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Yield and economic benefits of the national cultivar trials for wheat in South Africa: 1998–2016

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ABSTRACT
Cultivar choice is an important production decision by which producers aim to achieve highest returns with the lowest risk, for yield optimisation. Cultivar testing through evaluation trials provides information on selected cultivar characteristics and performance under different conditions, which farmers use to minimise risk elements associated with limited cultivar performance information. In South Africa, the Agricultural Research Council conducts national wheat cultivar trials funded from public resources. However, the economic value of the programme remains unknown. The study estimates aggregate economic benefits associated with the programme using data from 1998 to 2016 and attribution methodologies used in other studies, modified within the context of this study. Yield gain estimates are used as indicators to estimate the contribution of seed choice to yield growth at selected levels of the assumed plausible yield gains. Overall, the study estimates that 0.04 ton (40 kg) per hectare of extra wheat yields accrued to wheat producers as a result of cultivar trials in the period under consideration. The net present value was found to be R173 million (in 2016 prices), while South Africa received R4.33 for every Rand invested into the programme. An estimated MIRR of 7 per cent suggests that investments into the programme have been a worthwhile use of public funds. The observed yield gains and favourable efficiency measures motivate continuation of the programme.

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1. Introduction

Small grain crops in South Africa are produced under very dynamic and often harsh environmental conditions. Therefore, selection of cultivars best adapted to the conditions under which small grain crops are to be grown is very important. Cultivar choice is an important economic and production decision by which a producer aims to achieve highest returns with the lowest risk, and if correctly planned, could contribute greatly to optimising yields (DAFF, no date). There are cultivars for different agro-ecological conditions, with varying yield potential, whilst some cultivars are preferred more by millers than others are. It is within this context that seed becomes one of the most significant production inputs in agriculture.

Morris (1998) suggests that seed plays a bigger role and, when compared with other inputs, it has the utmost potential to determine production. Similarly, Eaton (2013) highlights the importance of seed in determining the possible production frontier, in terms of quality and quantity. Once reliable cultivar

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performance information has been provided to farmers, it becomes easier for farmers to decide which cultivars are best adapted to the conditions under which they are to be produced. Therefore, cultivar evaluation becomes a key condition in advancing the process of identification of appropriate cultivars for different environments (Olver, 1982). Cultivar trials minimise risk elements inherent in the seed selection decision as a result of inadequate cultivar performance information (Hall and Khan, 2002).

1.1 Wheat breeding research and cultivar trials in South Africa

Neethling (1962) in van Niekerk (2001) indicates that wheat-breeding research in South Africa dates back to 1891 in the Western Cape Province when the first cultivar evaluation programme began. While the first series of artificial crosses between varieties marked the beginning of modern wheat breeding research in the country to retain resistance to rust disease, the main aim focused on replacing the poor milling quality and aptness to shed grain before harvesting. With progression of time, records of wheat harvests in South Africa made in 1935 reported extreme poor wheat quality attributed to the fact that none of the cultivars were of bread wheat quality. This led to the establishment of the Wheat Industry Control Board in the same year to regulate the industry. Under the Board there were continued efforts to improve efficiency of the wheat breeding programmes. This led to nationalisation of the small-grains breeding effort within the public domain, marking establishment of the Small Grains Centre during 1975, which subsequently became a fully-fledged Institute in 1992 under the Agricultural Research Council (ARC). To date there are three other private wheat breeding companies in South Africa, namely Sensako (established in the mid-1960s), Carnia (which started selling Cargill hybrids during the 1980s) and PANNAR (which entered the breeding scheme in the 1990s).

The ARC's Small Grain Institute (ARC-SGI) is mandated to conduct national wheat cultivar trials (NCTs) on a scientific basis; not only of its own bred and selected cultivars, but also those of other private breeding institutions. This contributes to ARC's mandate to continuously supply information on the performance of small grain crops cultivars registered in the Varietal List in the Directorate–Plant Production of the Department of Agriculture, Forestry and Fisheries (DAFF).

The cultivar trial programme is publicly funded and conducted in three regions: winter (contributing about 50% of total production), summer (accounting for approximately 30%) and irrigation (accounting for about 20%). The purpose of conducting wheat cultivar trials is to provide unbiased information of new and existing grain crops cultivars in various localities covering a variety of cultivar characteristics (Olver, 1982; Gevers, 1988; 1992). Through these trials, farmers are in a better position to make informed decisions regarding which seed to procure and plant in their localities (Dlamini and Liebenberg, 2015). This is because a decision that a farmer makes is complicated by several factors that include adaptability, yield potential, grading and quality, diseases and pests, seed price, hectolitre mass, and disease risks of the commercially available cultivars in the market. While farmers often overlook a good new technology in support of an old one, the decision value of the NCTs is when a farmer is able to make a choice after a comparison of the performance of alternative new cultivars amongst themselves and against existing ones, and their performance within their specific context (Dlamini & Liebenberg, 2015).

This study comes at a time current trends in South Africa point towards a number of concerns. Figure 1 shows that despite a general increase in average wheat yield over time, there is a continuous decrease in area under wheat with corresponding decrease in wheat production over time. Consequently, the country remains a net importer of wheat to meet the domestic demand for wheat consumption. Although the observed yield increases are due to better planning, planting methods and management practices, they could also be attributed to wheat breeding research and cultivar evaluation programmes. The yield increase could also have compensated for potential decreases in wheat production despite the shrink in area under wheat over time.

An additional issue of concern is the general reduction in public funding of research programmes, due to shifting priorities that intensify competition for available public funds. As noted by Thirtle *et al.* (1998) and Liebenberg (2013), research funding in South Africa has been diminishing in inflation-adjusted terms. Dlamini and Liebenberg (2015) point out that, for programmes whose value is not

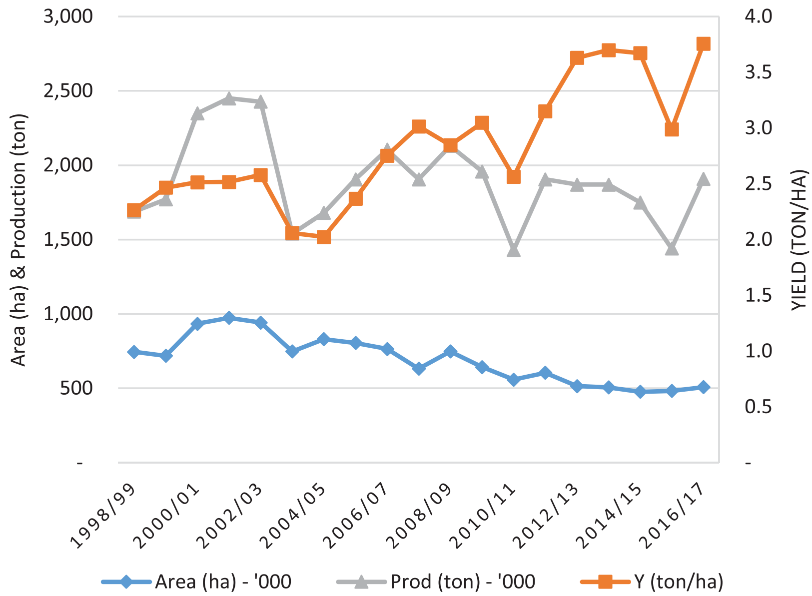

Figure 1. Wheat production trends in South Africa: 1998–2016. Source: Author compilation.

known, the inclination is likely to shelve such programmes. This therefore suggests a need for continued wheat research for sustained wheat production to improve, or at least maintain the rate of increase to meet the growing demand in the face of increasing population and buying power of the populace (Pakendorf, 2013).

The debate on allocation of scarce public resources can be informed by evidence of net gains from research investment (van Rooyen *et al.*, 1996). Tangible demonstration of the economic benefits of research is necessary and, hence, studies of this nature are imperative. Dlamini and Liebenberg (2015) investigated benefits of the national maize cultivar trials in South Africa, and found positive returns on investment into the programme. Another unpublished ARC study by Dlamini (2014) which investigated the benefits of trials for other grain crops such as soybean and groundnut also found positive returns on investment. Despite the fact that wheat is an important grain crop in South Africa, there is no similar study on the wheat cultivar trials programme. This study, therefore, seeks to contribute towards scholarly literature on benefits of R&D investments, by estimating the economic benefits of the wheat NCTs.

2. Data, sources and methodology

The study used data from 1998 to 2016 extracted from the small grains national cultivar trial evaluation reports of the ARC-Small Grain Institute and from the South African Grain Laboratory (SAGL). Data used included average experimental yields (ton/ha), cultivars evaluated in different localities in the three regions (i.e., irrigation, winter and summer). Data from the SAGL included area and wheat production levels in each region under study. Data used to aggregate costs related to the wheat cultivar trial programme were extracted from the ARC's financial databases and other relevant sources. Data on selected discount rates,[1] based on the long-term government bond were obtained from the South African Reserve Bank (SARB), supported by data accessed from the Treasury website.

2.1 Methodology: contextualisation

Griliches (1958) highlights that evaluations of economic returns to private and public research investments should be based on underlying assumptions that they are approximately equal to the value of the resulting increase in output and a price adjustment. Similarly, Pardey *et al.* (2004) emphasise the isolation of shifts in yields attributable to agricultural research and development (agR&D) in relation to some base period/year or the use of area planted to, and adoption rates of, technology to estimate the gross annual research benefits (GARB). This is to enable estimation of yield gains attributable to a technology, the wheat cultivar trials in this context.

Beddow (2012) and Pardey *et al.* (2012) state that agriculture and more especially crop enterprise is a physically expansive sector having diverse regions with different production capacities; therefore, it is crucial to apply attribution approaches that use indices to sufficiently estimate yield gains that accrue as a result of agR&D. The indices can be weighted based on a number of factors, which include area planted or estimations of agricultural production (Pardey *et al*., 2012). This is dependent on the nature of the available data. Similarly, because the NCTs are conducted in different and diverse regions, the use of weights was considered appropriate.

The estimation of experimental yield indices was based on area planted to wheat in the different regions of the country. Adoption rates in each of the regions were also used in the estimation the indices (see Table 1 and Figure 2). The data on cultivars and corresponding average experimental yields were captured for specific localities selected for the study in each respective region. Localities with inadequate data and gaps were dropped. Using area planted to wheat in each region, together with the adoption rates, the experimental yield indices were determined per region (Section 3.1).

Figure 2 shows that adoption rates of wheat cultivars were generally higher in the winter and irrigation regions while they were lower in the summer regions. Lower adoption rates lead to reduced wheat output levels as farmers continue cultivating old and poor yielding varieties that are susceptible to pests and diseases, in the midst of changing production patterns and climate variability among other factors. Overall, this creates a gap between production and demand, necessitating increased imports, with unfavourable consequences on the fiscus and balance of payments of the country.

2.2 Estimating the proportional gain in experimental yield

The proportional gain in experimental yield was estimated through establishing an index of experimental yield in region *l* in year *t* based on the observed pattern of adoption and the observed experimental yields of wheat varieties in each respective region under cultivar trials. The approach in this

Table 1. Area, number of sites and cultivars used in the study.

	Irrigation region			Winter region			Summer region		
Year	Area (Ha)	Local sites	No. of cultivars	Area (Ha)	Local sites	No. of cultivars	Area (Ha)	Local sites	No. of cultivars
1998	104 000	16	12	354 000	14	11	453 000	11	23
1999	141 200	9	8	345 500	13	7	447 300	8	20
2000	125 600	13	8	345 000	22	9	502 900	12	19
2001	133 600	14	12	364 000	20	10	443 500	13	20
2002	100 500	15	13	325 000	24	9	322 500	15	18
2003	119 400	25	11	354 000	11	10	356 600	11	20
2004	119 000	27	13	302 000	13	10	384 000	16	21
2005	110 000	23	11	292 000	21	14	362 800	12	23
2006	88 200	35	12	325 000	17	14	218 800	16	26
2007	112 500	23	12	350 000	13	9	285 500	16	23
2008	102 500	27	12	300 000	20	11	240 000	7	26
2009	84 600	19	14	265 000	22	11	208 500	15	20
2010	109 700	23	19	265 000	23	12	230 000	14	18
2011	104 700	25	25	272 000	25	15	134 500	17	18
2012	101 000	33	25	310 000	25	15	94 500	14	18
2013	94 070	26	19	310 000	26	12	72 500	9	20
2014	130 440	31	13	305 800	29	14	40 330	8	20
2015	116 997	24	18	305 500	29	14	59 653	6	20
2016	104 405	20	15	315 000	29	14	88 960	10	22

Source: SGI cultivar trial reports and SAGL wheat quality reports: 1998–2016.

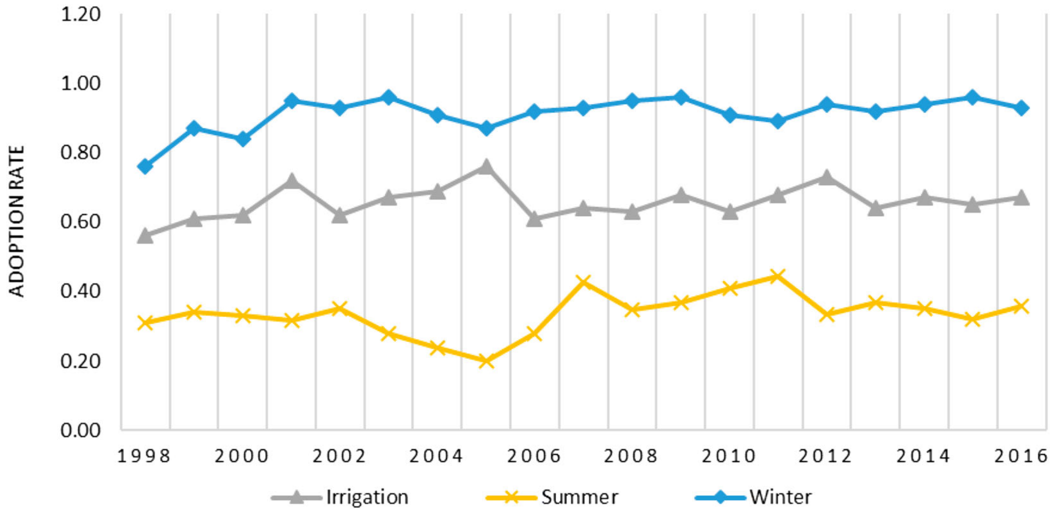

Figure 2. Adoption rates for wheat cultivars selected for the study in each region: 1998–2016. Source: Authors' own calculations using data from the SGI cultivar trial reports.

study followed Dlamini and Liebenberg (2015) in a study estimating the economic returns to maize cultivar trials programme. This is specified in equations illustrated below:

$$Y^a_{lt} = \sum_{i=1}^{n} Y_{lt}\,.\pi_{lt}$$
$$\text{and } \pi_{ilt} = \frac{A_{ilt}}{A_{lt}} \text{ and } A_{lt} = \sum_{i=1}^{n} A_{ilt} \tag{1}$$

where Y^a_{lt} is the experimental yield index in region l, in time t. Y_{lt} is the experimental yield in region l in year t, π_{lt} is the proportion of area planted to wheat in region l in year t, A_{ilt} is area grown to variety i in region l. An alternative experimental yield index performance in region l in year t, given a *counterfactual* adoption pattern would, however, differ in terms of the adoption weights applied to the same experimental yields.

To represent this scenario of no change in varieties over time, adoption proportions are held constant over time at their values in the base year (i.e., in Equation (1), setting $\pi_{lt} = \pi_{lb}$ for all the years, t, where π_{lb} is the share of the total area planted to wheat in locality l in the base year). This specification is illustrated in Equation (2) below:

$$Y^b_{lt} = \sum_{i=1}^{n} Y_{lt}\pi_{lb} \tag{2}$$

The study also draws from a similar approach by Pardey *et al.* (2004), by estimating additional yields gains (or losses) (k_{lt}) due to national wheat cultivar trials using the specified Equation (3) below:

$$k_{lt} = \left(\frac{Y^a_{lt} - Y^b_{lb}}{Y^a_{lt}}\right) \tag{3}$$

where Y^a_{lt} defines an experimental yield index in region l after wheat cultivar trials were instituted, in year t and Y^b_{lb} is an experimental yield index in region l before the national wheat cultivar trials in base year b. Having estimated the proportional yield gain (k_{lt}) as a result of the cultivar trials programme, it was possible to estimate economic yield benefits of the cultivar trials at selected levels of assumed plausible yield gains attributed to the programme.

2.3 Estimating the economic value of the national wheat cultivar trials in South Africa

The evaluation used the attribution method following other studies (e.g., Pardey *et al*., 2004; Dlamini & Liebenberg, 2015) to estimate benefits of the wheat cultivar trials focused on yield benefits, *ceteris paribus*. The study estimated the GARB based on the assumption that they were equivalent to a proportion of the value of additional output attributable to the wheat cultivar trials programme. Estimated experimental yields were used to quantify additional gains in wheat yields, while other variables influencing wheat yields were purposively held constant. The estimation of aggregate economic benefits (B_l) for each region attributable to wheat cultivar trials, equivalent to the aggregate benefits obtained in region l for all localities L at year t for all the years T, considering proportional yield gain (k) are determined as specified in Equation (4) below:

$$B_l = \sum (ak_{lt}.\, P_t.\, Q_{lt}) \tag{4}$$

where PQ measured the value of production for a given region l for all the regions at year t for all the T years; k being the proportional gain in yield as a result of wheat cultivar trials, while α represented a proportion of the credit that is attributed to the wheat cultivar trials. Multiplying the k factor by the actual value of production yielded a measure of the additional value of production attributable to the adoption of new, higher-yielding wheat varieties. This proportion also assists estimating a financial value for the benefits accruing from cultivar trials (Equation (4)).

Similarly, the ak estimate, as used by Dlamini and Liebenberg (2015), was also used to quantify the proportional decrease in wheat production in the event that the national wheat cultivar trials were not introduced. In simple terms and as applied by Dlamini and Liebenberg (2015: 48), 'multiplying the proportional decrease in production by the actual value of production gives a value of production forgone had farmers continued to speculate about which seed or cultivar to plant'. Overall, estimating the economic value of the national wheat cultivar trials indicates whether public funds invested into the programmes have provided any significant benefits or not to farmers and South Africa at large.

2.4 Quantifying the costs[2] of the national wheat cultivar trials programme

A number of procedures are proposed to determine and quantify costs incurred for the activities involved in conducting the national cultivar trials. Following Dlamini and Liebenberg (2015), and inspecting the records of the programme and discussing with researchers, the cost drivers that were identified and their estimation approaches are discussed in subsequent sections.

2.4.1 Labour (personnel) expenditure

The labour costs constitute a bigger share of total costs incurred during field trials. Labour requirements of wheat cultivar trials were composed of researchers, technicians and some support personnel in each of the three wheat-producing regions in South Africa. To estimate the set of labour costs using time series data from 1998 to 2016, an inventory of staff associated with wheat cultivar trials was developed based on disciplinary classification (e.g., plant breeder, pathologist, etc.), qualification status (e.g., PhD, MSc, etc.) and other support staff categories. The portion of expenditure on labour was quantified by aggregating the amount of time spent on the trials by the personnel in a year. After accessing data on salaries, and taking R_{qct}, for qualification class, q, for each wheat cultivar c, and each year t, the share of labour costs ($SNCT_{ct}$) devoted to wheat cultivar trials programme were estimated as follows:

$$SNCT_{ct} = \frac{\sum_q R_{qct} S_{qct}\, L_{qct}}{\sum_q R_{qct} L_{qct}} \tag{5}$$

where S_{qct} is an estimate of the share of each respective labour class devoted to wheat NCTs in each year. The total labour/personnel expenditure associated with the programme were therefore estimated for each region.

2.4.2 Operational costs

These costs include field and laboratory chemicals, fuel, energy and various other costs used to undertake the wheat cultivar trials. Time series data on operational expenditure associated with the wheat cultivar trials from 1998 to 2016 was determined from ARC-SGI financial report databases. This data was used to estimate the operational expenditure directly related to wheat cultivar trials over the time under consideration.

2.5 Costs incurred by other collaborators

The seed companies whose cultivars are evaluated in national wheat cultivar trials are still faced with labour/personnel and other related research costs during the evaluation trials. Ideally, these expenditures should be considered to adequately capture the actual economic benefits associated with the wheat cultivar trials. Generally, the costs have no effect on the yield gains attributable to cultivar trials; however, they do affect the efficiency measures, e.g., the NPV, BCR, which may be overestimated in the case where research expenditure from other players is omitted in the analysis.

In this study, labour and operational expenditures that other collaborators incurred were assumed equal to those incurred by the ARC in a respective region in which trials are conducted. What motivated this decision is the fact that these costs, e.g., fuel, inputs, etc., in a given region can actually be incurred by one agency or shared by the parties. For example, expenditure items related to land preparation, fertilisation and all other inputs in the trials have been incurred and hence cannot be double counted. Furthermore, this data was also not available from the collaborators.

2.6 Aggregating benefits and costs for the wheat NCTs

After collating the benefits and costs associated with the wheat cultivar trials for the period 1998–2016 for different regions, benefits and costs streams were compared as applied in attribution studies by Alston *et al.* (1998), Pardey *et al.* (2004) and Dlamini and Liebenberg (2015). In this study, the net present value (NPV), benefit–cost ratios (BCR) and modified internal rate of return (MIRR) were used to aggregate research flows at a selected discount rate.[3] The efficiency measures were estimated for each region where cultivar trials were conducted. The efficiency estimates were also aggregated to reflect the overall efficiency of the wheat NCTs at national level.

2.6.1 Estimating the NPV

The NPV is a risk free measure used to evaluate if an investment is cost-effective or not and this is a measure of the present value (PV) of the net benefits stream ($Bt + j$). If the net benefits in year ($t + j$) over the next n years are greater than 0 or are positive, an investment is therefore said to be profitable. The NPV estimation is represented as:

$$PV(B)_t = (B)_t + \frac{B_{t+1}}{(1+i)} + \frac{B_{t+2}}{(1+i)^2} + \cdots + \frac{B_{t+n}}{(1+i)^n} \quad (6)$$

where i represents the interest rate that was used to discount future benefits, chosen as 10 per cent in this case. Taking the present values of the stream of benefits (B) and the costs (C) of an investment in year t, the estimation of the NPV is specified as:

$$NPV_t = PV(B)_t - PV(C)_t \quad (7)$$

$$= \frac{\sum_{j=0}^{n} (B_{t+j} - C_{t+j})}{(1+i)^j} \tag{8}$$

2.6.2 Estimating the benefit–cost ratio

The benefit–cost ratio (BCR) is a measure of performance of the investments. It is a ratio of the present value (PV) of benefits (B) over the present value (PV) of costs (C) as specified below:

$$BCR_t = \frac{PV(B)_t}{PV(C)_t} \tag{9}$$

Applying the thumb rule, an investment is regarded profitable where the BCR is greater than 1, and otherwise if the BCR is less than one.

2.6.3 Estimating the Modified Internal Rate of Return (MIRR)

The internal rates of return reported in a number of studies are generally perceived by policy-makers to be implausibly high (Hurley *et al.* 2014). To address this shortcoming, the authors thus used the modified internal rate of return (MIRR) to allow estimation of more credible and realistic rate of return estimates. Keirulff (2008) is of the view that MIRR is a more accurate measure of the attractiveness of an "investment because attractiveness depends not only on the return on the investment itself, but also on the return expected from cash flows it generates". Although Kelleher *et al.* (2004) reported that MIRR is not perfect it does, however, allow users to set more realistic interim internal rates and therefore calculate a realistic annual equivalent yield.

The MIRR is interpreted as 'the annual compounding interest rate paid by an investment and is directly related to the benefit-cost ratio' (Hurley *et al.* 2014). When compared with the IRR, the MIRR produces more modest rates of return, with a median of 9.8 per cent vs IRR of 39 per cent per year (Dlamini, 2014). In light of this, the study applied the MIRR approach to estimate the rate of return of the NCTs for each region covered by the trials, using selected discount rates of 8 per cent and 10 per cent as informed by the long-term government Treasury bond. An overall MIRR was also computed at national level.

3. Results and discussion

3.1 Yield benefits

The yield benefits were estimated using the data set of all commercial genotypes evaluated in wheat cultivar trials in the three regions through computation of experimental yield indices. Following Dlamini and Liebenberg (2015), estimation of the indices was chosen to allow better capturing of yield improvements over time. In addition, computation of indices was also meant to stabilise yield variance differences between years. This also stabilised any observed yield variations in experimental yields between years in each region.

Figure 3 shows unstable experimental yield indices (EYI) for all the regions under the cultivar trials. The EYIs were, however, generally declining in the winter and summer regions. The observed trend suggests that the irrigation region has been generally stable and performed better compared with winter and summer regions, characterised by generally unstable and decreasing experimental yield index values. As illustrated in Table 1, the summer region generally had higher number of cultivars on average than other regions and this could explain the unstable indices observed over the time period.

3.2 Average yields for wheat cultivar trials: 1998–2016

Generally speaking, we assume farmers select higher yielding varieties in their localities based on the information provided from NCTs. Hence, we would ideally expect that their average yields in their

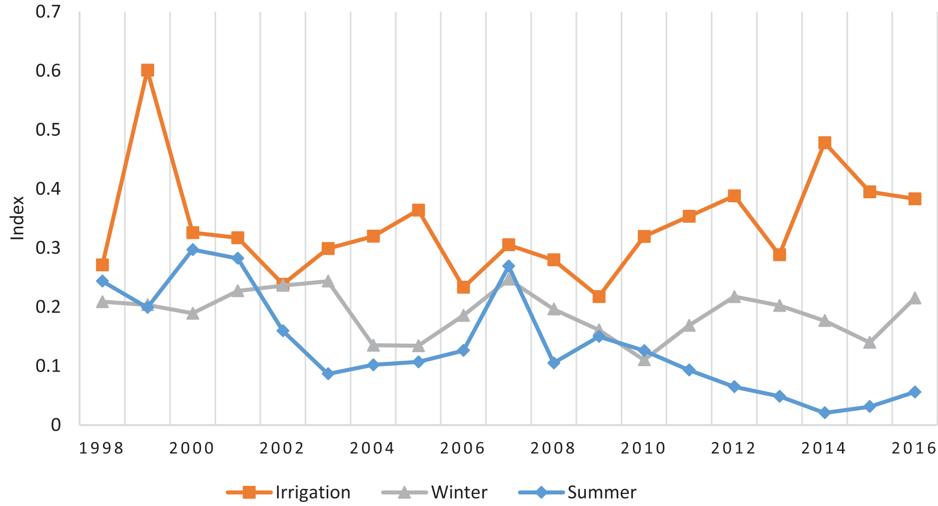

Figure 3. Experimental yield indices for wheat cultivar trials. Source: Author's own calculations using data from the SGI NCT reports: 1998–2016.

localities would move along or above average experimental yields, suggesting how efficient farmers are in wheat production. Figure 4 shows average yield changes under commercial and experimental conditions over the period 1998–2016. The results presumably depict yield gap changes attributable to institution of the national wheat cultivar trials among other factors.

Figure 4 shows higher average experimental yields in the irrigation, winter and irrigation regions when compared with average commercial yields in the country. The irrigation region had higher yields compared with the winter and summer regions. In this case, we would expect that farmers in the irrigation region would perform better and record higher yield gains than the winter and summer regions. This, however, is only achieved if farmers have access to, and make effective use of, NCTs performance information and adopt the higher yielding varieties. Therefore, it is important that information be relayed to farmers through provision of advisory services. In their maize study, Dlamini and Liebenberg (2015) indicate that trials make it possible for extension agents to

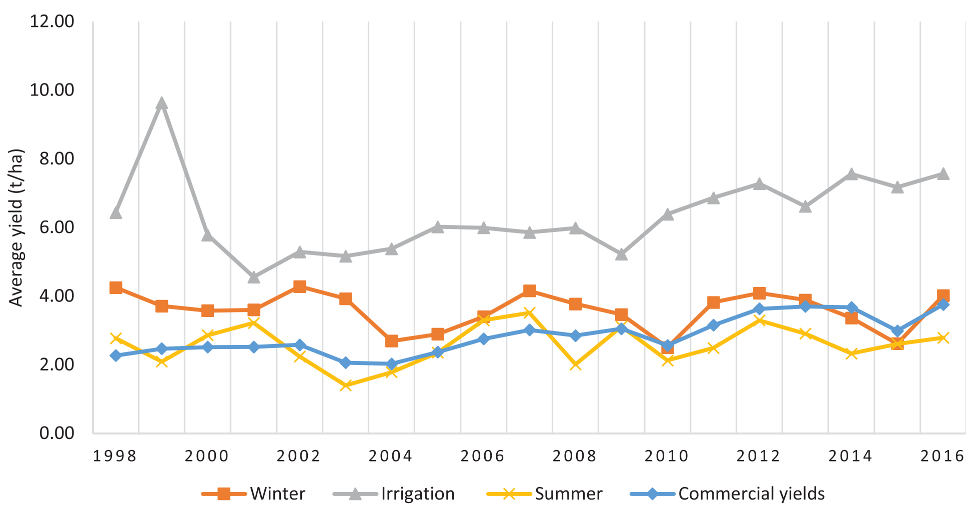

Figure 4. Average yields for wheat cultivars: 1998–2016. Source: Authors' own calculations using data from SGI NCT reports (1998–2016).

recommend cultivars that are highly adapted in farmer localities. This, therefore, ends farmer speculation regarding which seed to plant, a scenario that is congruent to the wheat NCTs. The trends suggest the importance of cultivar trials in the provision of performance information to farmers on higher yielding wheat varieties, leading to increased adoption of higher yielding wheat varieties. Therefore, farmers are able to improve their performance, achieve yield gains, thus leading to increased wheat production in the country.

The yield gain estimates attributable to wheat cultivar trials were first quantified by determining the *k*-shift at a 5 per cent level[4] of the assumed plausible yield gain estimates as a result of institution of wheat cultivar trials from 1998 to 2016. This is illustrated in Figure 5.

The *k*-estimates represented in Figure 5 show additional gains (or losses) in yields due to wheat cultivar trials. While the *k*-shift values fluctuated in the irrigation and winter regions they, however, remained positive over the time period under consideration when compared with the summer region, which has generally recorded yield losses. The increase and decline in the *k*-shift values could be attributed to favourable and unfavourable weather conditions exhibited in the different wheat producing regions of the country. The different weather conditions in these regions influence yield gains attributable to the programme differently.

3.3 Yield gain estimates

The yield gains attributable to the NCTs were estimated at selected levels ranging from 5 per cent to 15 per cent of assumed plausible yield gains for each region under the cultivar trials. This is illustrated in Table 2.

As is shown in Table 2, the irrigation region recorded higher yield gains compared with the other two regions. The region shows yield gains ranging from 0.59 ton/ha per year at the 5 per cent level to 0.72 ton/ha output per year at the 15 per cent level of the plausible yield gain estimates attributable to wheat national cultivar trials. The winter region recorded yield benefits ranging from 0.19 ton/ha at the 5 per cent level to 0.23 ton/ha at the 15 per cent level. The increases in the tonnage per hectare also represent an equivalent of what farmers would have lost had the national cultivar trials for wheat

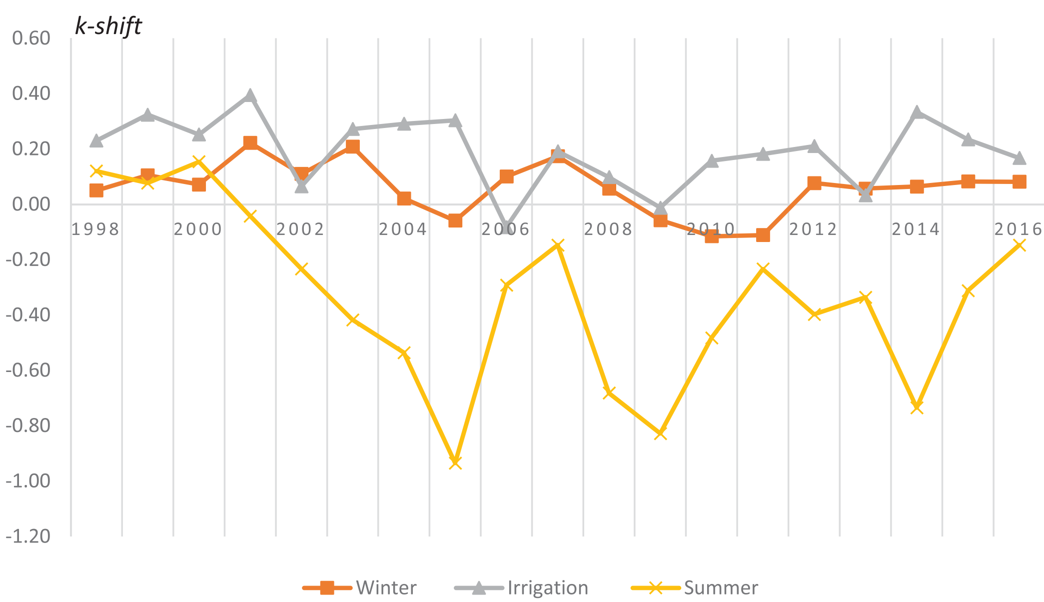

Figure 5. *K*-shift values attributed to national wheat cultivar trials. Source: Authors' own calculations based on the SGI data: 1998–2016.

Table 2. Yield gains attributable to the NCTs per region: 1998–2018.

Region	Period of trials	Additional yield gains attributable to the selection of good cultivars if NCTs contributed *a* (ton/ha)				
		5%	7.5%	10%	12.5%	15%
Irrigation	1998–2016	0.59 ton (590 kg)	0.62 ton (620 kg)	0.65 ton (650 kg)	0.68 (680 kg)	0.72 (720 kg)
Winter	1998–2016	0.19 ton (190 kg)	0.20 ton (200 kg)	0.21 ton (210 kg)	0.22 ton (220 kg)	0.23 ton (230 kg)
Summer	1998–2016	−0.74 ton (−740 kg)	−0.78 ton (−780 kg)	−0.82 ton (−820 kg)	−0.86 ton (−860 kg)	−0.90 ton (−900 kg)
Aggregated	1998–2016	0.04 ton (40 kg)				

Source: Authors' own calculations.

not been instituted. The findings also show that as the assumed possible yield gain estimates attributable to NCTs increase, the yield gains (ton/ha) also increase.

On the contrary, the summer region recorded yield losses ranging from 0.74 ton/ha at the 5 per cent level to 0.90 ton/ha at the 15 per cent level. Generally, this is what wheat farmers would have gained had they effectively used cultivar trial information. This information would have been accessed through various means that also include extension officers. On the other hand, farmers could have had access to the cultivar trial information, but their poor performance could have been a result of other factors that include poor farming and management practices, in addition to the agro-ecological conditions in which they produce wheat.

3.4 Estimation of the costs of the wheat cultivar trials: 1998–2016

Using cost data from the ARC-SGI, operational, labour and total costs associated with the institution of the wheat cultivar trials were determined for each region and then aggregated at national level. This is illustrated in Figure 6.

The larger proportion of the total cost expenditure went towards personnel costs. This is consistent with trends as observed in the maize NCTs study by Dlamini and Liebenberg (2015). Notably,

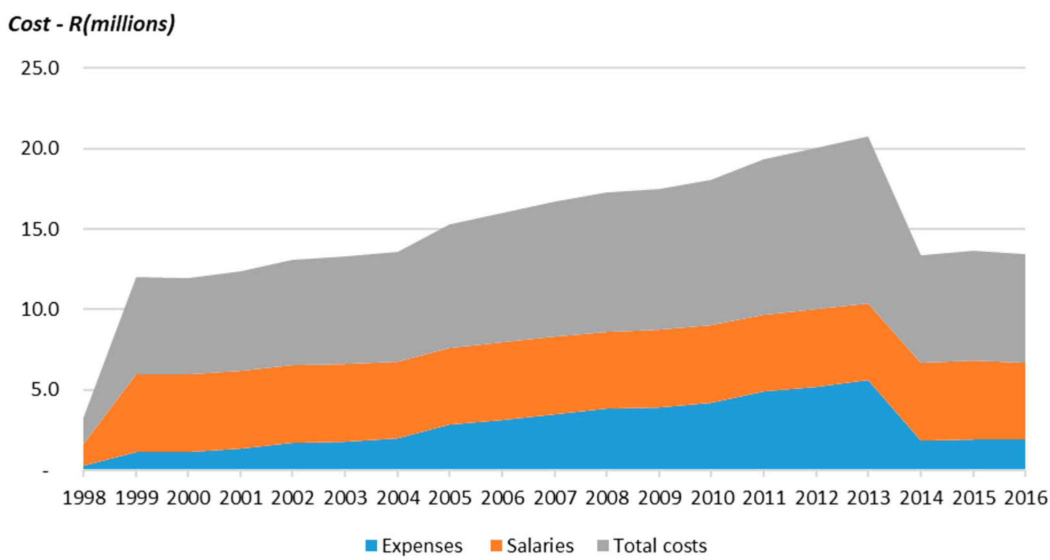

Figure 6. Cost expenditure for national wheat cultivar trials: 1998–2016. Source: Authors' own calculations using ARC-SGI data: 1998–2016.

findings also show a decline in funding of the programme from the year 2013. This trend could have had negative effects where programme operations are concerned. This compromises on the mandate of the cultivar trial programme regarding provision of cultivar performance information on higher yielding varieties. This would lead to low adoption of higher yielding cultivars, leading to a decline in wheat output in the country. This would derail the country's efforts to improve wheat productivity to meet the national wheat demand and cater for an increasing consumption of wheat products.

3.5 Estimating the value of economic benefits

The total economic value attributable to the national wheat cultivar trials were estimated using net present value (NPV) and benefit–cost ratio (BCR). For both the NPV and BCR, a lower and upper bound of 5 per cent and 15 per cent, respectively, of the plausible yield gain estimates attributable to the national wheat cultivar trials was used. The modified internal rate of return (MIRR) estimated the rate of return on investments towards the NCTs. The results of these estimates are illustrated in Table 3.

In the irrigation region, the estimated present values of benefits that accrued as a result of investment into NCTs were R28 351 043 at the 5 per cent level and R85 053 129 at the 15 per cent level. The corresponding net present values at the 5 per cent and 15 per cent levels were R8 826 496 and R65 528 582 respectively. Also shown in the results are favourable BCRs of 1.45 at the 5 per cent level, which increased to 4.36 at the 15 per cent level. This implies that the NCT programme generated R1.45 and R4.36 respectively for every Rand invested in the programme at respective levels of plausible yield gain estimates attributable to cultivar trials. An estimated MIRR of 4 per cent was observed, suggesting worthwhile public investments in the irrigation region.

The winter region estimates for the present values of benefits that accrued as a result of investment into wheat cultivar trials ranged from R17 747 746 at the 5 per cent level to R53 243 237 at the 15 per cent level. The corresponding net present values also ranged from R7 145 909 to R53 243 237 at the 5 per cent and 15 per cent levels respectively. A BCR of 1.67 was observed at the 5 per cent level and increased to 5.02 at the 15 per cent level. This implies that the programme generated R1.67 and R5.02 respectively for every Rand invested in the programme at the respective levels of plausible yield gain estimates attributable to cultivar trials. An MIRR of 3 per cent suggested worthwhile use of public funds in the winter region.

Table 3. Estimated value of economic benefits attributable to the wheat cultivar trials in South Africa.

	Total benefits if the wheat cultivar trials contributed (Rands)				
Efficiency measure	5%	7.5%	10%	12.5%	15%
Present value (B)					
Irrigation	28 351 043	42 526 565	56 702 086	70 877 608	85 053 129
Winter	17 747 746	26 621 618	35 495 491	44 369 364	53 243 237
Summer	174 741 803	262 112 705	349 483 607	436 854 509	524 225 410
Aggregated benefits	280 840 592	331 260 888	441 681 184	552 101 481	662 521 776
Net present value					
Irrigation	8 826 496	23 002 017	37 177 539	51 353 060	65 528 582
Winter	7 145 909	16 019 782	24 893 655	33 767 528	42 641 401
Summer	157 060 026	244 430 928	331 801 830	419 172 731	506 543 633
Aggregated NPV	173 032 431	283 452 727	393 873 024	504 293 319	614 713 616
BCR					
Irrigation	1.45	2.18	2.90	3.63	4.36
Winter	1.67	2.51	3.35	4.17	5.02
Summer	9.88	14.82	19.77	24.71	29.65
Aggregated BCR	4.33	6.50	8.67	10.84	13.01
MIRR					
Irrigation	4%		Aggregated MIRR = 7%		
Winter	3%				
Summer	13%				

Source: Authors' calculations using data from ARC-SGI: 1998–2016.

The summer region estimates for the present values of benefits ranged from R174 741 803 to R524 225 410 at the 5 per cent level and 15 per cent level respectively, with corresponding net present values also ranging from R157 060 026 to R506 543 633 at the respective levels of plausible yield gain. A BCR of 3.41 was observed at the 5 per cent level, and increased to 10.23 at the 15 per cent level. This implies that the programme generated R3.41 and R10.23 respectively for every Rand invested in the programme. An estimated MIRR of 13 per cent suggested worthwhile public investments in the winter region.

The favourable efficiency estimates presented above suggest worthwhile public investments into national wheat cultivar trials in all the three regions under the cultivar trials. However, the summer region had higher economic benefits attributed to the institution of the NCTs compared to the irrigation and winter regions as shown by the efficiency estimates. Given that the summer region recorded yield losses, but still recorded higher benefits, it is thus an opportunity for sustained investments in such regions to increase and sustain yield gains and thus to benefit more in terms of wheat production and the economic value that accrues as such.

3.6 Sensitivity analysis

In an attribution study in Brazil by Pardey *et al.* (2004: 66) on benefits from varietal improvement research, the authors highlight that there is a tendency to overestimate rates of return from these studies. This is also acknowledged by Dlamini and Liebenberg (2015) in their study on the aggregate economic benefits of the national cultivar trials for maize in South Africa. As a result, the authors from these studies suggest a need to consider the "aspects of the analysis that involve analytical judgements that would otherwise have repercussions on the results". According to Pardey *et al.* (2004: 68), cited in Dlamini and Liebenberg (2015: 57), "the appropriate interest rate for discounting streams of research costs and benefits is the social opportunity cost of public funds committed to long-term investments". For developing countries, both studies note that a higher interest rate could be more justifiable because of the high costs of capital.

In light of the above, a sensitivity analysis was, therefore done to test effects of changing costs and choosing different discount rates on the magnitude of benefits accruing to national wheat cultivar trials. The study therefore re-estimates the net present value, benefit–cost ratio and modified internal rate of return using two discount rates (8% and 10%). The corresponding efficiency estimates for the different regions are, thus presented in Table 4.

The results in Table 4 indicate that the BCRs decreased by various magnitudes in all the regions. In the irrigation region, at the 5 per cent and 15 per cent level of the assumed plausible yield gain estimates, the BC ratio declined by between 0.29 and 0.88, suggesting a decrease of R0.29 and R0.88, respectively, for every Rand invested in the NCTs. In the winter region, the BCR declined by between 0.33 and 1.00, implying a loss of R0.33 and R1.00 for every Rand invested in the NCTs at the respective levels of the assumed plausible yields. The summer region had the largest declines in the BCR, ranging from 1.97 to 5.93. This indicated that R1.97 and R5.93 has been lost for every Rand invested in the NCTs at the respective levels.

The sensitivity analysis findings also reveal that at the selected 8 per cent and 10 per cent discount rates, there is a general decline in the NPVs in all regions under the wheat cultivar trials. With reference to the MIRR, at the 8 per cent discount rate, the MIRR generally increased in the irrigation and winter regions, recording 7.28 per cent and 6.83 per cent respectively while the summer region recorded a decrease from 13 per cent to 12.26 per cent. At the 10 per cent discount rate, similar trends were also observed, with increases in the irrigation and winter regions to 7.16 per cent and 6.48 per cent respectively, while the summer region recorded a decrease to 11.34 per cent. Generally, these findings suggest that benefits of the cultivar trials are sensitive to changes in costs.

Table 4. Estimated value of economic benefits attributable to the wheat cultivar trials in South Africa.

	Total benefits if the wheat cultivar trials contributed (Rands)				
Efficiency measure	5%	7.5%	10%	12.5%	15%
NPV (if *r* = 8%)					
Irrigation	4 018 421	18 456 452	32 894 484	47 332 515	61 770 546
Winter	4 578 699	13 616 903	22 655 107	31 693 311	40 731 515
Summer	155 466 241	244 455 122	333 444 003	422 432 885	511 421 766
Aggregated NPV	164 063 361	276 528 477	388 993 594	501 458 711	613 923 827
NPV (if *r* = 10%)					
Irrigation	3 945 359	18 120 881	32 296 402	46 471 924	60 647 445
Winter	4 495 450	13 369 323	22 243 196	31 117 069	39 990 942
Summer	152 639 582	240 010 484	327 381 385	414 752 287	502 123 189
Aggregated NPV	161 080 391	271 500 688	381 920 983	492 341 280	601 761 576
BCR (Irrigation)	1.16	1.74	2.32	2.90	3.48
BCR (Winter)	1.34	2.00	2.68	3.35	4.02
BCR (Summer)	7.91	11.86	15.81	19.77	23.72

MIRR	**If *r* = 8%**		
	Irrigation	7.28%	Aggregated MIRR = 9%
	Winter	6.83%	
	Summer	12.26%	
	If *r* = 10%		
	Irrigation	7.16%	Aggregated MIRR = 8%
	Winter	6.48%	
	Summer	11.34%	

Source: Authors' own calculations.
NB: Costs were inflated by 25%.

3.7 Aggregated economic benefits of national wheat cultivar trials in South Africa

Overall, the country recorded a yield gain of 40 kg/ha accruing from institution of the NCTs for the period under consideration. Generally, South Africa realised economic benefits attributable to the cultivar trials as reflected by the efficiency estimates in each region under the cultivar trials. The overall aggregated estimates for the present values of benefits that accrued as a result of investment into wheat NCTs ranged from R280 840 592 to R662 521 776 at the 5 per cent and 15 per cent level respectively. The corresponding net present values also ranged from R173 032 431 to R614 713 616 at the respective levels. Aggregated BCR estimates of 4.33 and 13.01 were observed at the 5 per cent and 15 per cent level. This implies that the trial programme generated R4.33 and R13.01 respectively for every Rand invested in the programme at these respective levels of plausible yield gain estimates attributable to cultivar trials. The observed overall MIRR was estimated at 7 per cent. The sensitivity analysis conducted also revealed how sensitive the benefits are to changing costs. Nonetheless, the favourable efficiency estimates still suggest investment into the national wheat cultivar trials was a worthwhile use of public funds.

The yield gains and economic benefits can potentially increase if there is an increase in the adoption of cultivars that suit different conditions in different regions under wheat production in the country. As explained earlier on, as an example, cultivar adoption patterns observed revealed lower adoption rates in summer when compared with other regions. It is in some of these regions that there is a need for cultivar performance information to reach farmers given the changing agro-ecological and climatic conditions in various localities. This will ensure that farmers adopt high yielding cultivars best suited to their conditions for increased wheat production in the country. This can be enhanced through various ways that include increased access to production and management information and improved management practices and provision of extension services.

4. Conclusions

The study estimated the economic benefits of national wheat cultivar trials in the three different regions of the country. This was to determine the extent to which the trials have contributed to yield growth and economic value in South Africa. Furthermore, the study also estimated the rate of return on investments made into the NCT programme. The study employed attribution methodologies that have been used in other similar studies in and outside of South Africa. These approaches were adopted and modified within the context of this study. Data and information from various localities in three regions; irrigation, summer and winter, were used. Overall, aggregated estimates were also presented to determine the economic contribution of the NCTs in South Africa at large.

Yield gain estimates were used as indicators to estimate the contribution of seed choice to yield growth at selected levels of the assumed plausible yield gain estimates. The analysis revealed yield gains per hectare because of the institution of the NCTS. Given the contribution of the NCTs to yield gain, this is indeed favourable for the country as it can contribute to increase in wheat production to meet the demand for a growing population in the midst of global change challenges that include climate variability. In addition, this could also decrease the import costs that the country is facing in an attempt to cover the shortfalls in wheat production.

The economic benefits were determined using efficiency measures that include the NPV, BCR and MIRR. The investments in the NCTs have proven to be worthwhile use of public funds given the favourable estimates. The evidence thus far, suggest that the national cultivar trial programme should be sustained to continue giving advice to farmers regarding higher yielding wheat varieties that are adapted to their local condition, thereby ensuring increased and sustained production of wheat in the country.

A study of this nature was imperative given growing concerns in the wheat industry, characterised by continuous decreases in area under cultivation and reduction in wheat production. The debate on allocation of scarce public resources to research and development should be informed by tangible demonstration of the economic benefits of research, illustrated through empirical studies of this nature. Continued investment in the national cultivar trials is recommended as it has potential to improve agricultural productivity in South Africa in the long run.

Notes

1. These were informed by the long-term government bond in South Africa, which was 9.59% in 2016.
2. Data were converted into 2016 currency values.
3. The selected discount rate was informed by the government Treasury bond as of 2016.
4. Conservative percentage estimates were used as assumptions to avoid over magnifying benefits from the national cultivar trials.

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