DIFM-project: Lessons from on-farm variable soya bean seeding rate trials

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Variable rate seeding (VRS) and precision agriculture technologies are gaining more attention with the rise of data-driven grain farming. VRS involves tailoring seeding rates based on the requirements of different parts of a field – unlike traditional farming methods, where the same rate of inputs is applied uniformly across a field. For example, VRS makes it possible to increase soya bean seeding rates in areas of fields where productivity is lower and decrease rates in more productive areas of the same field.

Implementing VRS requires careful planning with various methods for determining rates including soil maps, yield data, and normalised difference vegetation index (NDVI) images. Despite its complexity, many producers see the potential of VRS to boost productivity, profitability, and sustainability.

A key gap in our understanding of precision agriculture is determining whether variable rate seed applications can enhance on-farm profitability. To explore this, we analysed data from data-intensive farm management (DIFM) trials across three multi-season soya bean case studies. Over the past five years, the Bureau for Food and Agricultural Policy (BFAP) and DIFM-US have applied this methodology on various South African farms, with support from the Protein Research Foundation (PRF), Sasol Agricultural Trust, Grain SA, and Stellenbosch University.

Methodology

The DIFM trials generate data on localised crop responses to site-specific inputs (Bullock *et al*. 2019). Trials typically test seeding and fertiliser rates using a checkered-board, randomised design. Each trial results in a large dataset with global positioning system (GPS) points connected to a seeding rate, fertilisation rate, and yield value. Various analytical processes are followed to clean the data and determine optimal seeding and fertilisation rates for either the whole field or management zones within the field.

An example of a soya bean seeding rate trial is shown in *Figure 1 A-B* (soya bean trial typically only includes variable seeding rates). The management zones are sections of a field grouped based on similarities in how they respond to seed and fertiliser input rates (*Figure 1 C*). We analyse trial data to divide the field into zones that qualify for different management strategies. The process relies on actual as-planted, as-applied, and yield data from each field.

The focus of this article is on three soya bean case studies – each spanning multiple seasons on the same farm over multiple fields. *Table 1* includes descriptions of the included trials. The initial DIFM trials were planted during three consecutive La Niña years with above-normal rainfall conditions. The 2023/24 summer rainfall season (harvest from May to June 2024) was drier in most of the production regions, compared to the previous seasons.

Profit was determined for each management strategy per field. Only the variable input costs (treatments such as seed costs) were considered when calculating the profits (i.e. indirect and other direct costs such as fuel expenditure were assumed constant and therefore omitted). While soil chemical and physical properties were not explicitly included in trial layouts, our methodology assumes that yield is influenced by multiple factors, including soil properties, weather, and input management. These properties either have a positive or negative influence on the yield outcome, which are then indirectly incorporated in the management zones we identify.

We did not directly compare uniform and variable application rates in field trials. Instead, we used data from the randomised trial to simulate both scenarios in the same field. Thus, the same data was used to determine the optimum flat rate and the optimum variable rate for three zones in the field (as illustrated in *Figure 1 C)*.

Key findings

Findings from 12 site years of soya bean trials conducted in the Free State,

Figure 1: Trial design (A), as-planted (B) maps, and delineated management zones (C) for a soya bean trial on a farm located in North West.

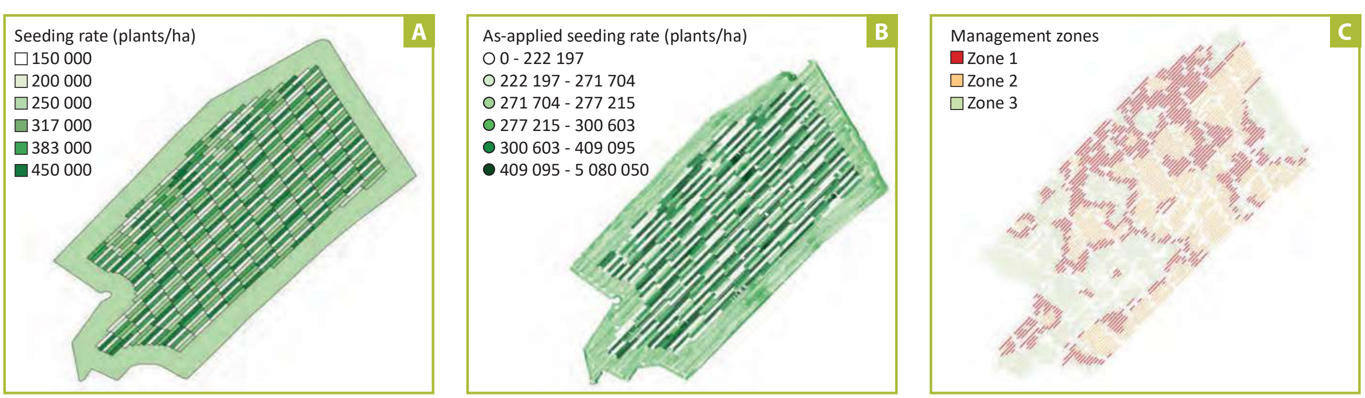


Table 1: Field names, localities and trial design information for all included soya bean seeding rate trials.

Field	Province	Season	Cultivar	Plant date	Harvest date	*Status quo* seed rate	Min seed rate	Max seed rate
						Plants/ha		
Botesrust	FS	2020/21	PAN1623R	18 Nov 2020	12 April 2021	250 000	150 00	400 000
Vliegveld	FS	2021/22	PAN1521R	11 Dec 2021	22 April 2022	250 000	150 00	450 000
Uitsny	FS	2022/23	SY 657	23 Dec 2022	19 April 2023	300 000	150 00	450 000
Vliegveld	FS	2023/24	PAN1521R	11 Nov 2023	12 April 2024	300 000	150 00	450 000
D3	MP	2019/20	PAN1521R	26 Oct 2019	9 May 2020	280 000	170 000	370 000
NK1	MP	2020/21	PAN1521R	26 Oct 2020	12 April 2022	280 000	180 000	380 000
D3	MP	2022/23	PAN1555R	19 Nov 2022	18 April 2023	280 000	200 000	400 000
NK1	MP	2023/24	PAN1521R	3 Nov 2023	11 April 2024	280 000	200 000	400 000
Geluk	NW	2020/21	P64T39R	12 Nov 2020	9 April 2021	300 000	100 000	400 000
Schietfontein	NW	2020/21	Agriocare EC24	23 Nov 2020	5 April 2021	300 000	100 000	400 000
VDAMR	NW	2021/22	P64T39R	5 Nov 2021	6 May 2022	300 000	200 000	450 000
Geluk	NW	2022/23	P64T39R	24 Oct 2022	11 April 2023	300 000	180 000	370 000

Producer preference and equipment influenced the increments of variation and number of seeding rate factors. Cultivar selection was mainly based on planting dates. FS: Equaliser planter with 0,915m row widths; MP: John Deere 1755 Seedstar2 with 0,76m row widths; NW: John Deere 1750 planter with six rows of 0,76m, 'skip rows', resulting in average row widths of 1,14m.

Mpumalanga, and North West provinces underscore the importance of tailoring seeding rates based on seasonal and provincial conditions. Statistical analyses showed that yield differences were significantly influenced by the chosen seeding strategy. In all seasons, the variable rate strategy performed better than the *status quo* rate, but did not differ significantly from the optimal flat rate. Nonetheless, province and seasonal conditions still played a role in the yield outcome.

Key factors included:

- Rainfall distribution during reproductive stages (flowering to seed fill).
- Cultivar adaptability to stress and drought conditions.
- Planting date, affecting cultivar selection, and development timing.

The yield potential is influenced by multiple interactions including cultivar characteristics, planting date, row spacing, and environmental conditions. While maize typically exhibits a more predictable, linear relationship between plant density and yield, soya beans show a more flexible, non-linear response.

Modern cultivars can compensate for lower plant densities through increased branching and pod development. This means that under the right conditions, fewer plants can still result in good yields – ultimately saving input costs. However, even in dry years or seasons with erratic rainfall, increased seeding rates could not overcome the challenges posed by water stress at critical growth stages.

Case study 1: Free State

Optimal flat rate recommendations varied by season. For two of four site-years, an increase in seeding rate was suggested. Notably, a 79% increase in 2021/22 increased yield by 940kg/ha, with 2022/23 only suggesting a 12% increase (50kg/ha). However, the 2020/21 season suggested a 40% reduction with minimal yield benefit (10kg/ha) and in 2023/24, a 45% reduction had no yield impact.

Where the variable rate calculations suggested adjusted plant populations based on field zones, optimal seeding rates on average ranged from 150 000 to 469 000 plants/ha. In three of four site-years, the optimal variable rate was higher than the *status quo*. Suggested increases were on average 69, 12, and 4% higher than the original *status quo* rates for respectively 2021/22, 2022/23 and 2023/24. The 2020/21 season was the only one where a reduced average seeding rate was suggested based on the management zones. Neglectable yield differences of approximately 85kg/ha were achieved in 2020/21, 2022/23 and 2023/24, while an 860kg/ha difference was measured in 2021/22.

VRS delivered the greatest profit in 2021/22, outperforming the *status quo* by R7 025/ha (33% improvement). In other years, profit gains were between R722/ha and R1 457/ha. Changes towards more optimal seeding rates had a positive impact on profitability in all four seasons. However, the magnitude of the profit difference ranged significantly.

Case study 2: Mpumalanga

Optimal flat rate recommendations varied over seasons, suggesting both increases and reductions from the *status quo* of 280 000 plants/ha. A 32% increase in 2019/20 led to a 260kg/ha yield gain. However, in two subsequent seasons (2020/21 and 2021/22) lower seeding rates were suggested (16 to 28% reduction) with negligible or no yield penalty. In 2023/24, a 40% increase in seeding rate offered a minor 50kg/ha yield improvement, indicating limited return from uniform seeding adjustments.

Yield responses were again inconsistent when adjusting seeding rates by management zone. The 2019/20 season had the biggest positive influence on yield, where an 8% increase in seeding rate resulted in a 420kg/ha yield increase. All three consecutive seasons had a much smaller impact on yield response despite different suggested optimal seeding rates per management zone. The years 2020/21 and 2022/23 suggested on average 19% higher seeding rates compared to the *status quo*, but yield improved by only 30kg/ha or reduced by 50kg/ha depending on the season. In 2022/23, a 22% reduction in the average seeding rate was suggested, with a 30kg/ha yield improvement.

In the 2019/20 season, VRS significantly outperformed other strategies, with a profit increase of R9 300/ha. In other years, profitability was similar across

Figure 2: Soya bean seeding rates (plants ha-1) and yields (tonne ha-1) (A) and profit differences for *status quo* seeding rates, flat rate, and variable rate strategies (B) in the Free State. Standard error for variable rate approach is an average over the three zones.

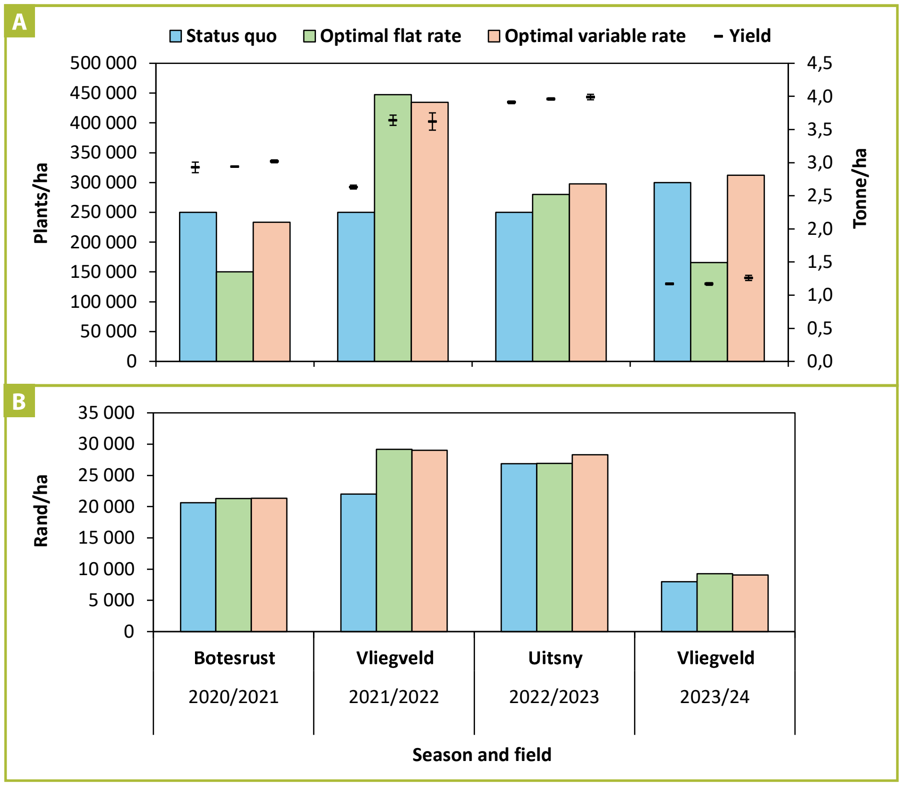
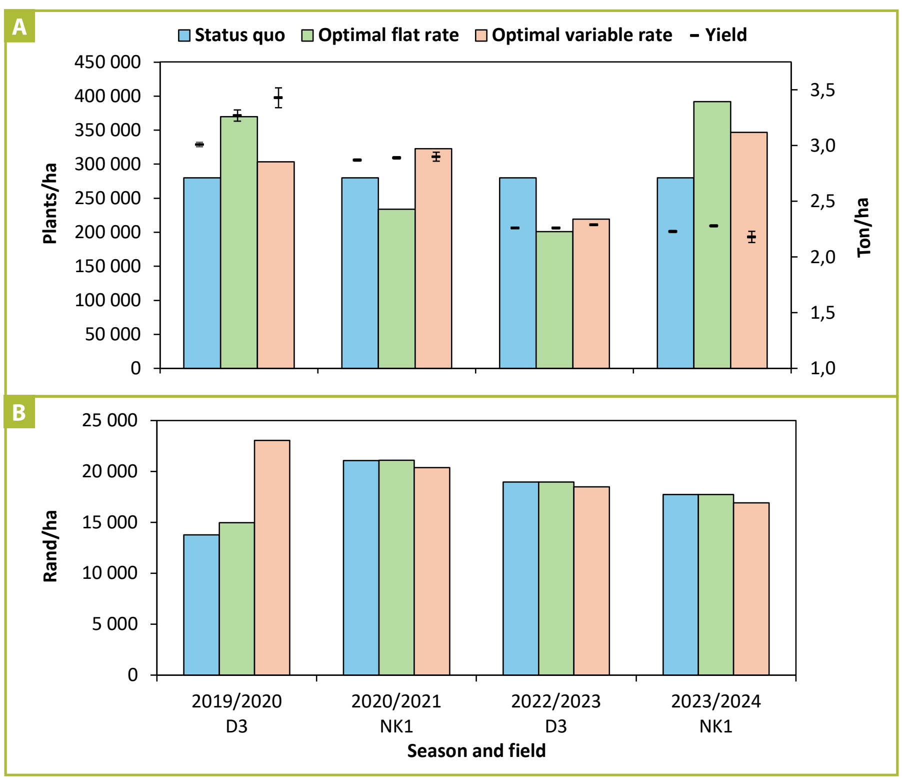


Figure 3: Soya bean seeding rates (plants ha-1) and yields (tonne ha-1) (A) and profit differences for *status quo* seeding rates, flat rate, and variable rate strategies (B) in Mpumalanga. Standard error for variable rate approach is an average over the three zones.



all approaches or slightly favoured the flat rate. Profit differences between the variable rate strategy and *status quo* differed on average with R667/ha (in favour of the *status quo*). The optimal flat rate preformed on average R672/ha better than the producer's usual *status quo*. These findings suggest that while VRS can offer substantial returns in favourable seasons, its profitability is not guaranteed under all conditions.

Case study 3: North West

The North West province trials produced the highest yields (up to 5,8t/ha) and showed the greatest profitability from VRS. In two out of four site-years, higher flat rates were recommended, with seeding rate increases of around 98 000 plants/ha from the *status quo* rate (300 000 plants/ha). These increases were modestly rewarded with yield gains of 60 to 90kg/ha. In contrast, the following two seasons favoured lower seeding rates. In 2021/22, a 33% reduction in the seeding rate led to a 350kg/ha yield increase. Meanwhile, the 2022/23 season showed no yield change despite a slight decrease in seeding rate (5%), emphasising limited response to uniform rate adjustments under variable field conditions.

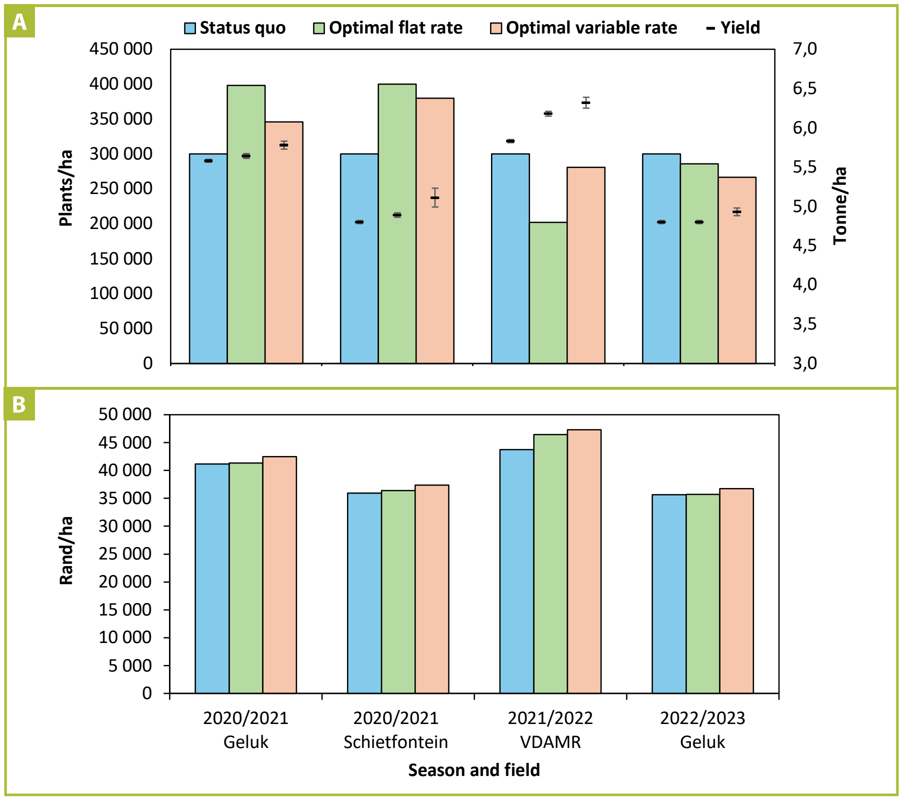
Suggested variable seeding rates ranged widely (between 190 000 and 461 000 plants/ha), influenced by within-field variability. Yield response to these rates was field- and season-specific. In 2021/22, good yields (6,25 to 6,45t/ha) were achieved at lower seeding rates in two zones, highlighting efficiency. Conversely, in 2020/21, stable yields across zones suggested tolerance to varied seeding rates.

VRS consistently delivered the highest profits across all fields and seasons. In 2020/21, profit increased by R1 370/ha on average over the *status quo*. In 2021/22, the highest overall profit was achieved, exceeding the *status quo* by R3 509/ha and the flat rate by R2 692/ha. Even during the lower-yielding 2022/23 season, VRS maintained a financial edge, albeit with smaller margins.

Summary

Our findings highlight that an optimal flat rate or VRS strategy provides an improved management approach, but site-specific and seasonal variability still plays an

Figure 4: Soya bean seeding rates (plants ha^{-1}) and yields (tonne ha^{-1}) (A) and profit differences for *status quo* seeding rates, flat rate and variable rate strategies (B) in North West. Standard error for variable rate approach is an average over the three zones.



important role in yield responses. The observed differences in optimal seeding rates across provinces emphasise that a standardised seeding recommendation is insufficient. Instead, regionally tailored seeding rate approaches are necessary to account for interactions between plant population, environmental conditions, and management practices.

The optimal flat-rate seeding recommendations across the 12 site-years averaged 293 875 plants/ha, aligning with previous research. On average the recommended increase in seeding rates was 38% for six site-years and the average decrease was 28% in the remaining site-years.

Within provinces, yield was either similar or higher for the optimal flat rate seeding rates, with increases varying from 10 to 1 010kg/ha for the Free State, 60 to 250kg/ha for North West and 20 to 260kg/ha for Mpumalanga. While higher seeding rates in low-productivity environments can enhance yield potential, excessive plant populations may not always translate to higher profitability, particularly in resource-limited conditions.

VRS demonstrated statistically significant yield and economic benefits when compared to the *status quo* rates, but it did not differ from the optimal flat rate approach. Eight site-years resulted in an increased planting population of 22% for the variable rate approach, the remaining four site-years resulted in a decrease of 12% compared to the usual *status quo* rates. Only one site-year resulted in a yield decrease of 50kg/ha, while the rest increased between 30 and 990kg/ha (~260kg/ha).

VRS demonstrated economic benefits, particularly in fields with greater in-field variability, but magnitude of profit differed. The extent of economic advantage depended on specific field conditions and seasonal rainfall. The strongest profitability benefits were observed in North West and the Free State, whereas Mpumalanga showed mixed outcomes. Nine site-years demonstrated an increased profit margin compared to the initial *status quo* profit, while three of the site-years from the same province resulted in a reduced profit. These results align with global studies suggesting that variable seeding rates can optimise profit by tailoring plant populations to soil properties and historical productivity.

Ultimately, while seeding rate adjustments offer a valuable tool for improving profitability, the success depends on the integration with other agronomic practices such as cultivar selection, planting date optimisation, and soil management. Future research should further refine VRS recommendation based on site-specific yield potential and environmental stress factors.

As adoption of precision agriculture technologies continues to grow, South African producers can leverage data-driven, adaptive approaches to soya bean seeding, ensuring both sustainability and profitability across varying environments.

What does this mean for soya bean producers?

- ***No one-size-fits-all solution:*** Uniform seeding rates across all fields – or even within a single field – may result in missed opportunities for input cost savings and potential yield gains.
- ***Flexibility is key:*** Producers who are willing to adjust practices each season – based on local conditions and crop performance data – stand to gain the most in the long run.
- ***Room for optimisation:*** Even though no one-size-fits all solution exist, there remains room for improvement in terms of soya bean seeding rates.
- ***Environmental impact:*** Weather and soil conditions have the strongest impact on yield. Understanding rainfall patterns, soil type, and temperature is key to informed decision-making.
- ***Data-driven decisions payoff:*** VRS offers a promising way to balance input costs and yield potential, especially when coupled with soil chemical and physical maps – and yield history.

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For more information on cultivars, seeding, fertilisation rate and yield per management zones, send an email to trials@bfap.co.za