary with the region, sector and, often, over time, and they depend on the input of various stakeholders
- Need to be based on scientific principals
- The outcomes must be defined and measurable.

IFA task force document, 2009

- “The 4R path is the one most likely to harmonize profitable agronomics at the field scale with improved sustainability of the agricultural system as a whole (Bruulsema, 2019).

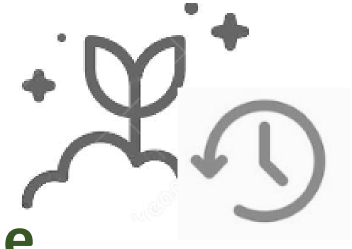
Know your Rights; 4R – in a nutshell

Source

- Consider rate, time, and place of application.
- Supply nutrients in available forms.
- Suit soil physical and chemical properties.
- Recognize synergisms among nutrient elements and sources.
- Recognize blend compatibility.
- Recognize benefits and sensitivities to associated elements.
- Control effects of non-nutritive elements.

Rate

- Assess plant nutrient demand.
- **Assess soil nutrient supply.**
- Assess all available nutrient sources.
- **Predict fertilizer use efficiency.**
- Consider soil resource impacts. – soil increase or decrease as result
- **Consider economics.**



Time

- Consider source, rate, and place of application.
- Assess timing of plant uptake.
- **Assess dynamics of soil nutrient supply.**
- Recognize dynamics of soil nutrient loss e.g. rain leaching
- Evaluate logistics of field operations.

Place

- Consider source, rate, and time of application.
- Consider where plant roots are growing.
- Consider soil chemical reactions.
- Suit the goals of the tillage system.
- Manage spatial variability.

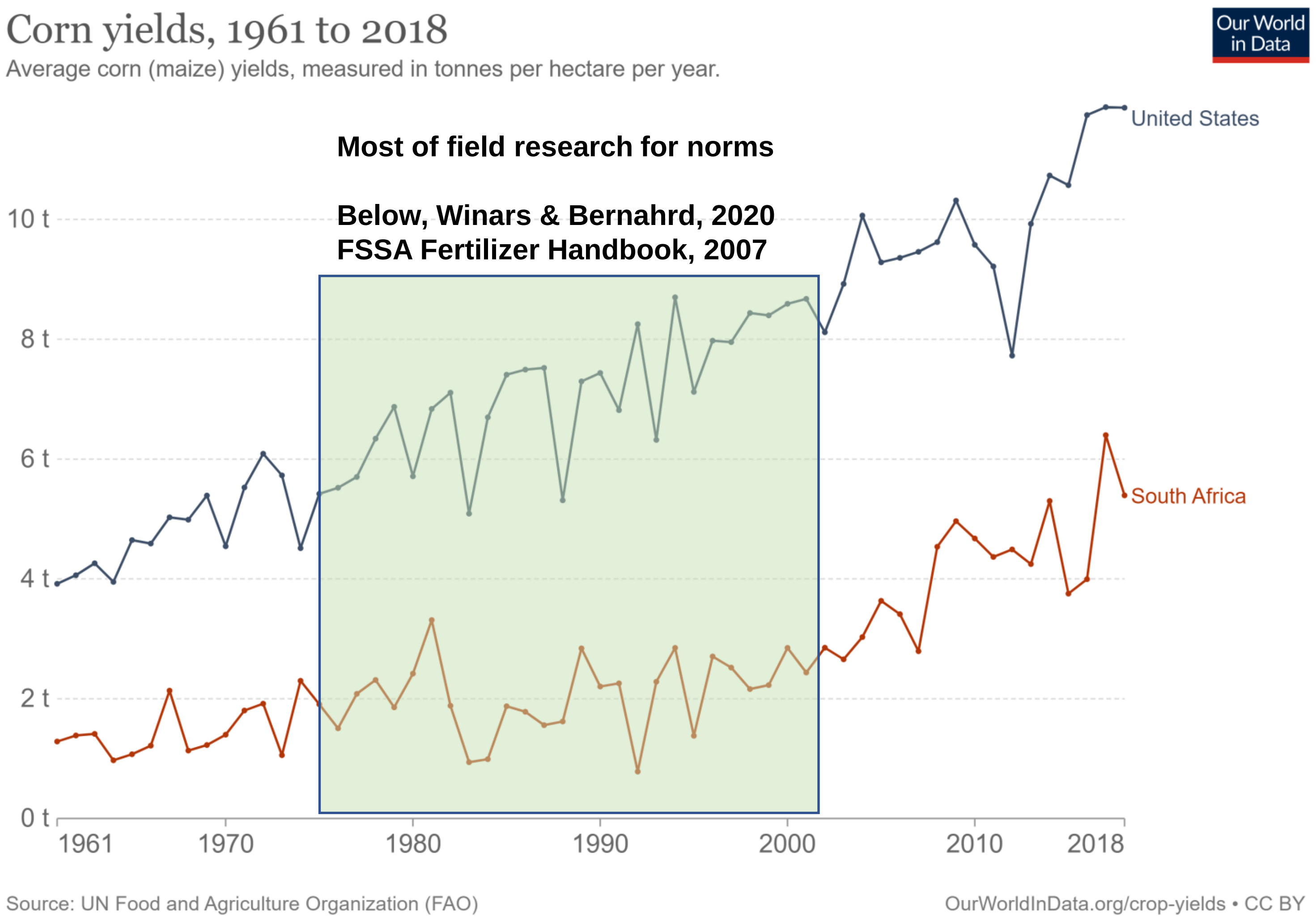
IFA task force document, 2009


Nitrogen

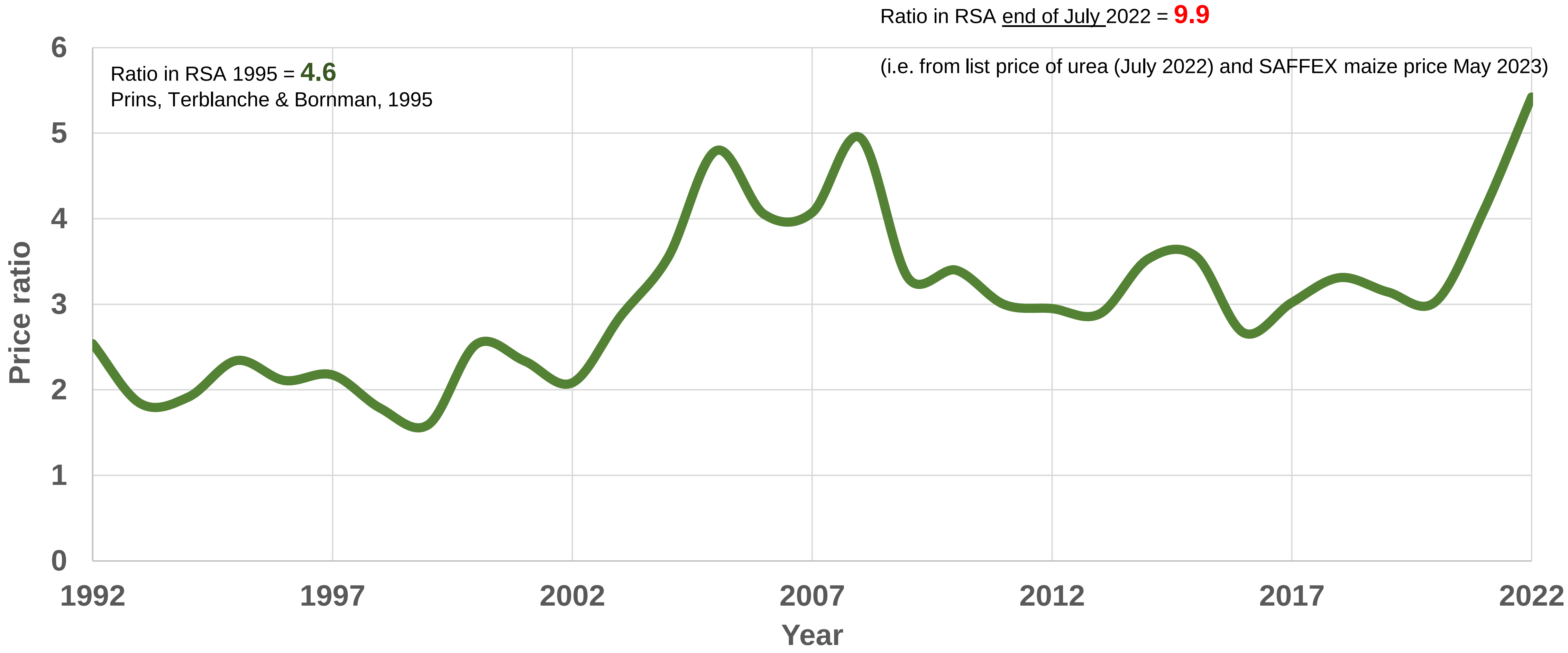
Economic considerations under current conditions
Utilizing production functions and price ratio

"A loaf of wheat bread will cost a day's pay" Rev 6:6 (NLT)

Average maize yields over time
Are the current guidelines relevant?



International price ratio of nitrogen (in urea) to maize Calculated from index mundi data



https://www.indexmundi.com/commodities/?commodity=urea&months=360&commodity=corn&indicator=price-ratio

Basic economics;
The neoclassical production function

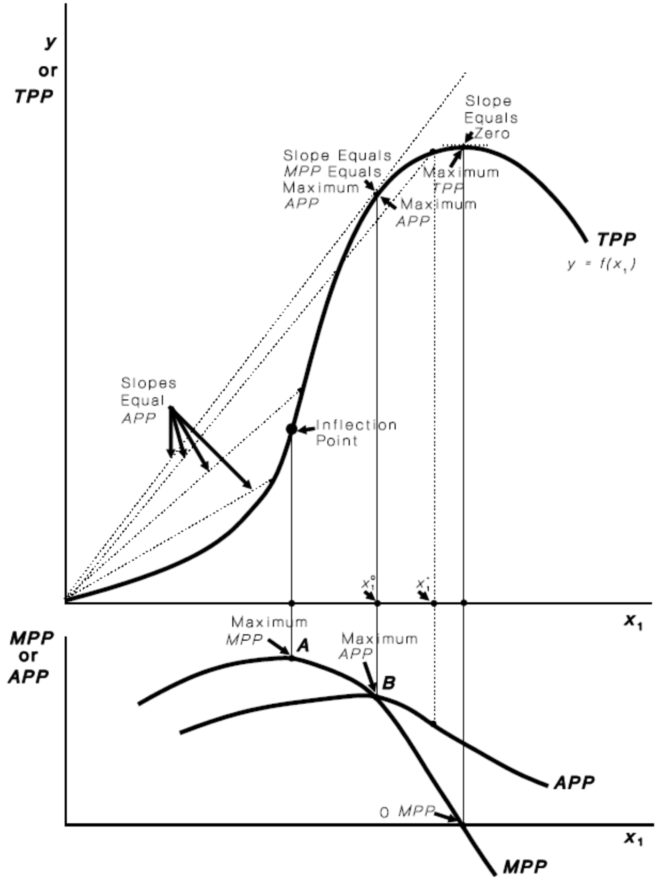


Figure 1: The neoclassical production function. Source: Debertin (2012)

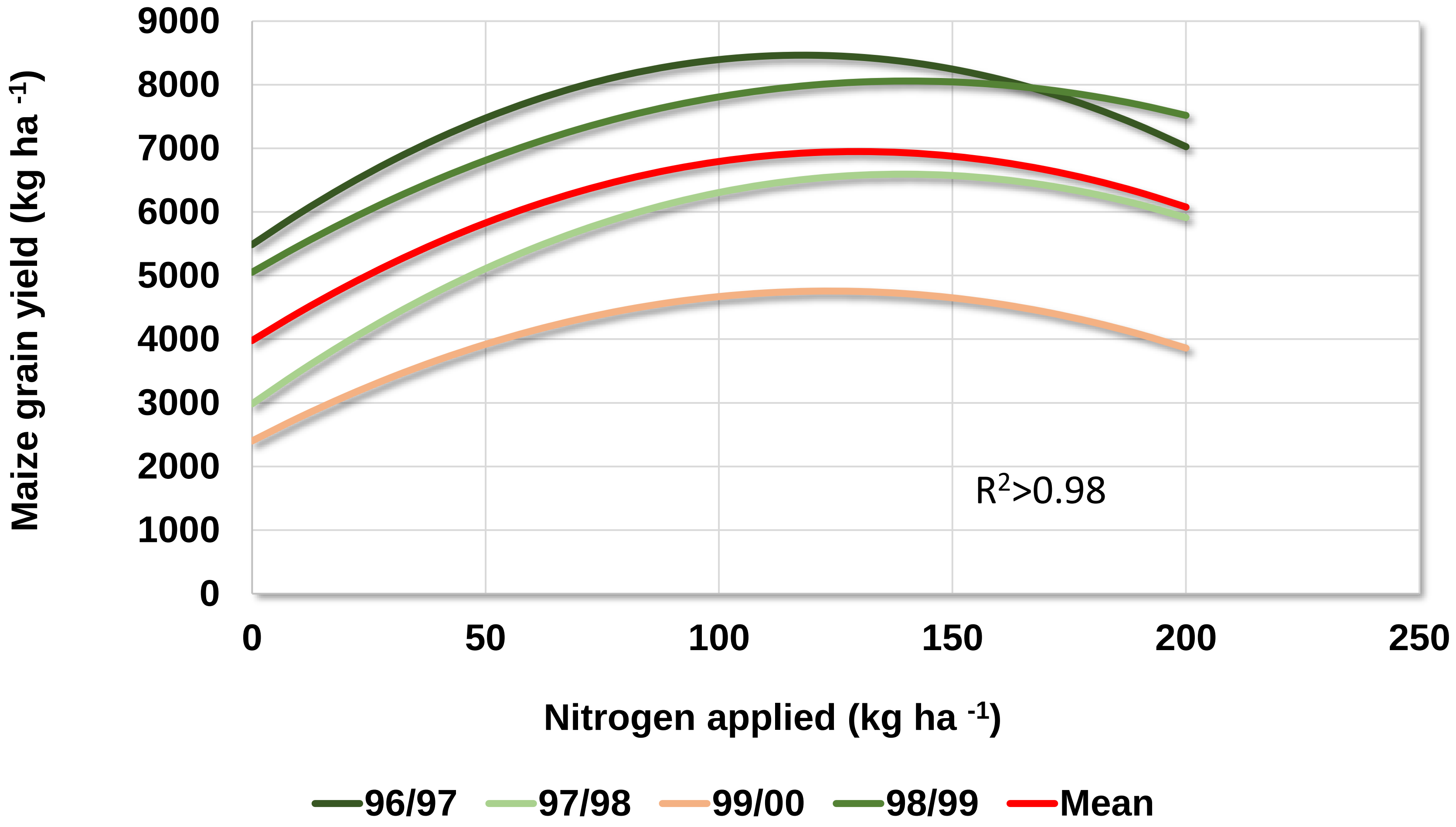
TPP: total produced product

APP: average produced product
MPP: marginal produced product

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

Sensitivity analysis: economic optimum nitrogen application (example: Response curves of maize to nitrogen – Nigel, Eastern Highveld)

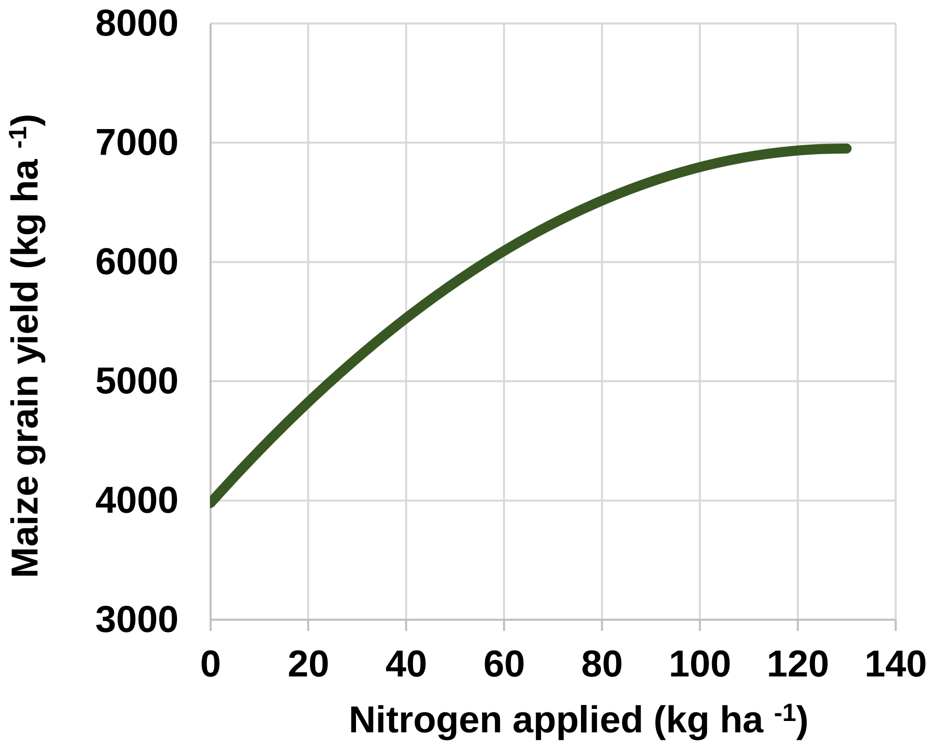
Hutton, >1.2 m depth, 24% clay

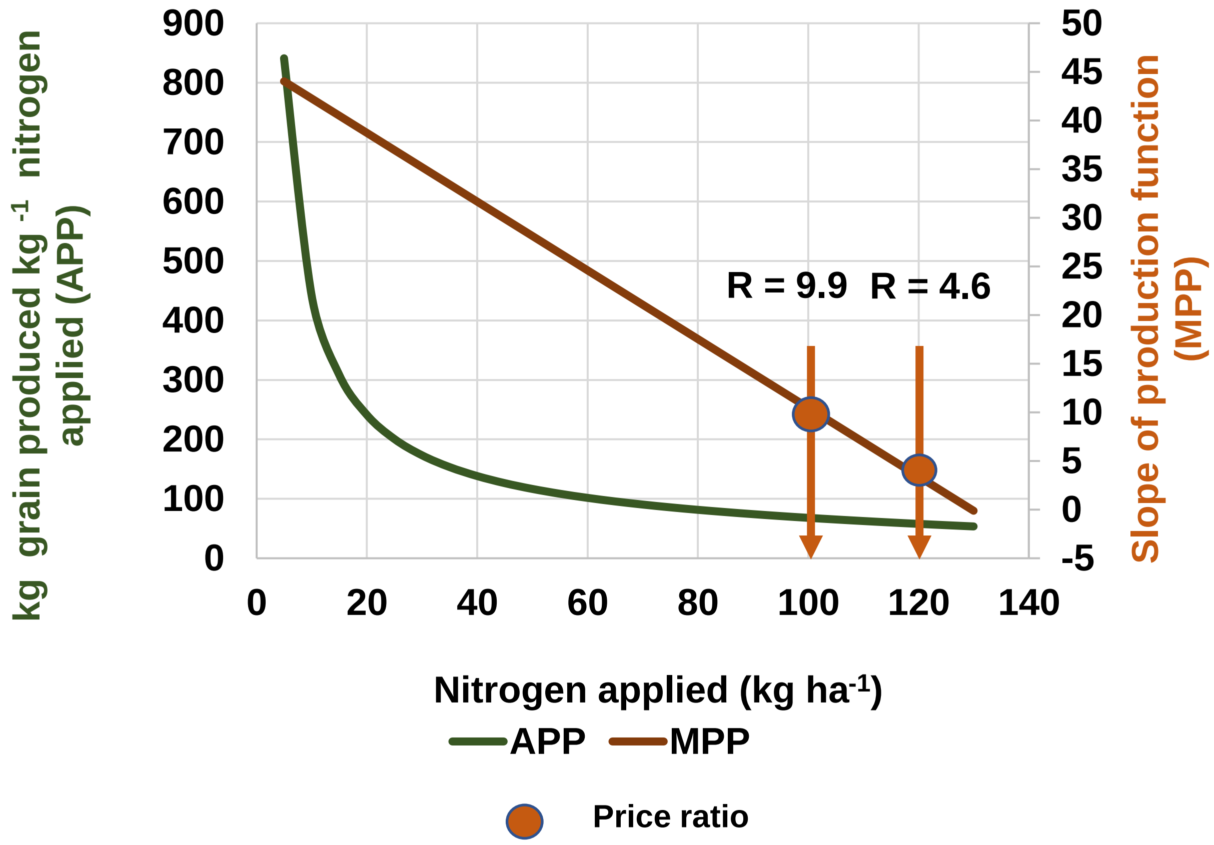


Data from AECI Agronomic Research project reports. M221/90/N

Sensitivity analysis: economic optimum nitrogen application (example: Response curve of maize to nitrogen – Nigel, Eastern Highveld

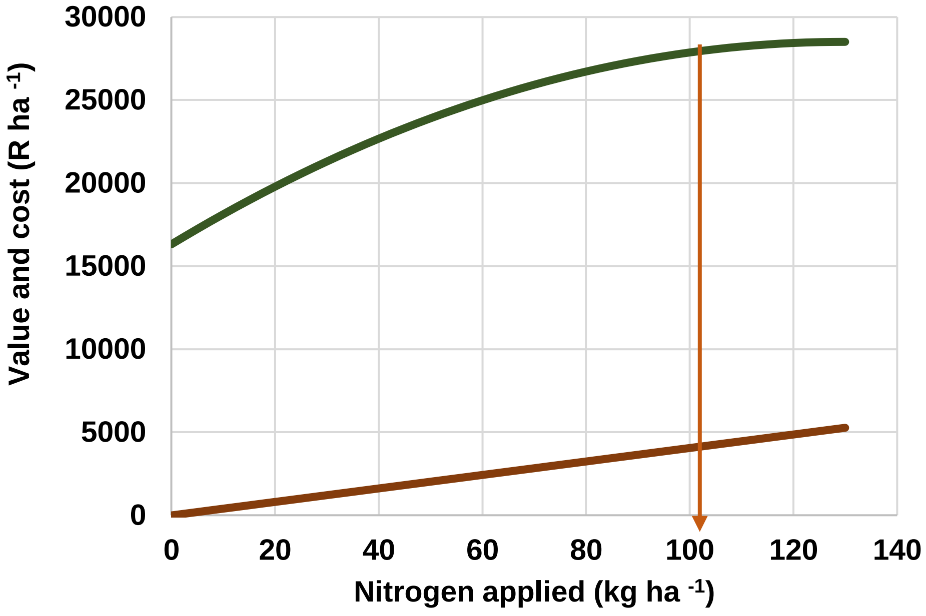
TPP, APP and MPP of mean function

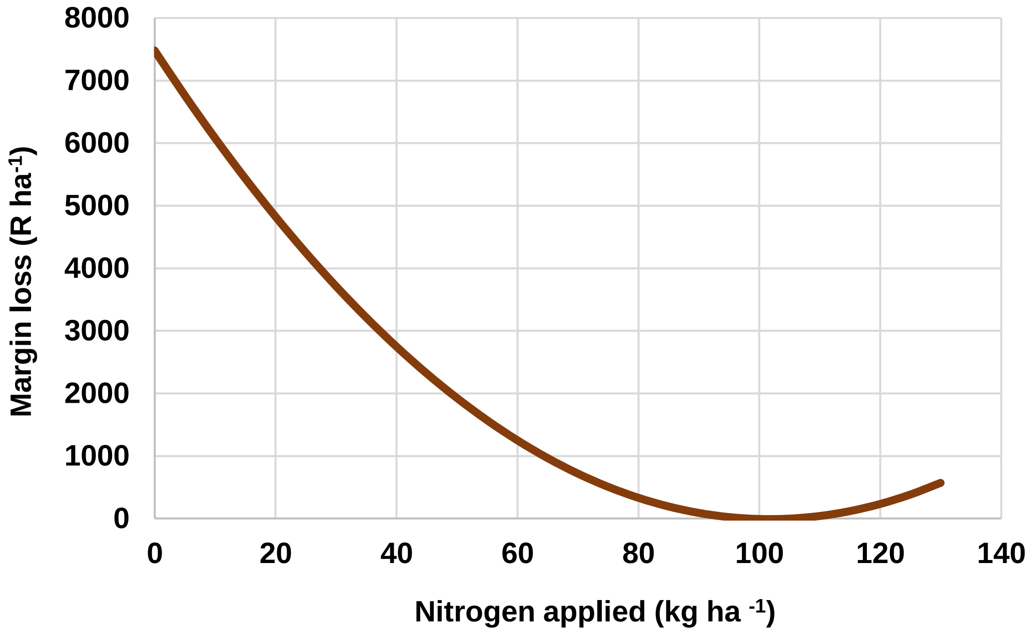




Sensitivity analysis: economic optimum nitrogen application (example: Response curve of maize to nitrogen – Nigel, Eastern Highveld)

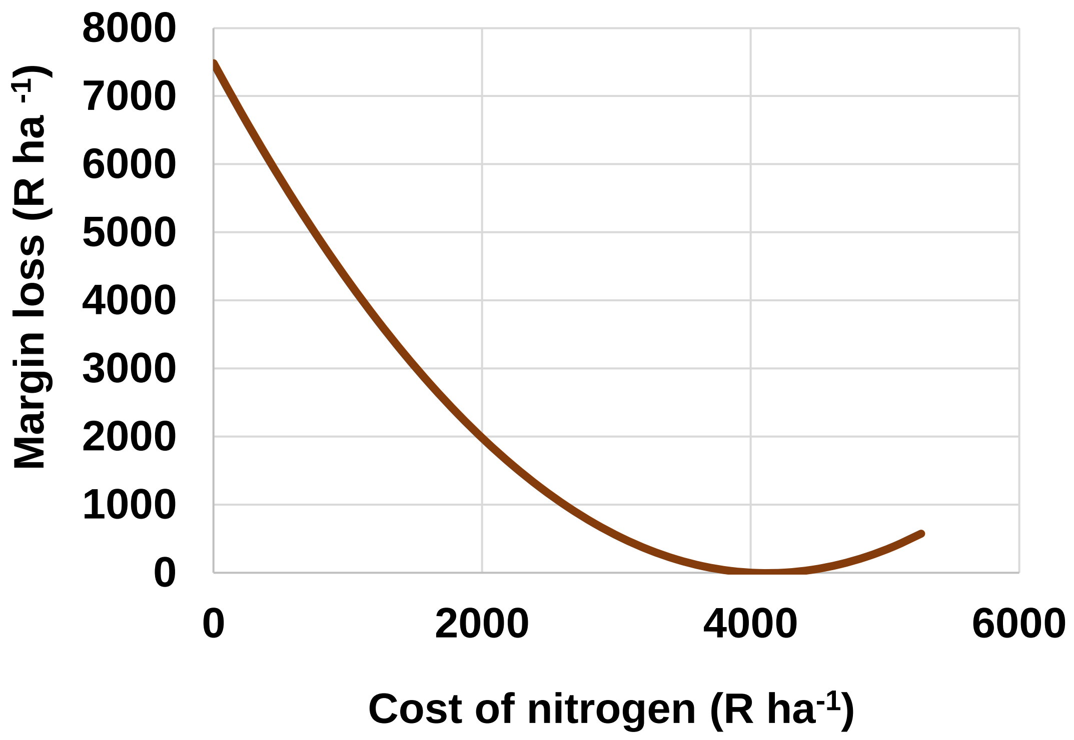
Potential margin loss curve using current price scenario

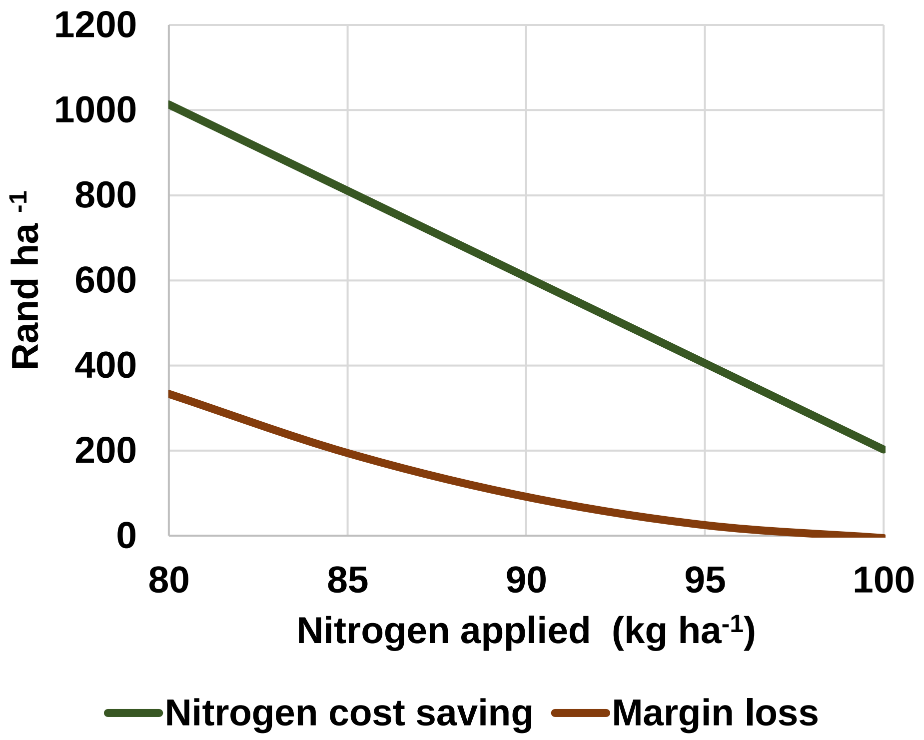




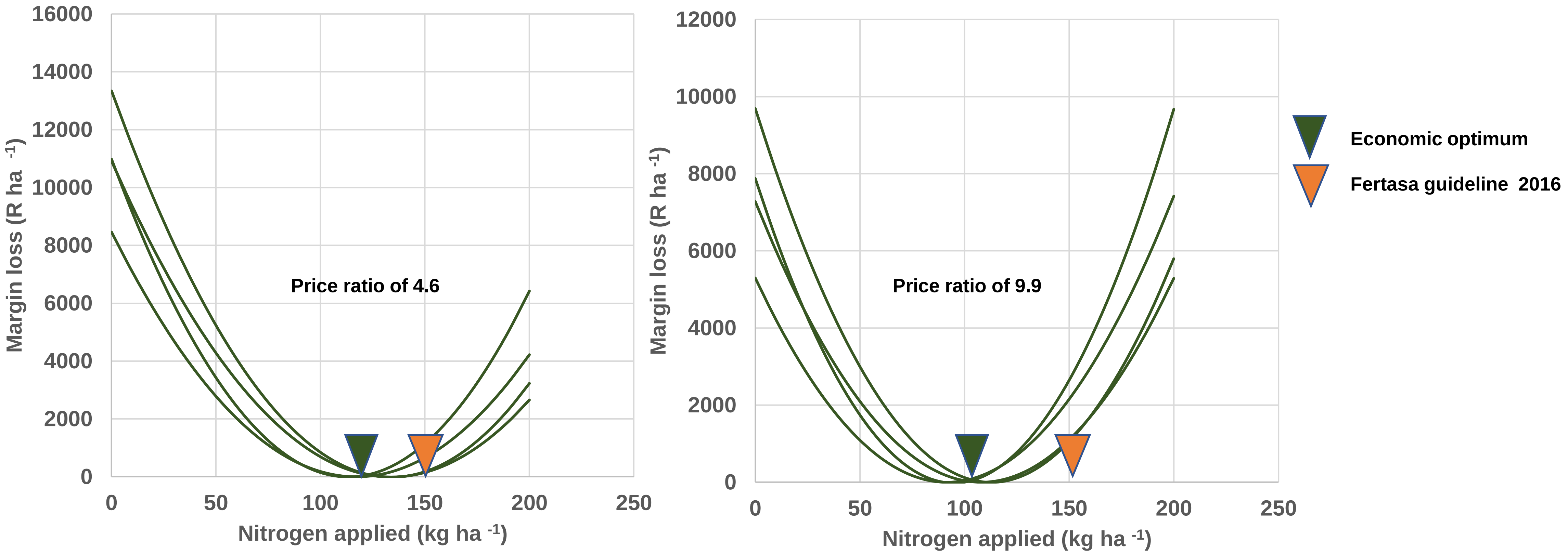
Sensitivity analysis: economic optimum nitrogen application (example: Response curve of maize to nitrogen – Nigel, Eastern Highveld)

Risk of margin loss vs nitrogen cost





Economic optimum and least risk – impact of current price ratio; (Example: Response curves of maize to nitrogen – Nigel, Eastern Highveld)



Skinner, 1986.
Bornman & Prins, 1993
Prins, Terblanche & Bornman, 1994, 1995

Herbicide carryover or too low application of banded nutrients?

e.g., Triazines

Symptoms

Gradual interveinal chlorosis. Height of plants may be highly variable.

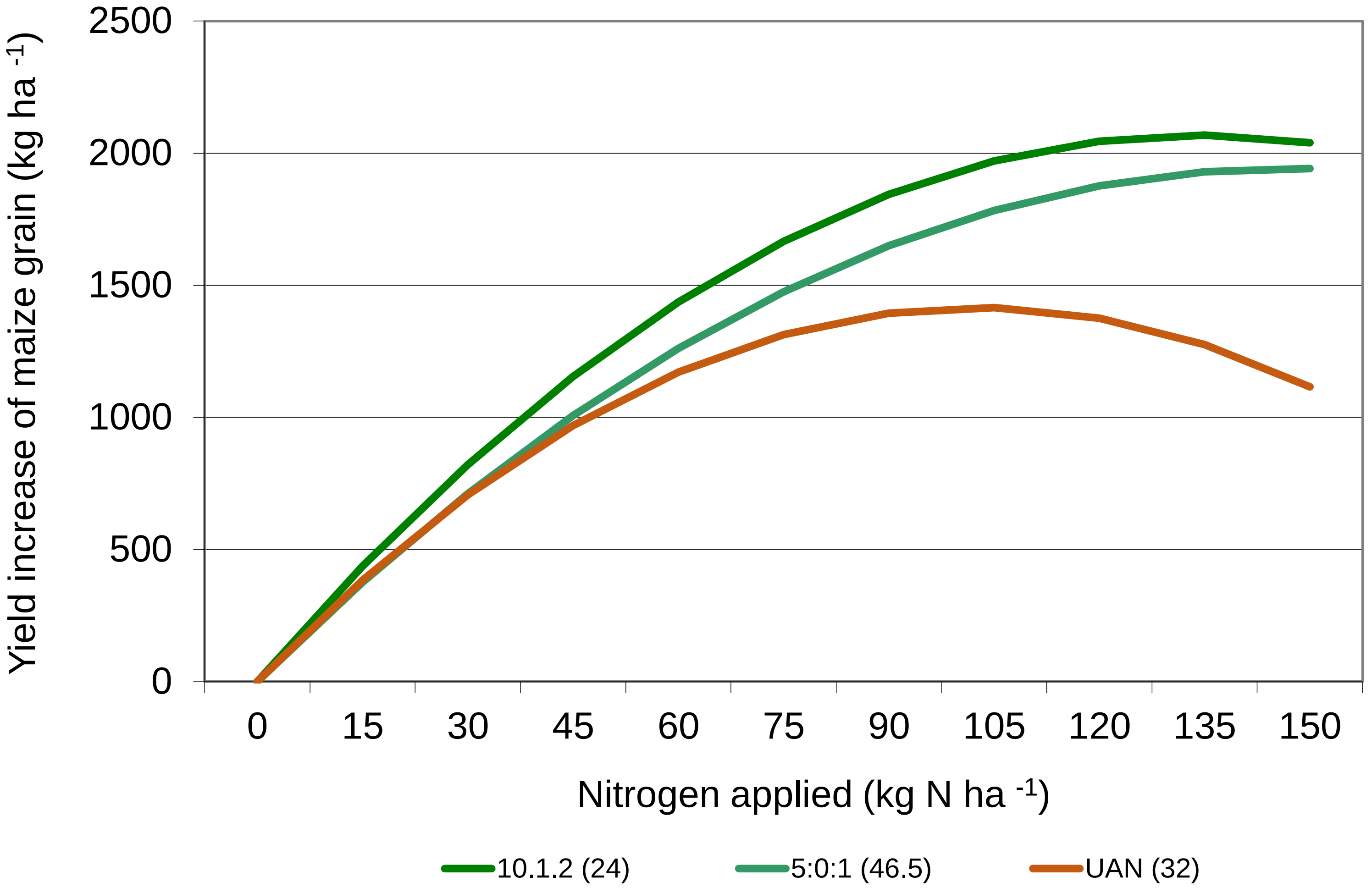
Remarks

Injury may occur on sandy soils low in organic matter or due to excessive rates. Cool, wet weather, or other factors adversely affecting plant metabolism.

Zublena, *et al*, 1983

Nutrient interactions and economic evaluation of fertilizer programs

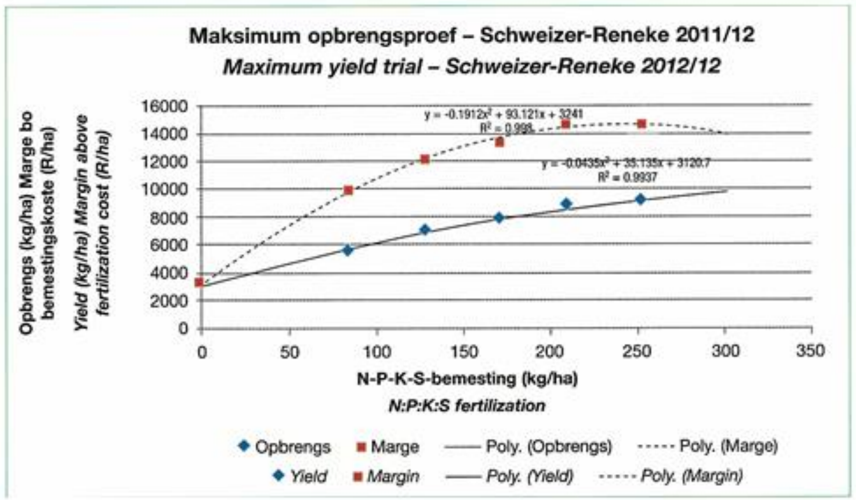
The importance of nutrient interaction (Pivot irrigation, top-dressed, high soil P and K levels)



Data from an AECI Agronomy Research project report, 2003 (M/509/W)

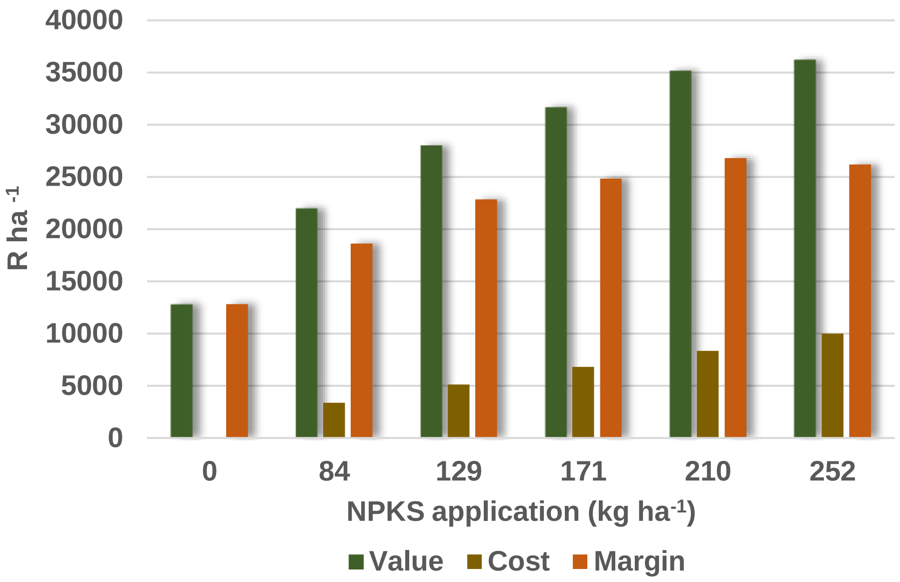
Evaluating program costs and returns

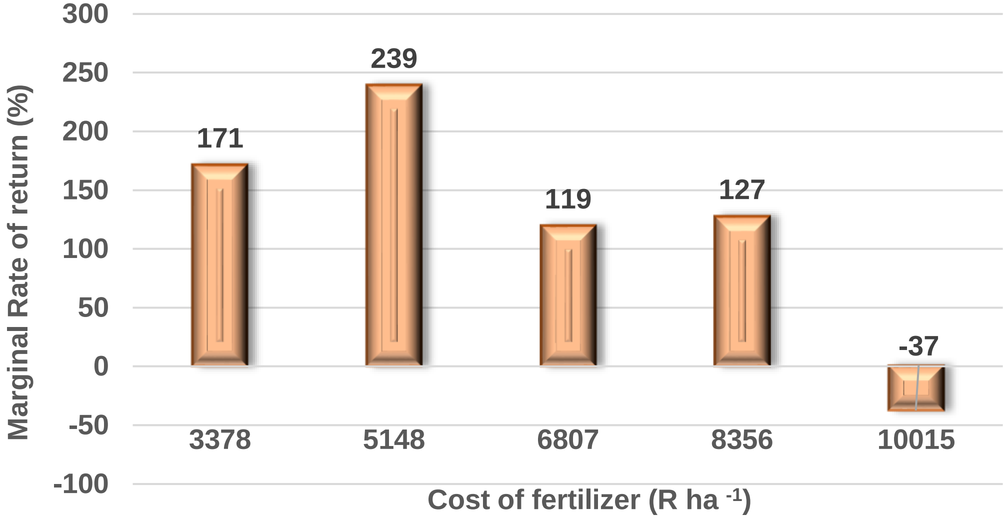
Graph 1. Yield and profitability of different N:P:K:S applications



Treatments	N	P	K	S	Total
1	0	0	0	0	0
2	60	12	0	12	84
3	90	17	5	17	129
4	120	21	9	21	171
5	150	24	12	24	210
6	180	28	16	28	252

Values in kg ha^{-1}

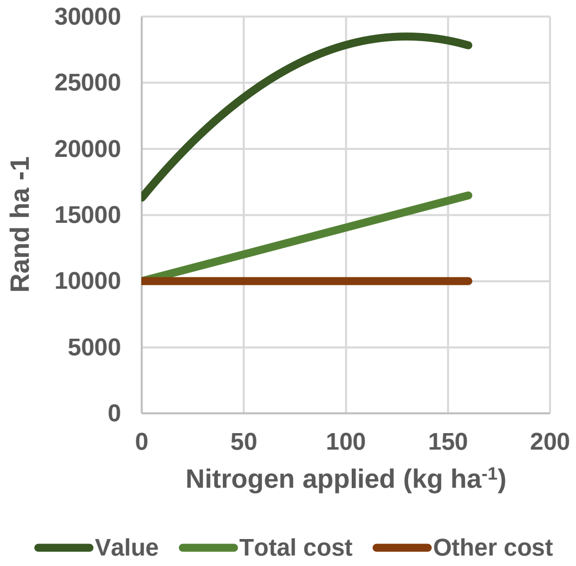


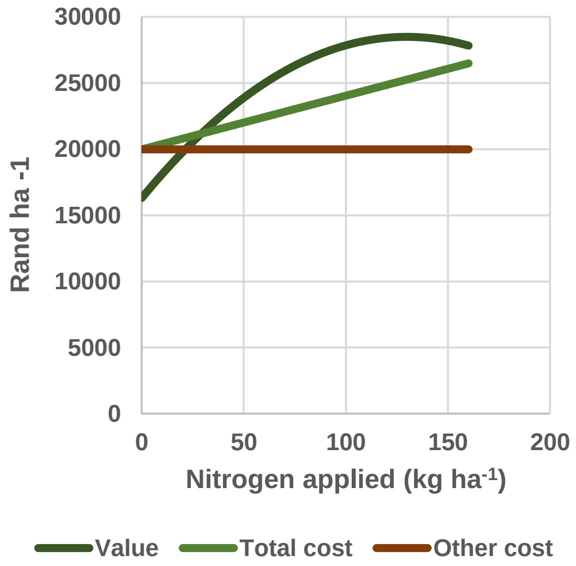


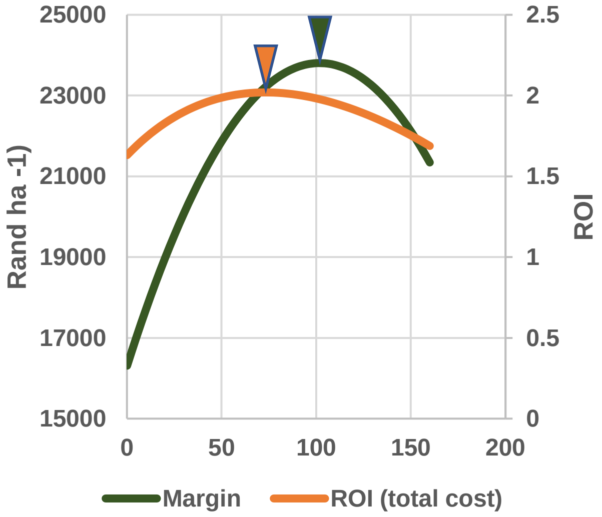
De Jager, 2012. Omnia Fertilizer trial in collaboration with UOFS.

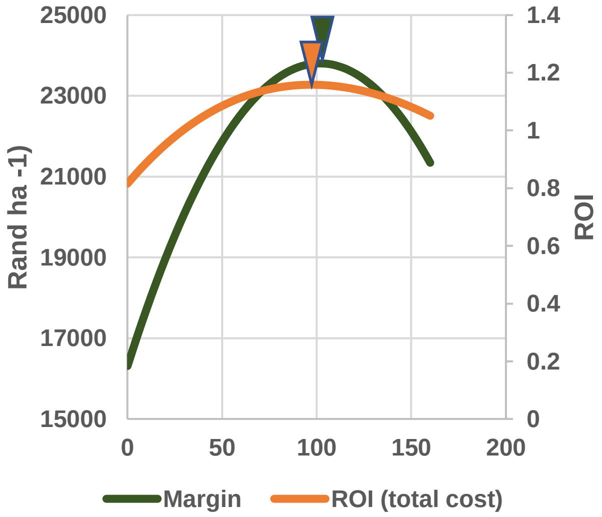
CIMMYT, 1988. From agronomic data to farmer recommendations. An economics training manual. Revised edition. Mexico, D.F.

Economic optimum – highest margin or highest rate of return on total investment?
Example: Response curve of maize to nitrogen – Nigel, Eastern Highveld







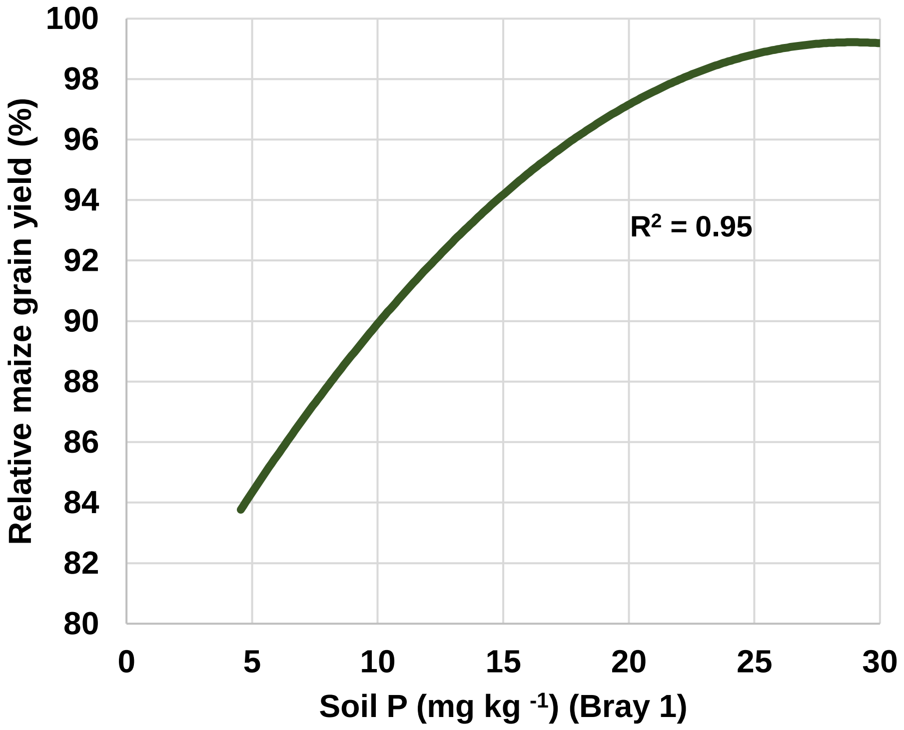


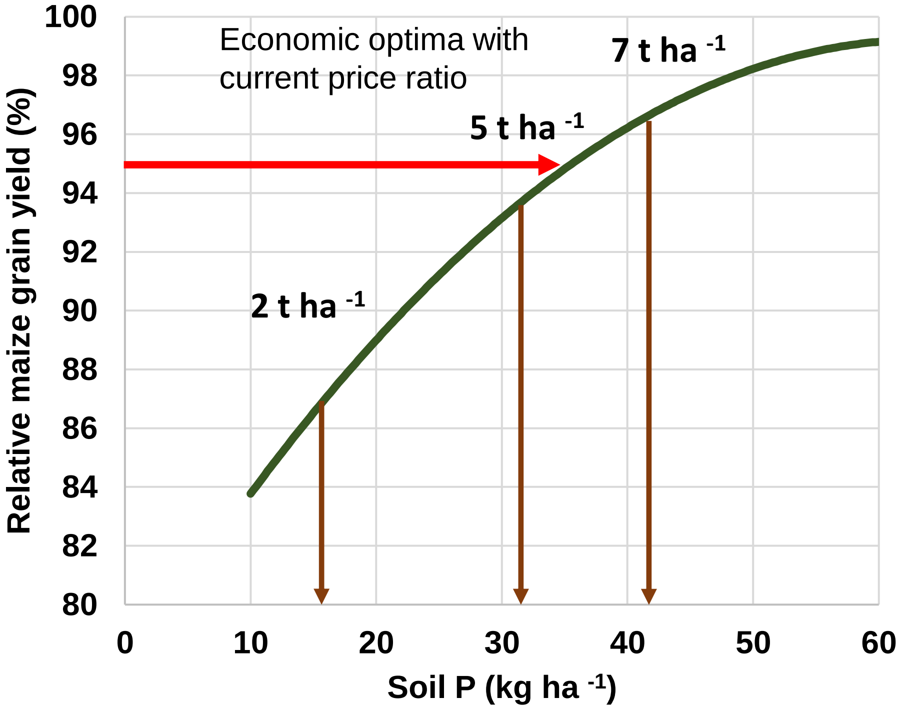

Phosphorus

Relative yield vs soil phosphorus as kg ha $^{-1}$. Can it be used to derive more accurate economic optimum applications?

Wesselsbron (2 seasons); Soil P originally 3 mg kg $^{-1}$ Bray 1, pH (KCL) – 4.8, 6% clay.

Refer to comprehensive work of Schmidt, 2003 and guidelines in Fertilizer Handbook 2016 (eighth edition)
Take note of importance of correct mathematical fitment of response curves as well as the correct interpretation of economic optima (Bornman, 2018)





Same for soil **nitrogen**? -Adriaanse, 2013
Some criticism in USA re sandy soils; Hochmuth & Hanlon, 2022.

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

Three philosophies of approach to nutrient management

- **BCR** (Basic Cation Ratio)
  - No scientific base (Olsen, Frank, Grabouski & Rehm, 1982; Kopittke & Menzies, 2007; Bornman, 2008; Hochmuth & Hanlon, 2010)
  - Costly over application
  - Not accepted by most state universities in the US
- **Build up and maintenance** (fertilizing the soil)
  - Could lead to over application at near threshold values
  - Could be beneficial in difficult economic scenarios
- **Maintaining sufficiency level** (fertilizing the crop – SLAN/CNR*)
  - No excess application
  - More environment friendly
  - Could under apply in excellent seasons
  - Regular soil sampling needed

*Sufficiency Level of Available Nutrient (SLAN), also called the Crop Nutrient Requirement (CNR)

Hochmuth & Hanlon, 2022; Hochmuth, Mylavarapu, Hanlon, 2018. Macnack Chim, Amedy, & Arnall, 2017

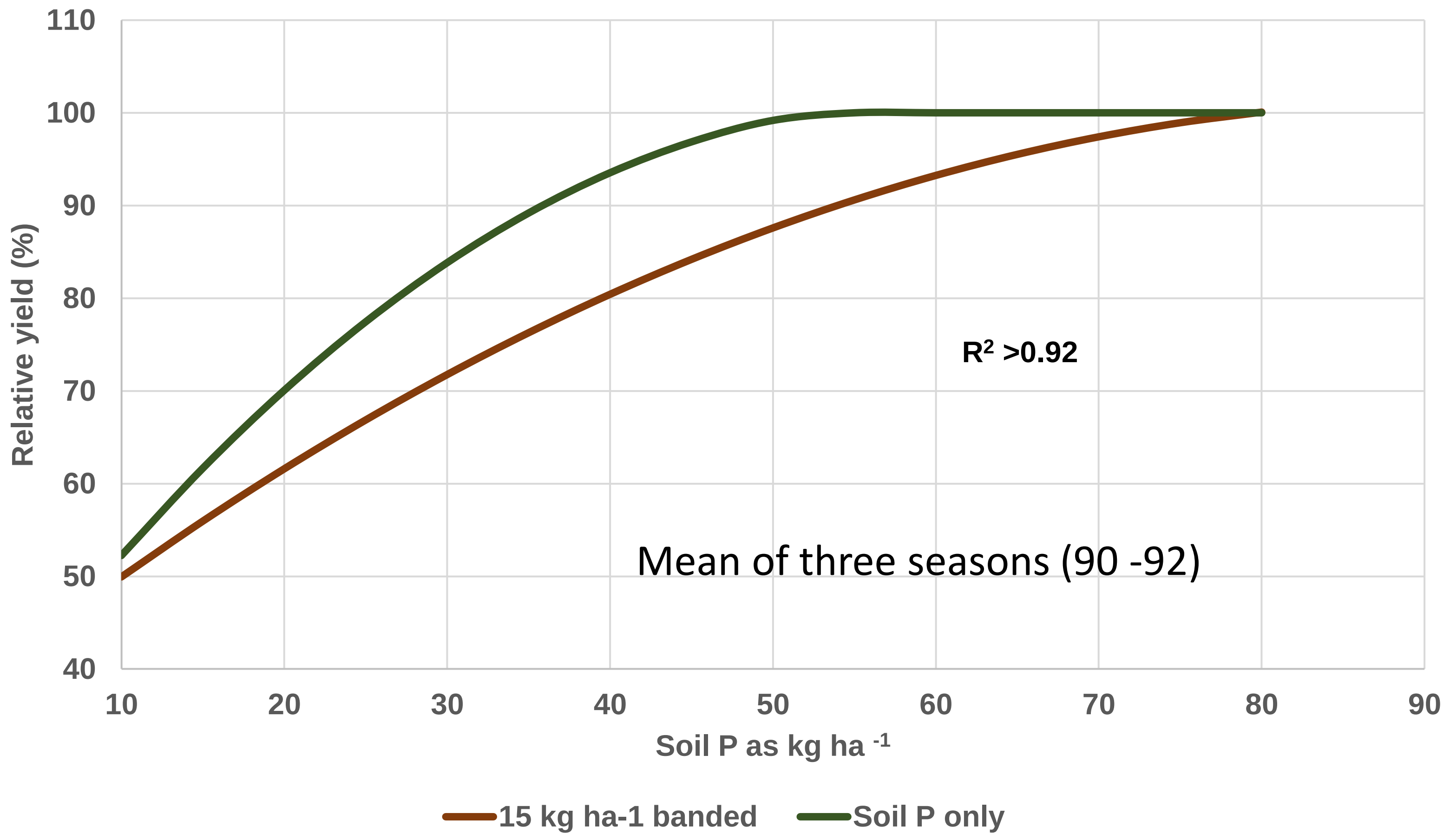
Uptake patterns of high yielding maize

- Nitrogen and potassium – more than 67% **<u>before</u>** VT/R1
- Phosphorus and sulphur – more than 60% **<u>after</u>** VT/R1

- Zinc – 70% **<u>after</u>** V14 – up to late reproductive phase
- Boron -65%% **<u>before</u>** V14

Bender, Haegele, Ruffo, & Below, 2013

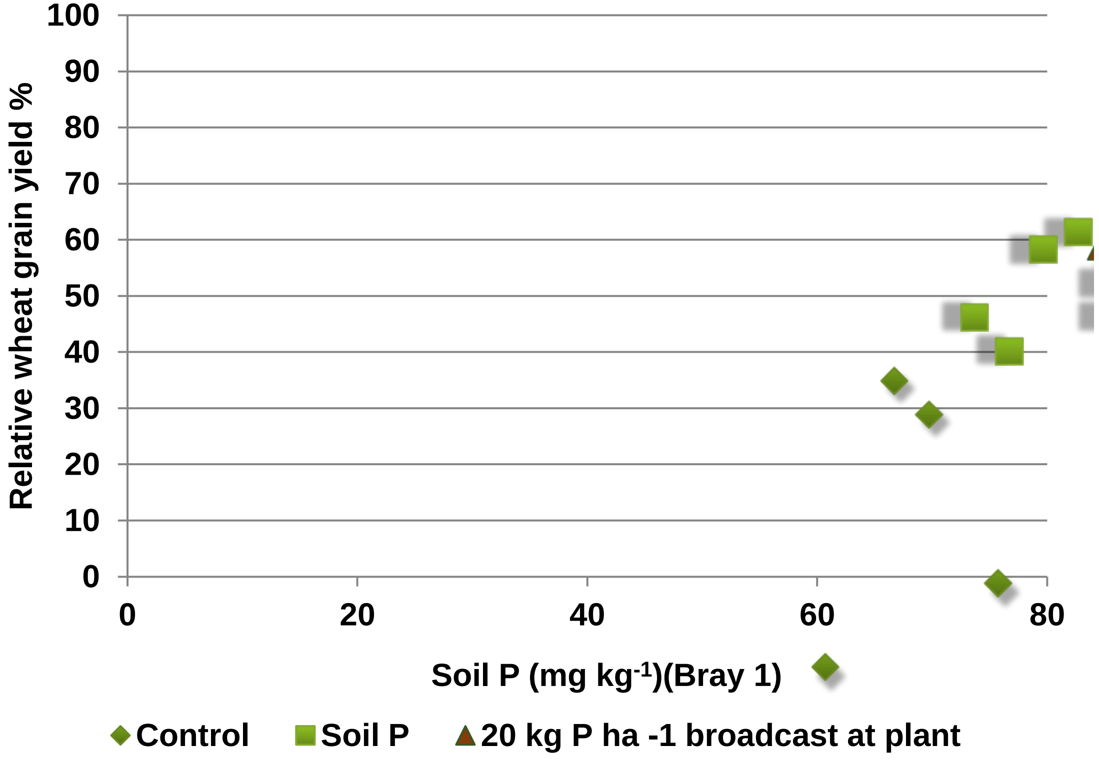
Phosphorus management options
Build and maintain or application of sufficiency levels?
Argent, Eastern Highveld (Clay – 12%)

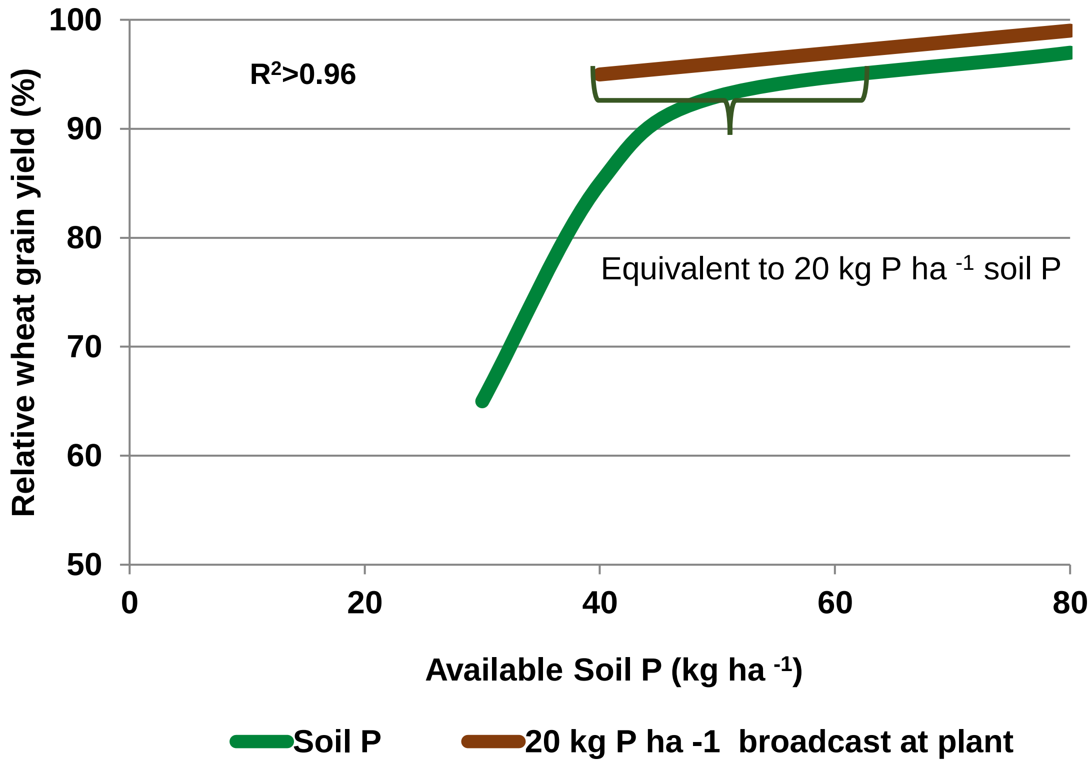


Soil P half life was 2 years despite the application of 15 kg ha $^{-1}$ banded with plant each season

Data from AECI Agronomy Research Project reports M/2/90/N (10 seasons)
Bornman & Venter, 1989; Bornman, 1991 a & b Syers, Johnston, & Curtin, 2008

Relative yield of wheat grain vs available phosphorus as calculated from soil analysis (Bray 1), soil density, soil depth and coarse fraction. Malmesbury, 26% clay, 30% stone volume, depth 35 cm Data of 5 seasons.



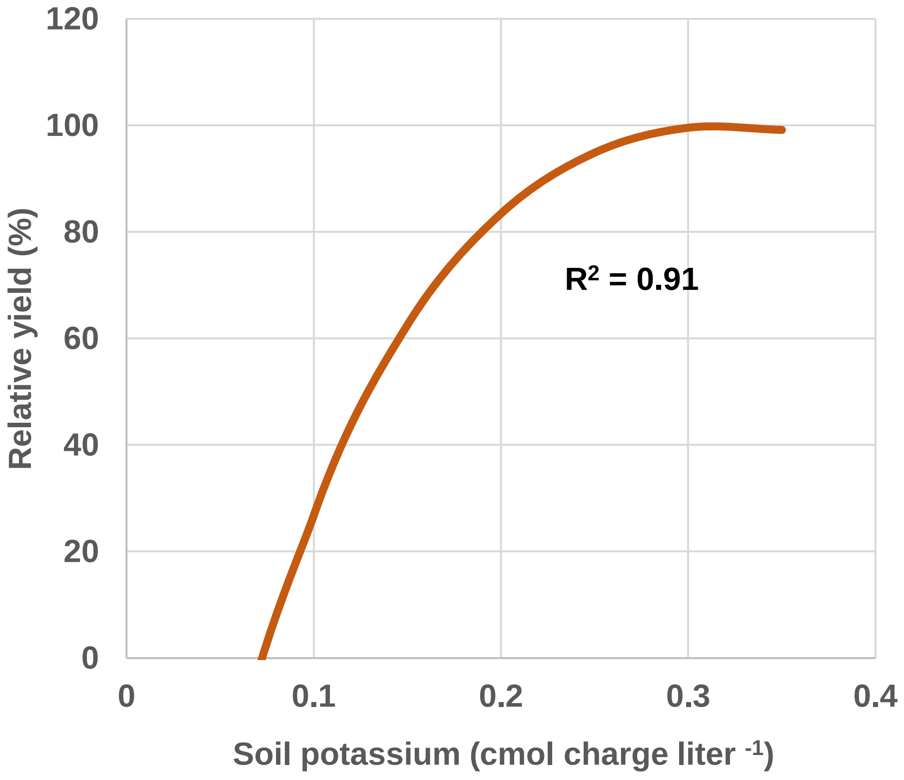


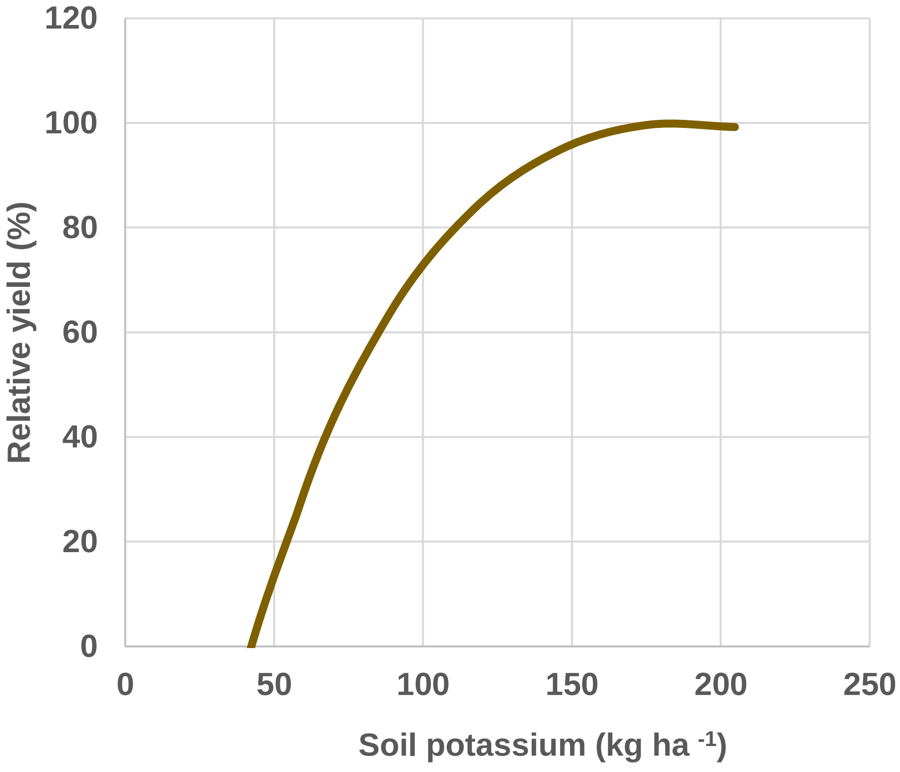
Bornman & Bester, 1991, 1994, 1998

Potassium

Maize response to potassium.
Should soil K also be expressed as kg ha^{-1}?

Example; Normandien site (40% clay) – 8 seasons – 20 cm depth





Farina & Channon, 1985
Farina, 2011

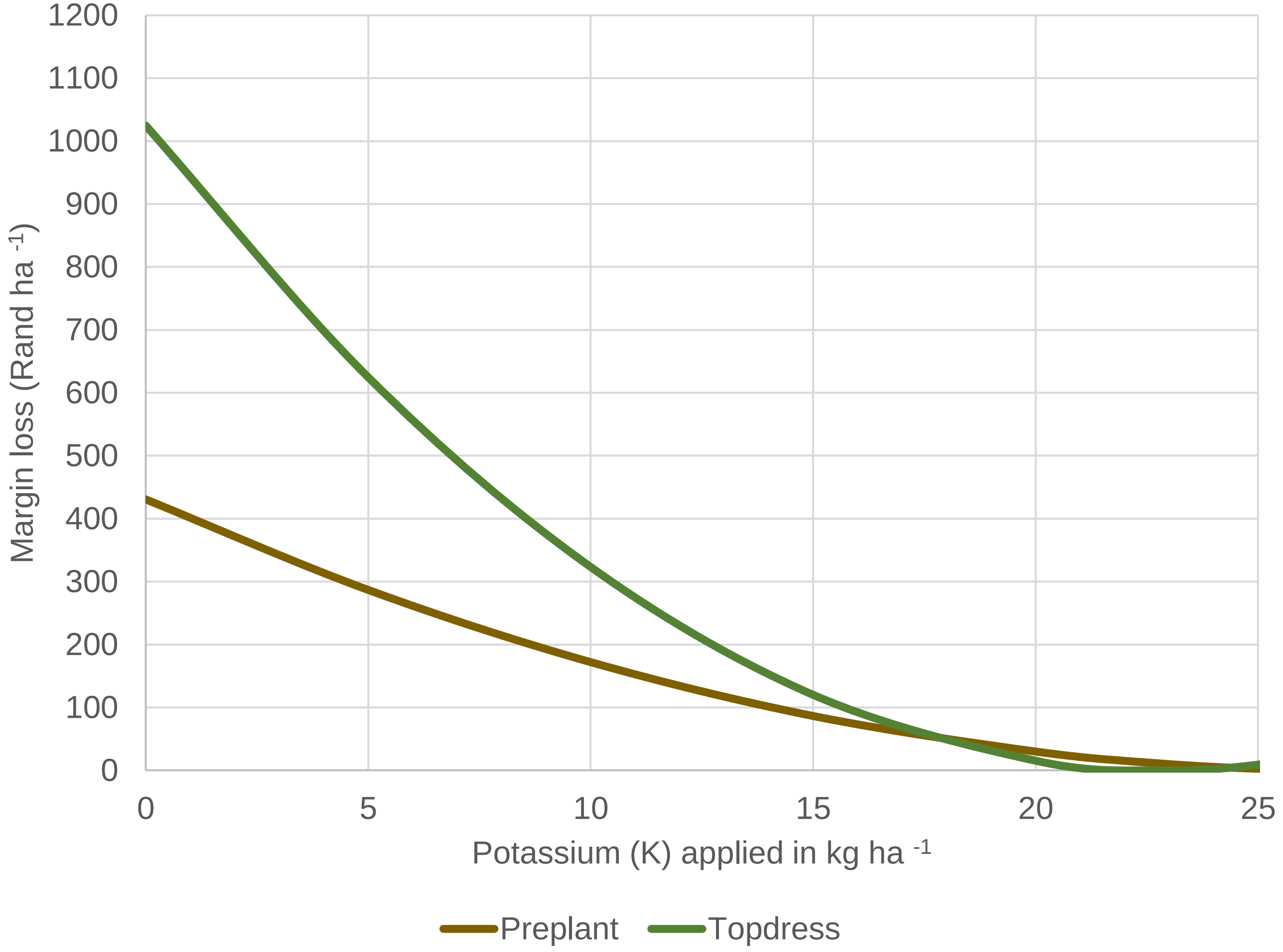
The rate of uptake of potassium is extreme for high yielding maize

Rb86 (radio-active isotope that mimics potassium to the plant root)

Photograph left and autoradiograph right showing the effect of maize roots on the distribution of Rb86 in the soil. White areas show Rb depletion around the maize roots at peak assimilation rate

Hissinger & Murrel, 2021

Maize response to Potassium application: Bultfontein: Clay 5%, K – 157 mg/kg. Average margin over 6 seasons. The current price ratio of 8.7 was used.

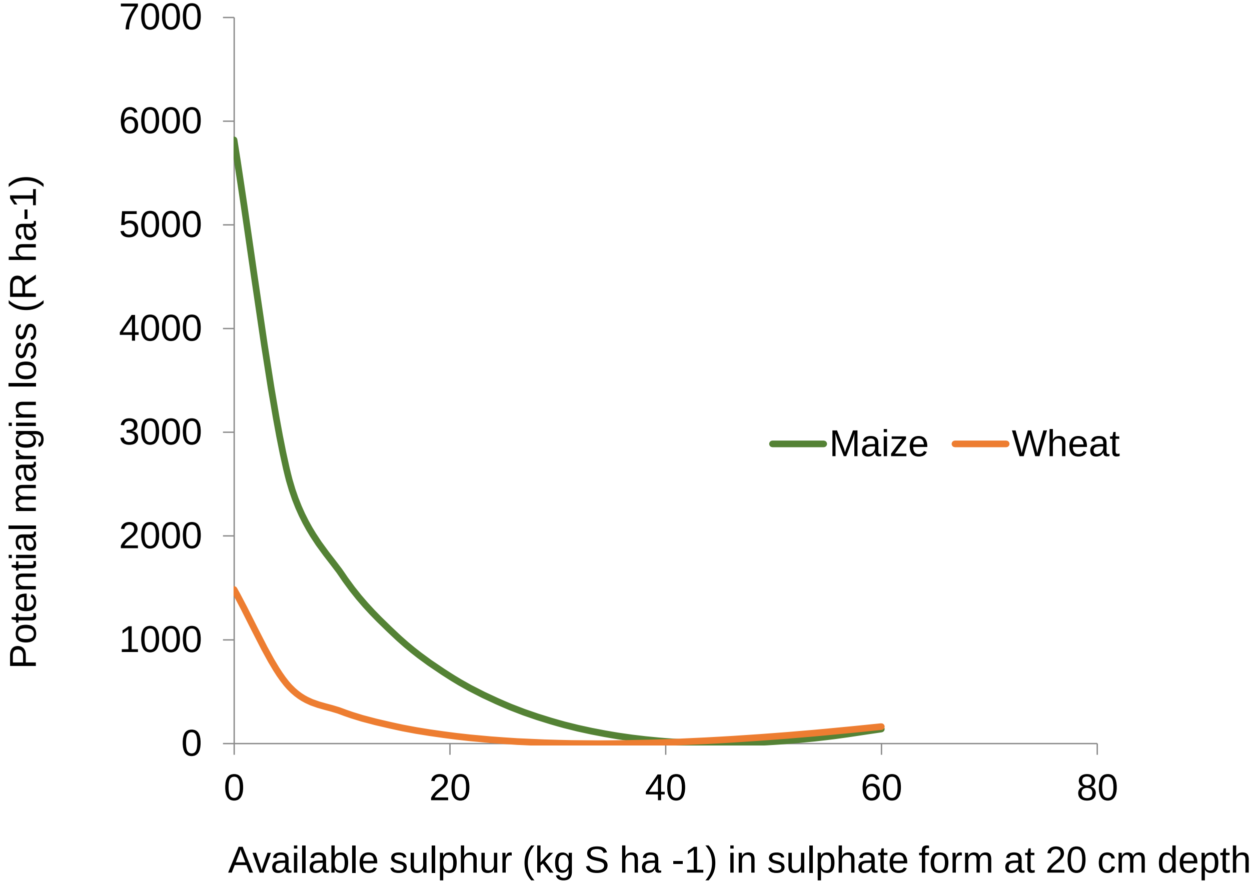


The importance of the Q/I concept should not be underestimated Praveen, 2019)

Data from a trial report 2002 (AECI Agronomy R&D trial data. Project M/509/97)

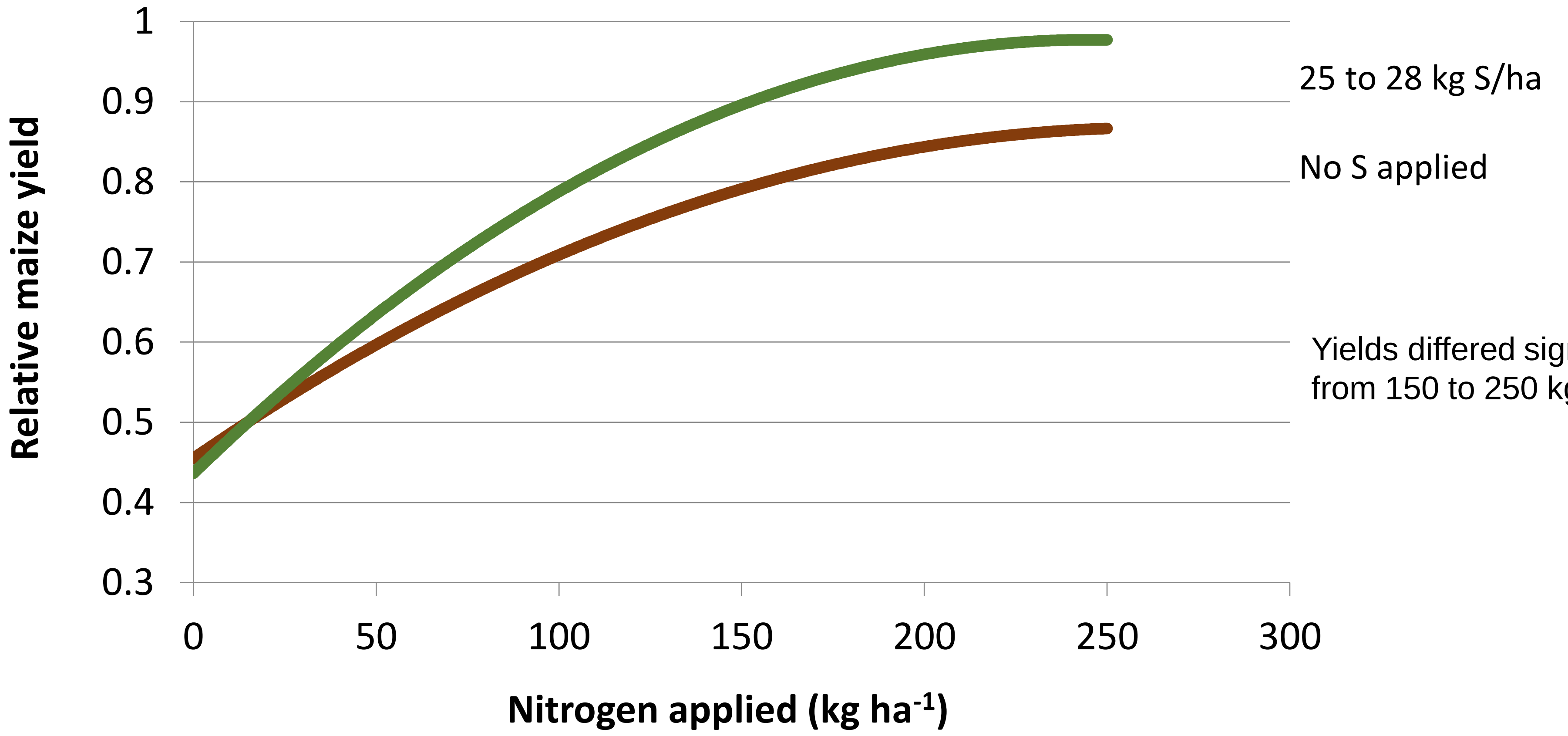

Sulphur

Potential average margin loss due to sulphur deficiency when under fertilizing grain crops with sulphur. The current price ratio for maize (2.6) and wheat (1.3) was used.



Bornman, 2015
Response data used from van Biljon *et al*, 2004 and Omnia project KS-MK-2009-03.

Nitrogen and sulphur interaction in maize.



Yields differed significantly ($p < 0.05$) from 150 to 250 kg Nitrogen applied ha $^{-1}$

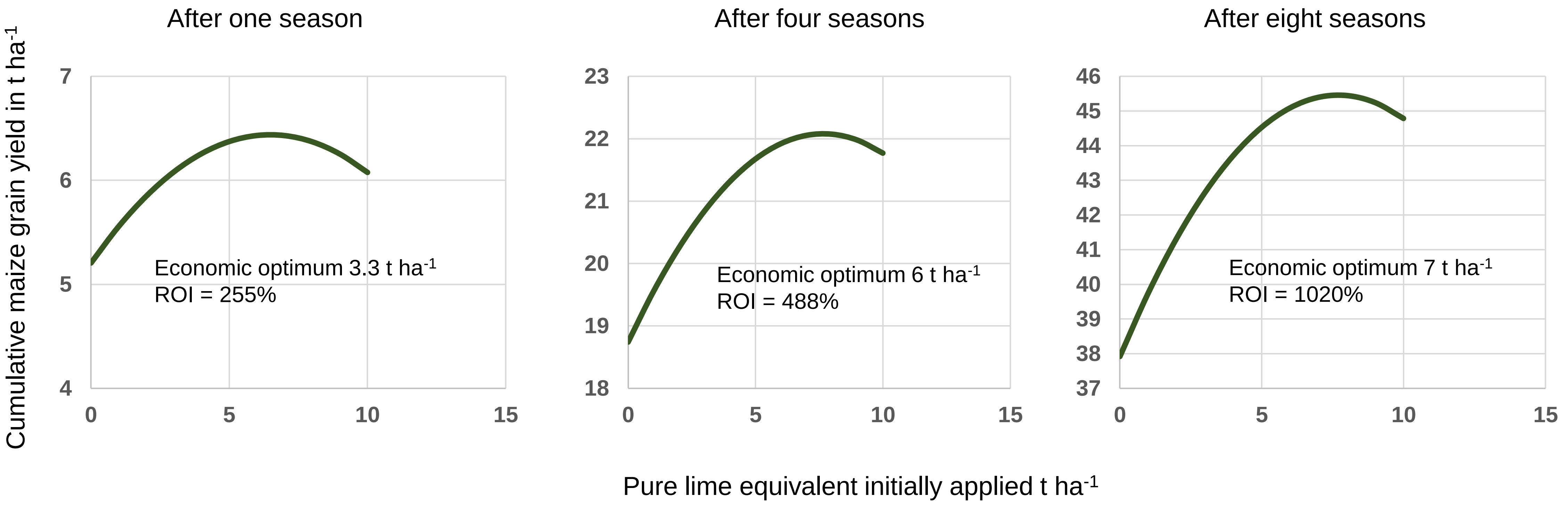
Bornman, 2015
Kim, Kaiser, & Lamb 2013
Sutradhar, Kaiser, & Fernández, 2017.


Liming

The economy of liming cycle

Example: Eight year trial at Davel – Eastern Highveld. pH 3.77 at onset, Clay% 10%

With cashflow constraints a shorter cycle of liming may be considered
The current price ratio (0.2) was used which includes transport and application cost



Project reports M265/90/N – AECI Agronomy Research trial (total of 12 seasons)
Bornman, Spies & Oliver, 1996.
Bornman, 1999

"Biologicals", micro-elements, growth inhibitors, and other

The economics and probability of response to the above mentioned should be carefully evaluated against statistical trial data

Prof Fred Below;

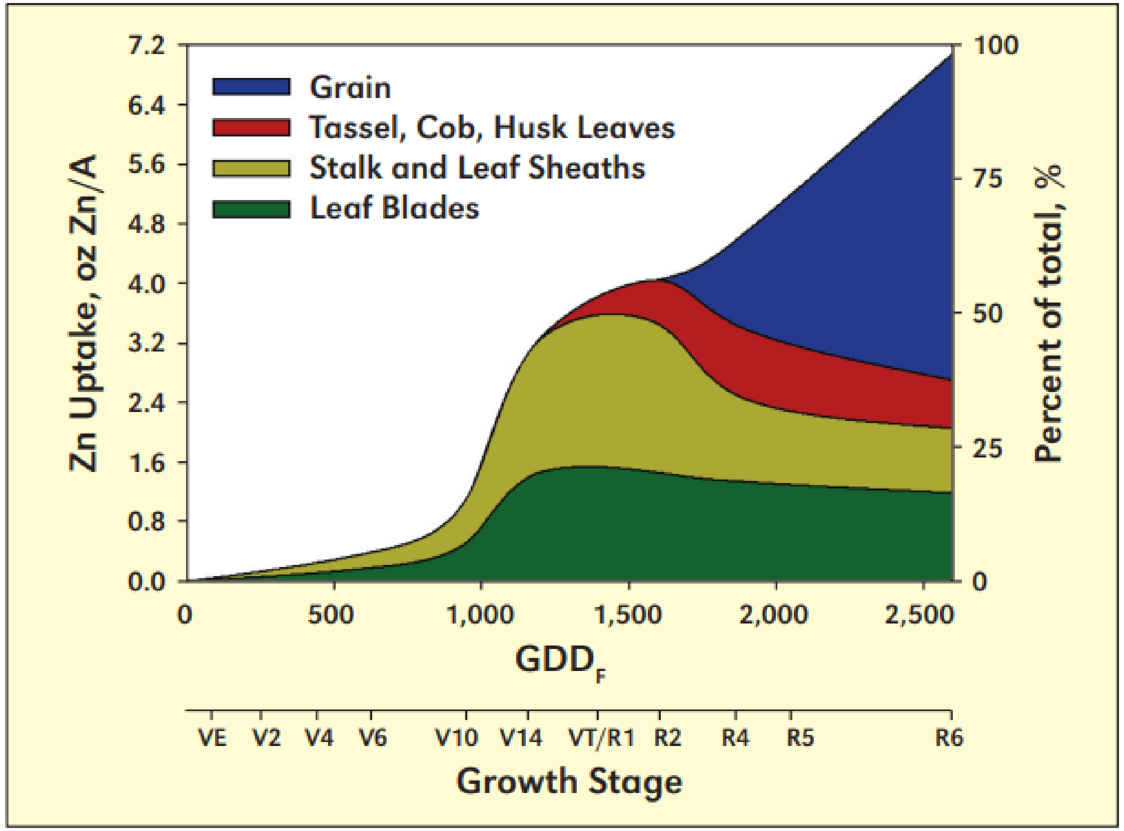
- “Biologicals fit into three broad categories; plant growth regulators, beneficial microbes, and biostimulants.”

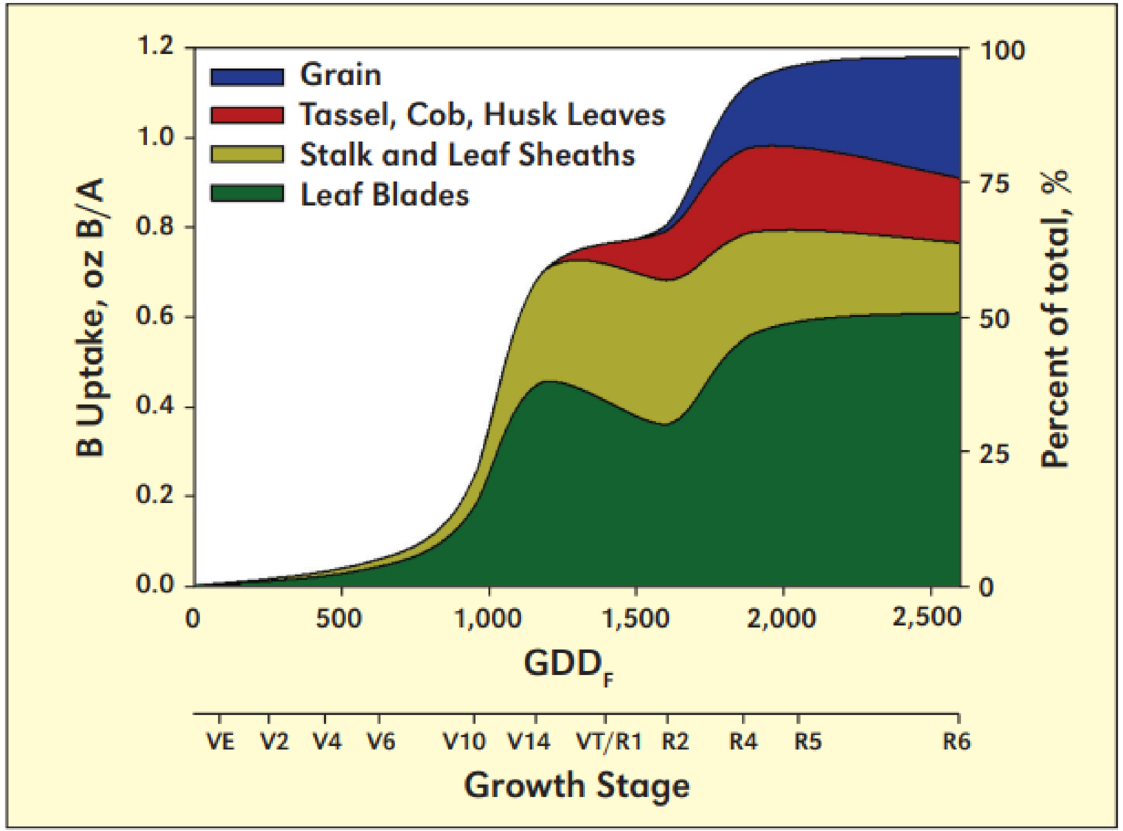
- “Biologicals offer opportunity for significant bushel gains. “Ten bushels is what I say biologicals give to a crop”

Ten bushels = (628 kg/ha)

Below & Sible, 2021

Zinc and Boron uptake patterns of maize

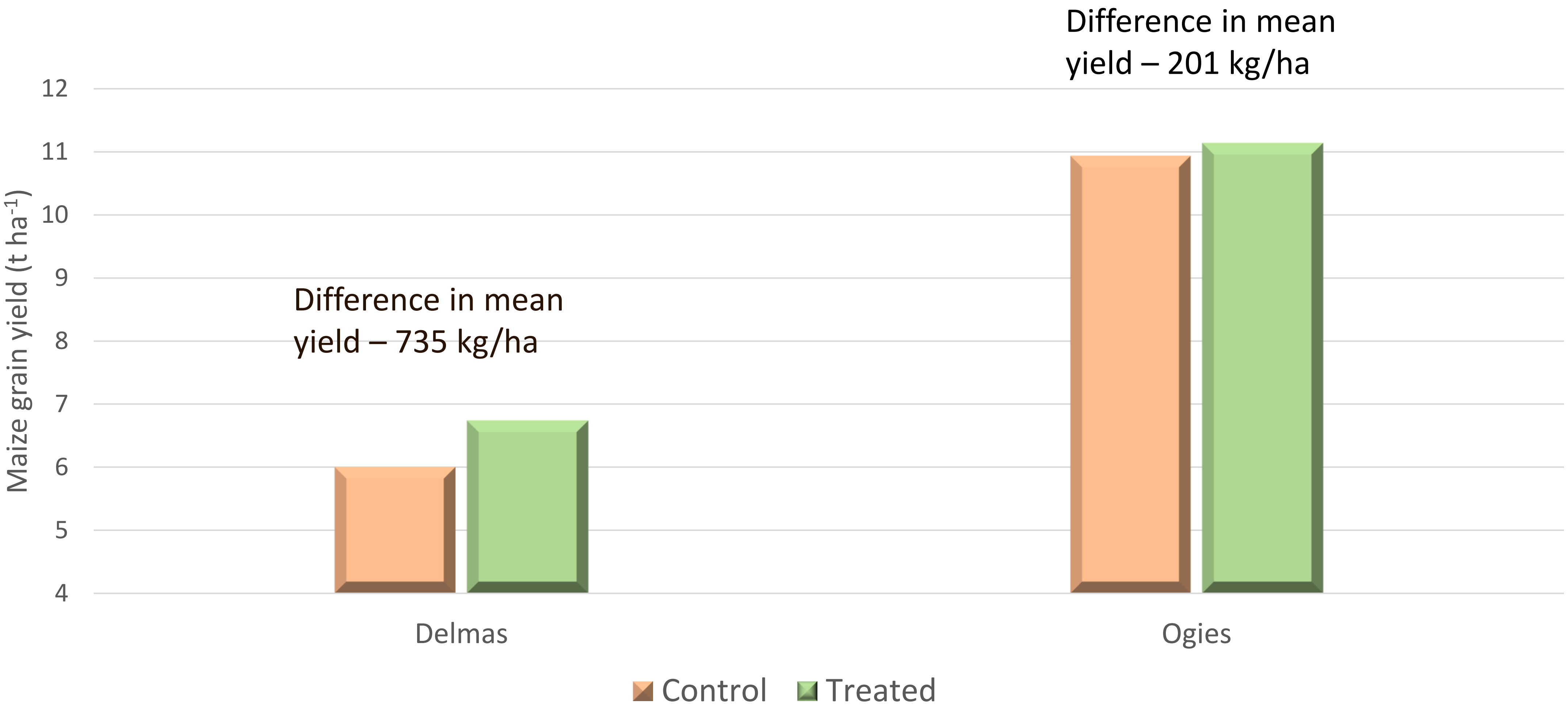




Bender, Haegele, Ruffo, & Below, 2013

Response of maize to zinc and boron

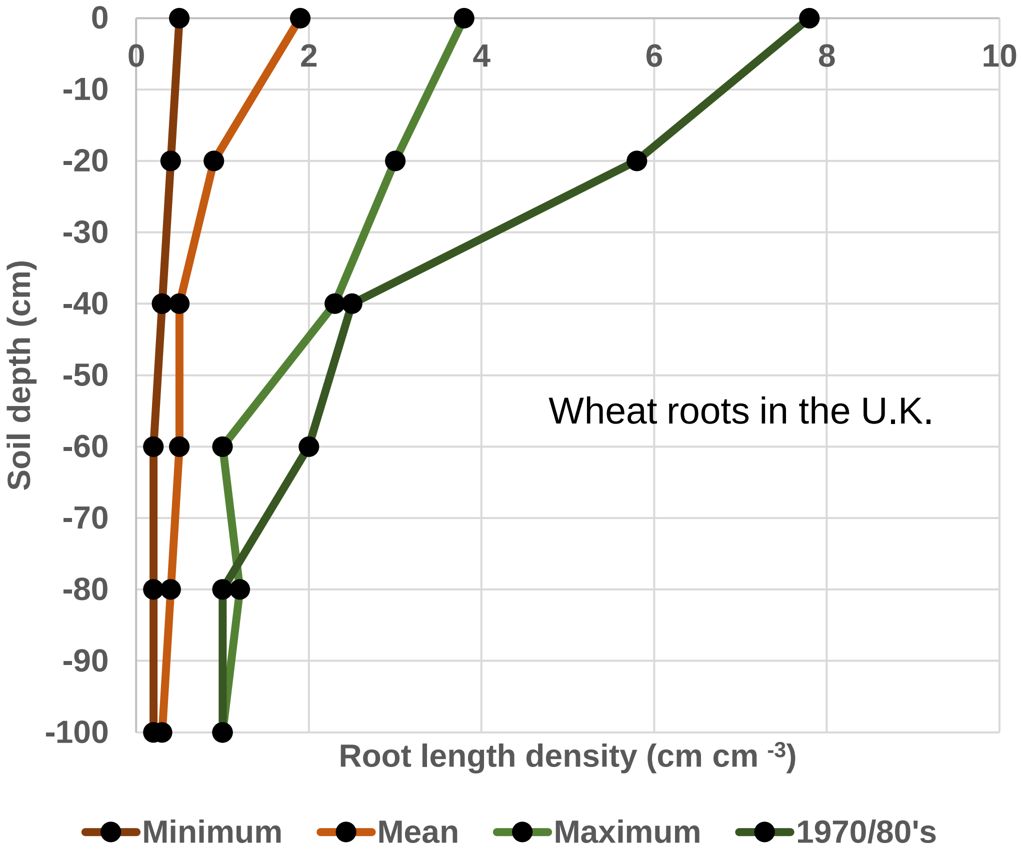
(Added to urea ammonium nitrate liquid topdressing – V4-6 stage)

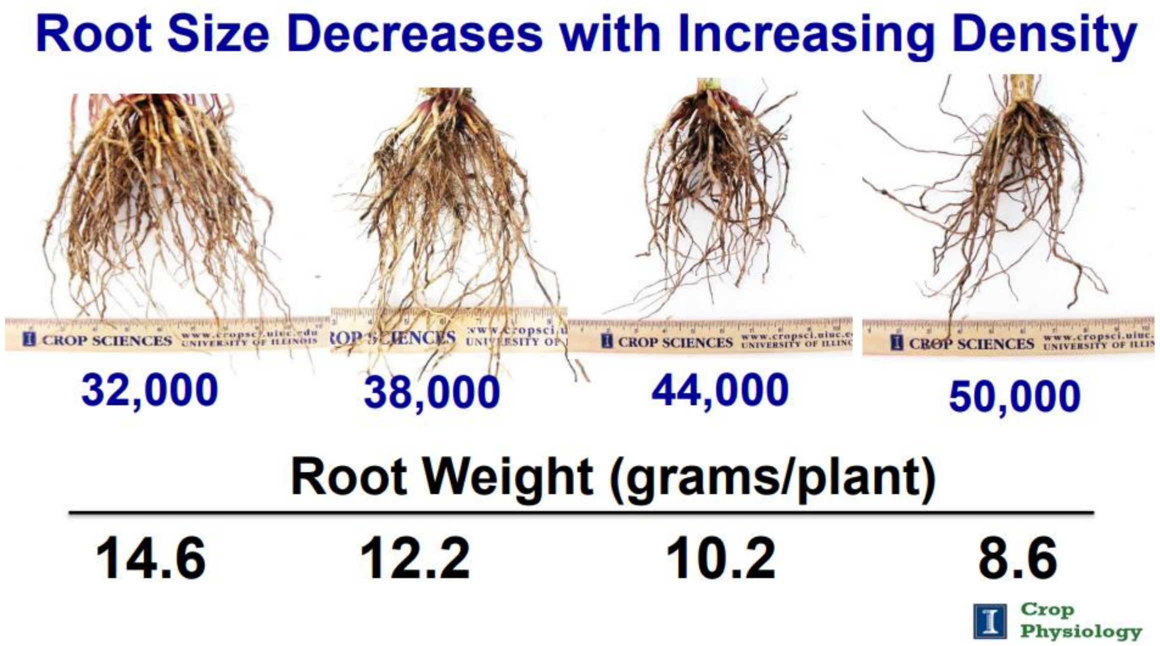


Omnia fertilizer trial code TY-2008-13. Sixteen paired strips at each site – Differences of mean significant **at p (<0.10)** for both sites.

A' Bear, Wright, C. & Bornman, J.J. 2011

Relative root density is decreasing with new cultivars and plant density Critical within the "Brown Revolution"



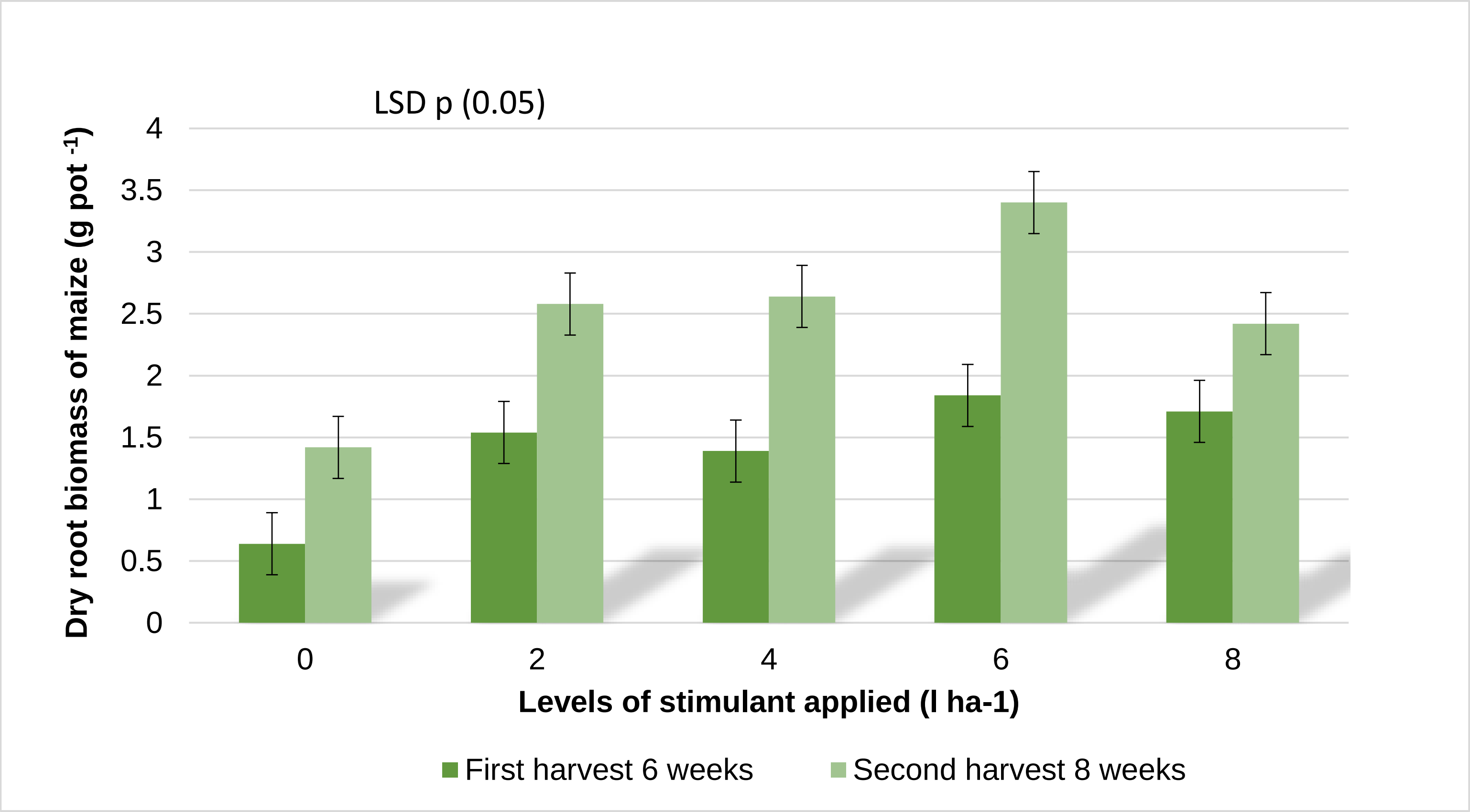


Density above is as plants acre $^{-1}$

Slide from presentation of
Below, Winans & Bernhard, 2020

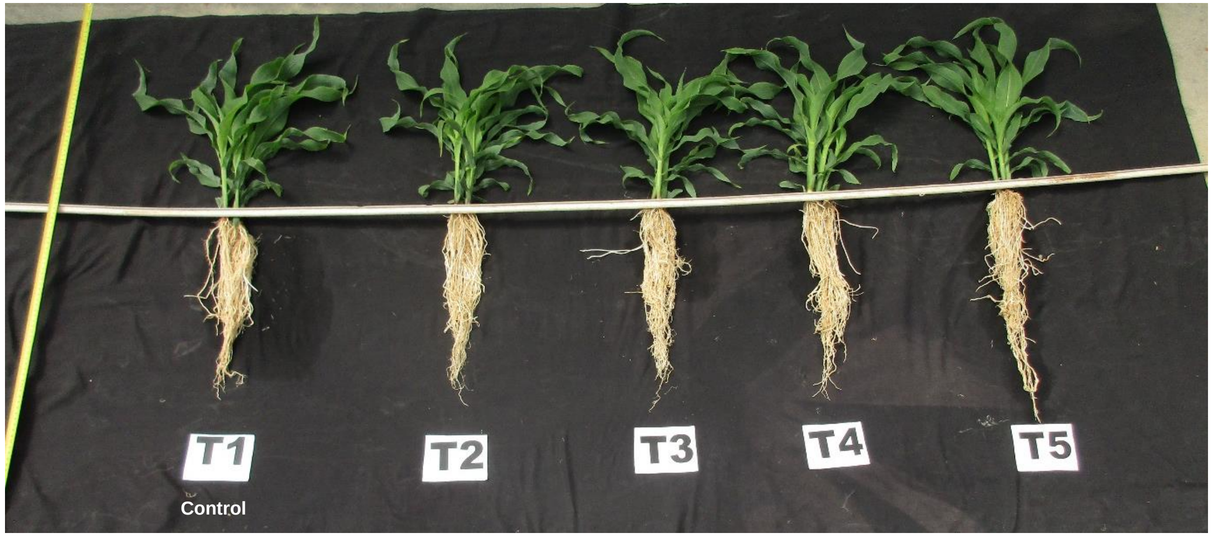
Bornman, 2015
De Dorlodot, Forster, Page's, Price, Tuberosa,& Draye, 2007 (for maize)
White, Bradley & Berry, 2015 (for wheat)

Results of maize root response to a root stimulant in a greenhouse trial.



Trial MM 2016 – 14 – Omnia Fertilizer project

Maize root response to a root stimulant at different levels in a greenhouse trial



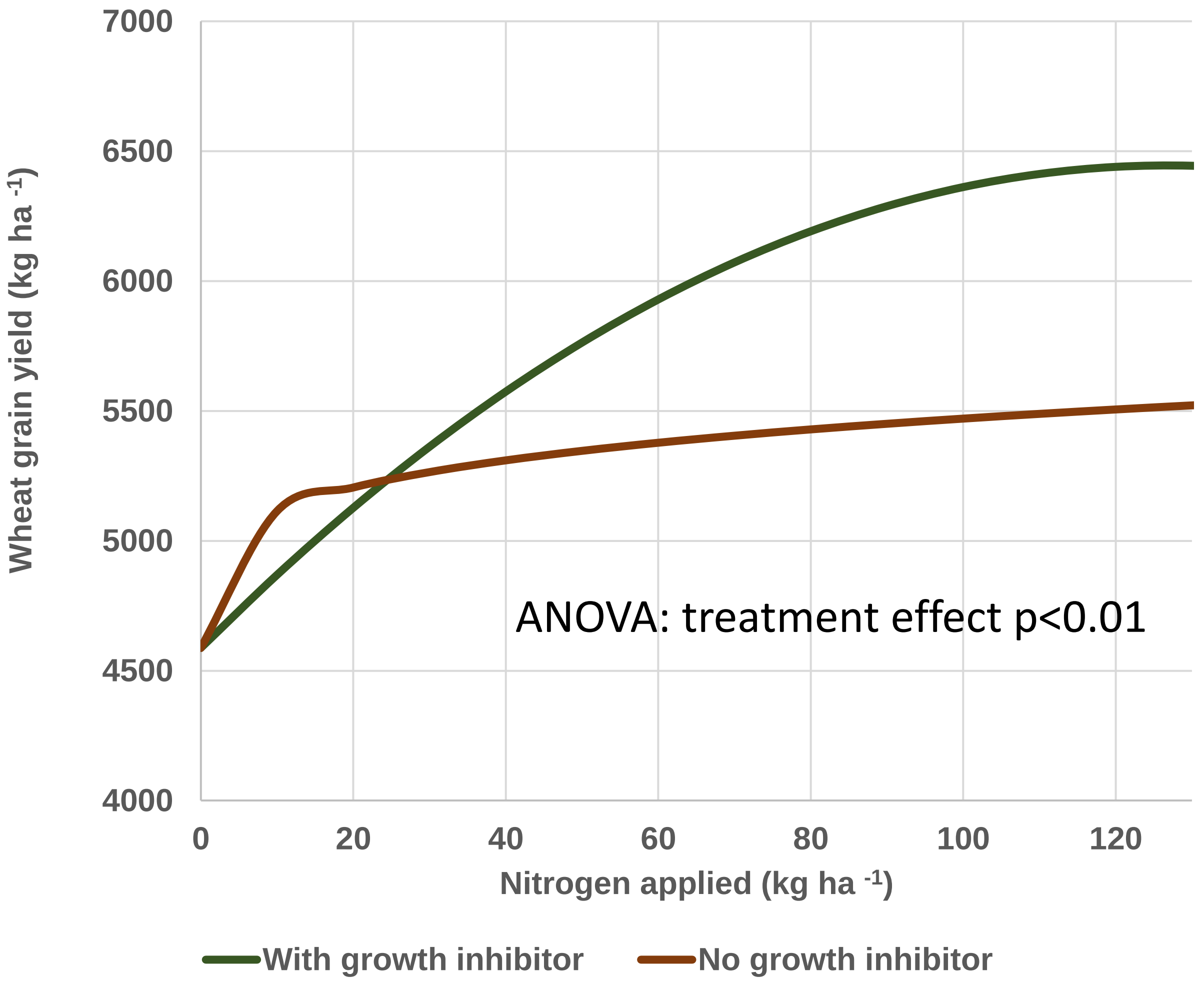
Trial MM 2016 – 14 – Omnia Fertilizer project

A root stimulant will most likely increase nutrient and water use efficiency.

22% increase in wet root mass
N=9 strips, P(T>t) – 0.0339

Omnia Fertilizer trials Southern Cape.
Bornman, 2016 – Field trial report

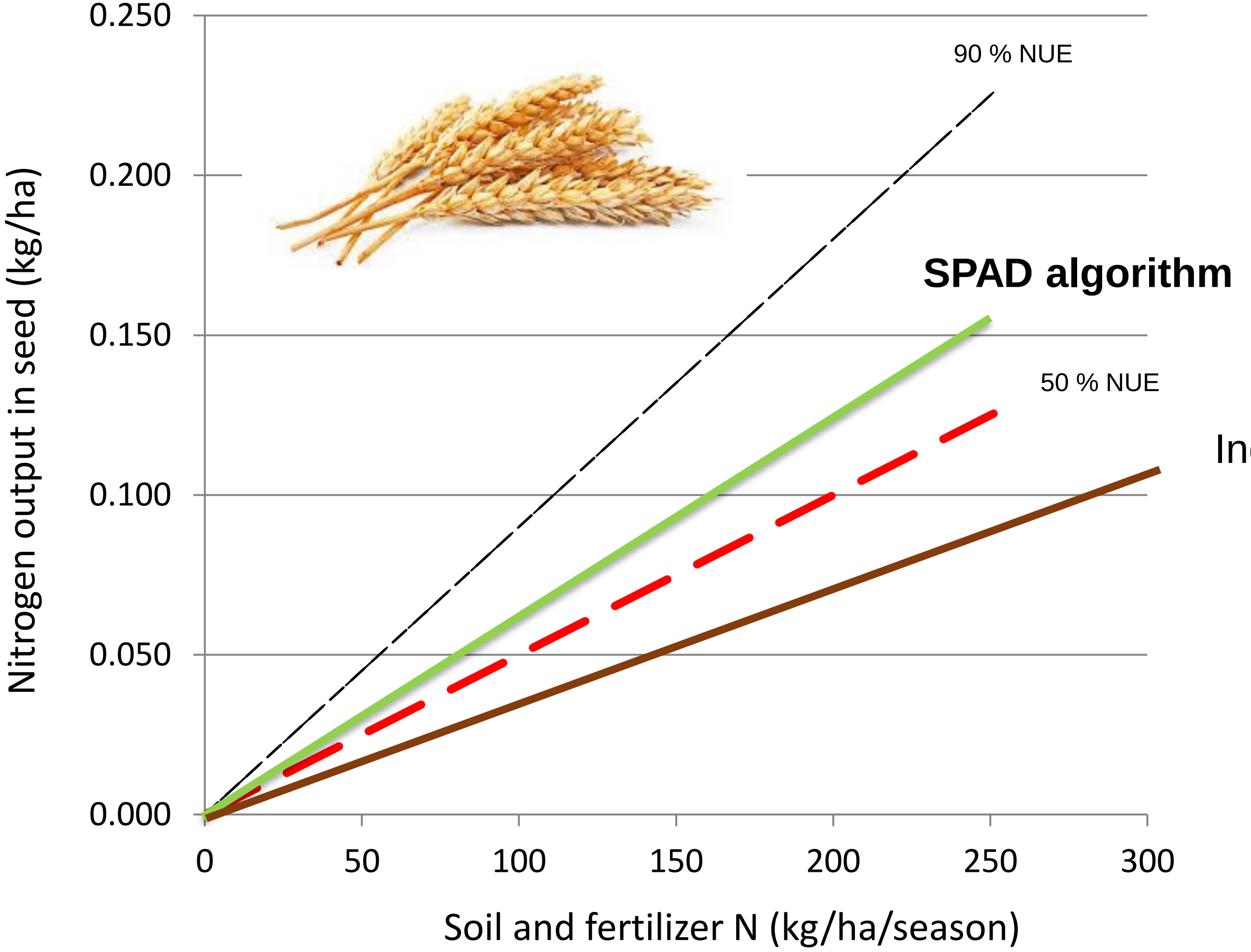
Response of wheat to nitrogen application under irrigation on a clay soil (46% clay) with and without a growth regulator



Data of two seasons (86 and 87) – joint trial AECI, BASF, MGK and FSSA. Project code W/8/86/N (Koedoeskop)

Precision Farming and Sensors

With the Minolta SPAD 502 wheat NUE's of more than 50% were achieved in 80% of recommendations (Western Cape).

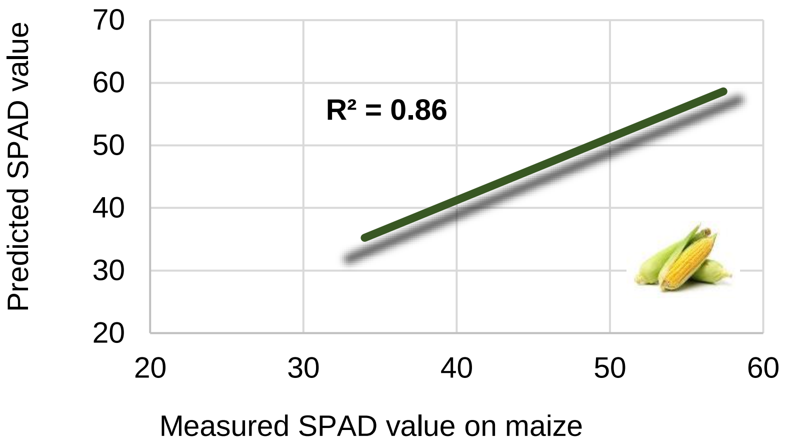


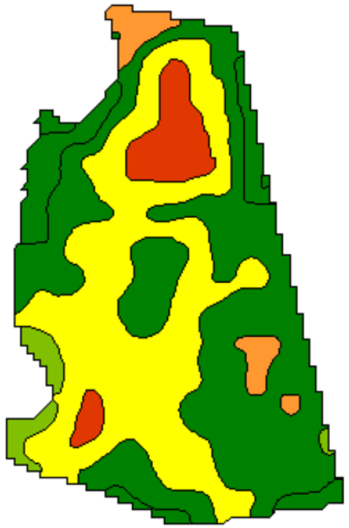
Industry recommendation = 30 to 40%

Values calculated as prescribed by the EU Nitrogen Expert Panel, 2015

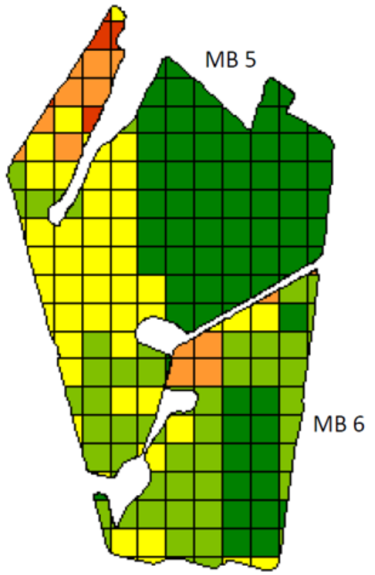
Kellerman & Bornman, 2015

Estimating chlorophyll concentration in foliage from satellite imagery enables scaling of concept





Management zone



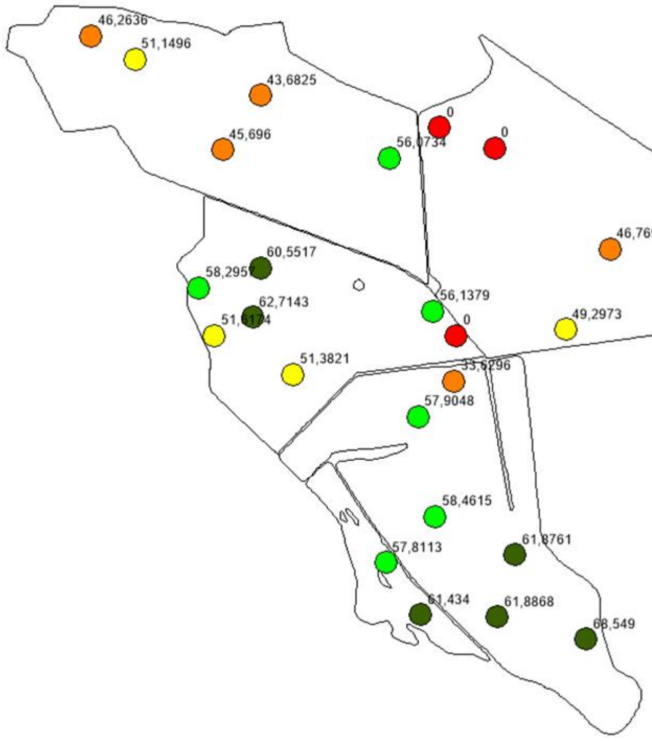
20 m^2 grid

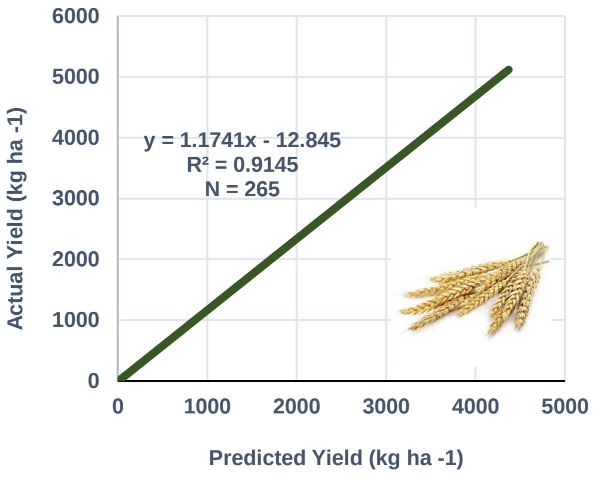
Geoterra Image and Omnia Fertilizer partnership project (4 years)

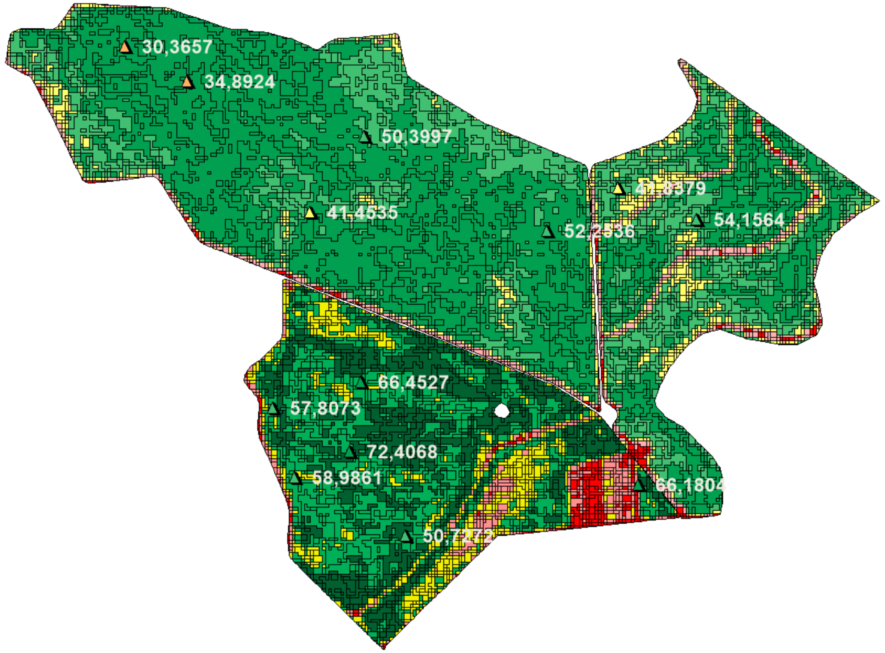
In season nitrogen use efficiency evaluation due to accurate biomass and yield estimation with satellite remote sensing (example: wheat and barley)

Field measurements 2019

In season 2020 (using satellite imagery)

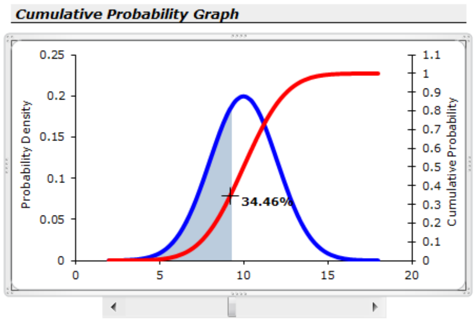






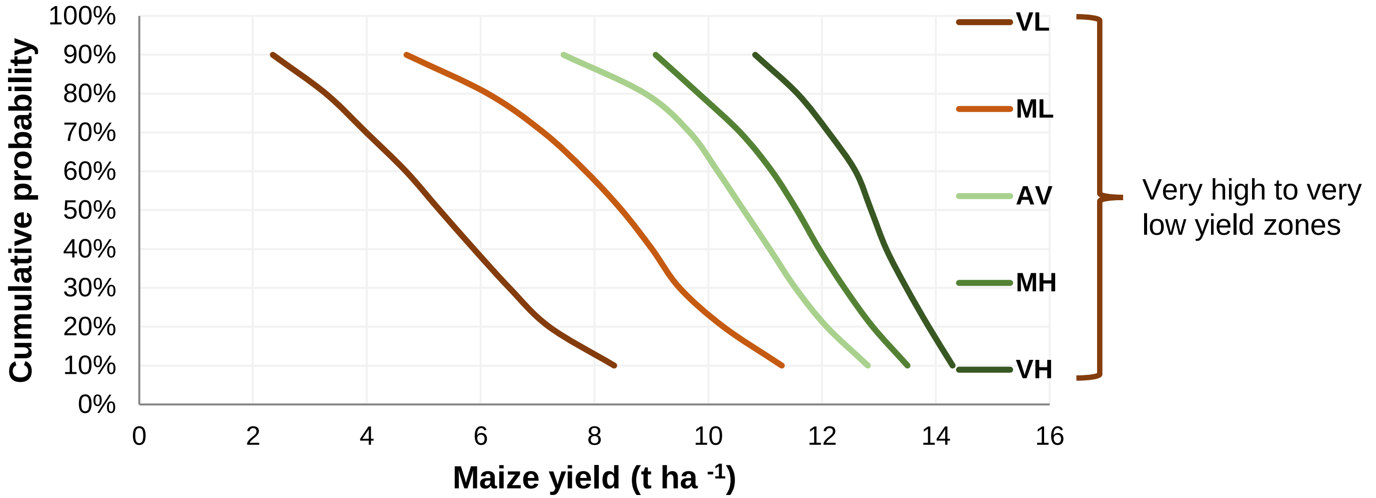
Bornman, 2020. Omnia Fertilizer Project report to ABInBev Caledon

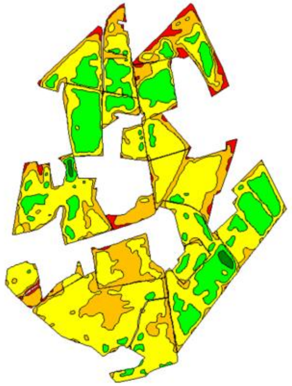
Using cumulative distribution functions to simplify risk quantification



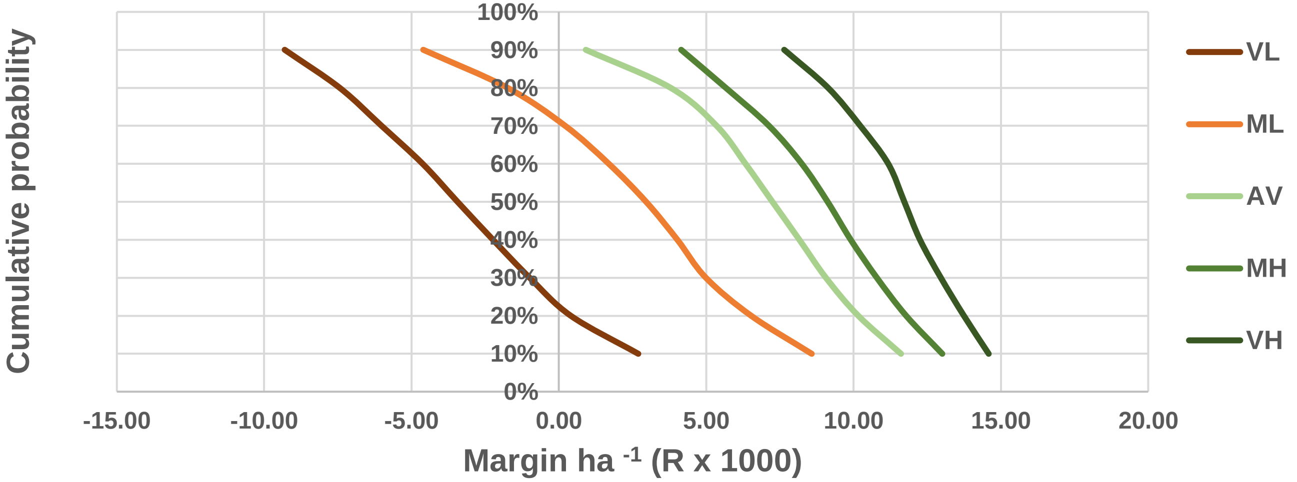
National institute of standards and technology, US Dept Commerce

https://www.itl.nist.gov/div898/handbook/eda/section3/eda3661.htm





18 years of yield data – from harvester combine and derived from satellite imagery



Example: Omnia Fertilizer project on a farm on the Eastern Highveld (maize/soybean rotation). Project report by Bornman, 2017

In summary

- More emphasis should be placed on probable response economics and risk analysis
  - By the use of production functions and price ratio.
  - More up to date site specific field data are needed

- The principle of expression of soil P, K and S as kg ha^{-1} should be revisited
  - The sufficiency approach and related economical evaluation should be reassessed

- More clarity is needed on minimum quantities to be banded with plant

- Statistical cost benefit analyses re “biologicals”, and the like are essential

- More use should be made of remote sensing and probability analyses to increase use efficiency and to quantify risk

End

List of 63 references available with this presentation