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CSSR Working Paper No. 365

June 2015



Published by the Centre for Social Science Research
University of Cape Town
2015

<http://www.cssr.uct.ac.za>

This Working Paper can be downloaded from:

<http://cssr.uct.ac.za/pub/wp/365/>

ISBN: 978-1-77011-352-7

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Acknowledgements:

The researchers would like to acknowledge all the farmers who willingly provided information about themselves and their farms. Special mention must also be made of Nelisa and Andiswa (the two guides), Rob Small, Dave Golding, and the rest of the *Abalimi Bezekhaya* field-management team, for facilitating the research.

Total factor productivity of urban agriculture on the urban periphery of Cape Town

Abstract

This paper investigates the efficiency relationships between inputs and outputs of urban micro-farms in two of Cape Town's townships: Nyanga and Khayelitsha. The inputs in this study were land, labour, seeds and seedlings, compost and farmer experience. Data Envelopment Analysis (DEA) was applied to 33 producers supplying a social enterprise box scheme, thereby generating individual efficiency measures relative to best practice. The DEA results revealed an average level of overall, technical and scale efficiency of 72.4%, 79.7% and 90.6% respectively. Overall efficiency was negatively correlated with land holdings and the use of compost and seedlings. This is supported by the finding that the nine best-practice farms were characterised by a smaller scale of production, indicating that efficiency losses are experienced as greater quantities of inputs are used. In terms of area differences, Nyanga farms exhibit significantly higher technical efficiency, whereas farms in Khayelitsha are more scale efficient. Standardised input and output data show both the expenditure on compost and seed to be profitable, but we failed to show that mulching or operator experience increases profitability. Fully efficient farms are R2,600 per plot more profitable than inefficient farms while farms that need a windbreak earn R700 less per plot per season than more sheltered operations. These results are the first of their kind for South Africa and lay the foundation for more effective extension to the sector.

Introduction

From 1993 to 2008, South Africa experienced real GDP per capita growth in the region of 40% (Leibbrandt *et al.*, 2010). However, this growth was not enjoyed evenly, resulting in inequality growth over the period. This has been triggered largely by a decline in real incomes amongst the lower income deciles. Concurrently, food security has become a mounting concern in South Africa, which is naturally felt most by the poor. Promoting urban agriculture has been one response to the problem. Webb (2011) summarised the now familiar benefits of urban agriculture: At the community level there are increased

economic efficiency (Nugent, 2000; Danso & Moustier, 2006), more sustainable resource use (May & Rogerson, 1995; UNDP, 1996; Howorth *et al.*, 2001), and greater community cohesion (Rees, 1997; Slater, 2001; Van Averbek, 2007). At the household level benefits include greater food security and improved nutrition (Chiapa & King, 1998; Maxwell *et al.*, 1998; Jacobi *et al.*, 2000), jobs (Binns & Lynch, 1998; Austen & Visser, 2002; Belete *et al.*, 2005; Thom & Conradie, 2012) and greater psychological wellbeing (Ngub'usim & Streiffeler, 1982; Slater, 2001; Van Averbek, 2007). According to Webb (2011) the problem with this literature is that it relies on advocacy rather than evidence.

It is important to compare like with like when assessing the performance of small-scale urban agriculture. In Botswana commercial crop production was found to be 82% efficient, compared to an efficiency level of just 34% in the small-scale sector (Thirtle *et al.*, 2003). Even where small-scale producers are compared to each other, many producers have been classified as inefficient relative to best practice (Chiremba & Masters, 2003; Speelman *et al.*, 2011). This is supported by the Data Envelopment Analysis (DEA) conducted by Piesse *et al.* (1996) in the Northern Transvaal, which revealed an average efficiency of below 50% for small-scale producers in the former homelands. A key finding was that inadequate farm size was responsible for an average of 50-60% of total inefficiency. This is particularly relevant to the present study, as all farms analysed are under a hectare in size. Of further consideration is research by Nyariki (2011), which illustrated that best-practice farmers were between 20% and 75% more efficient than the average farmer in southeast Kenya. Along with revealing a range and lack of efficiency, this study also identified land as one of the largest inhibitors thereof. Overall there is thus concern that similar inefficiencies may exist in smallholder farms of Cape Town's townships, where Harvest of Hope operates (Thom & Conradie, 2013).

To date, the productivity of urban agriculture of this nature and scale has yet to be examined. The studies referred to above have been conducted on larger, non-urban farms, distinguishing them from the township setting under examination. In this context the efficiency of urban micro-farming has implications for its effectiveness as a response to food insecurity and poverty. Poor efficiency indicates that profitability can be increased by generating the same amount of income with fewer inputs. This translates into a bigger impact on poverty. The purpose of this paper is therefore to determine the efficiency relationships of inputs and output in small-scale farming in Cape Town's Khayelitsha and Nyanga townships; and to explore whether any significant differences exist in the farming practices between these two areas.

Data and methods

The data used in this analysis was drawn from eighteen urban micro-farms (including eleven from Khayelitsha and seven from Nyanga/Gugulethu) which regularly supplies produce to Harvest of Hope, a box-scheme started by the public benefit organisation *Abalimi Bezekhaya* (Thom & Conradie, 2013). Weak recordkeeping on the part of farmers forced us to assume that they draw all their inputs from the organisation and supply their entire crop to it. We had two observations each for fifteen farms, for 2012 and 2013, and an observation for one or the other season for the remaining three farms. Data from the different seasons were pooled and where appropriate financial data were inflated to constant 2014 Rand using statistics South Africa's consumer price index. This was a convenience sample, shaped by the extent of data *Abalimi Bezekhaya* already had captured and the local knowledge of two Xhosa speaking guides who directed the site visits.

Table 1: Selected farm characteristics

Variable name (units)	n	Mean	Std. Dev.	cv
Output (Rand)	33	14,298	8,146	0.57
Compost (Rand)	33	5,376	3,982	0.74
Seedlings and seed (Rand)	33	1,768	1,133	0.64
Land (squared meters)	33	592	409	0.69
Labour (fulltime equivalents)	33	3.33	1.57	0.47
Experience	33	9.61	5.67	0.59

Table 1 lists the value of output per plot (at constant Harvest of Hope prices), plot size which is the actual land under cultivation at the time of the site visit (m^2), the amount of labour (workers) used in the past season, seeds and seedlings (further collectively referred to as 'seedlings'), compost used on the plot during the season (Rand), and years of experience (of the head farmer). These variables are largely in keeping with those investigated in the literature. Nyariki (2011) analysed land, labour, compost and seedlings whilst Piesse *et al.* (1996) distinguished between traditional inputs (land and labour) and modern inputs (hybrid seed and chemical fertilizer). However, the present study did not have to consider fertilizer as an input, as organic production is a condition for supplying to *Harvest of Hope*. Although the availability of irrigation water is essential for production during the Cape Town's dry summer months, the farmers draw water from outside taps at public institutions or from boreholes provided by the government, neither of which is metered. Furthermore, we would generally expect these farmers not to consider the amount of water

applied too carefully as they generally do not pay for the resource. Composting is there to maintain soil fertility, while mulching is supposed to be water saving. Both are labour intensive. While composting generates private benefits in the form of higher yields and healthier plants, mulching is a time-consuming operation which yields no private benefit as water is free.

In order to enhance accuracy, data regarding inputs and output were collected from two sources. The farmers provided data on labour and farming experience in short questionnaires conducted on their farms. Farms were visited over a period of five days during March 2015. Whilst on site, measurements of land under actual production were taken, ignoring unused areas. Observations were taken of whether beds were mulched at the time, and where windbreaks were present they were rated as adequate or good. All farmers were given a bag of groceries as a token of appreciation from the research project. This data collection was supplemented by data from *Harvest of Hope*, which supplied information on farmer output bought and compost and seedlings sold to each farmer. In most cases farmers indicated that they sold the vast majority of their produce to the box-scheme. However, output figures were adjusted slightly for farms that supply produce to other sources (such as their local communities), as this is unaccounted for by the PBO.

Coelli *et al.* (2005) set up the variable returns to scale data envelopment linear programming problem for I firms as follows:

$$\begin{aligned}
 & \min_{\theta, \lambda} \theta \\
 & \text{st} \\
 & -\mathbf{q}_i + \mathbf{Q}\lambda \geq \mathbf{0} \\
 & \theta \mathbf{x}_i - \mathbf{X}\lambda \geq \mathbf{0} \\
 & \mathbf{1}'\lambda = 1 \\
 & \lambda \geq \mathbf{0}
 \end{aligned}$$

This model maximises the efficiency score of the i^{th} firm, θ , across a series of firm weights, λ , subject to the constraint that all the efficiency measures must be less than or equal to one. It is done by radially contracting the input vector \mathbf{x}_i until the projected efficient input vector reaches the piece-wise linear frontier described by the efficient firms in the group. Since the frontier is set up by members of the group under consideration the set of efficiency scores is self-referenced. The constraints of the linear programming problem ensure that the projected point of efficiency $(\mathbf{X}\lambda, \mathbf{Q}\lambda)$ cannot lie outside the feasible set. The convexity constraint, $\mathbf{1}'\lambda=1$, forms a convex hull of intersecting planes that envelopes the data more tightly than in the constant returns to scale case. It ensures that firms are only benchmarked against firms of a similar size and thus improves the technical efficiency scores compared to what they would be under

the constant returns to scale assumption. Scale efficiency is computed by comparing a firm's TE scores estimated first with a constant returns to scale model and then with a variable returns to scale DEA programme. If the scores are the same, the firm is technically efficient. If different, $TE_{crs} = TE_{vrs} \times SE$. In a final step it is possible to establish if firm i faces increasing or decreasing returns to scale by substituting the convexity constraint with $\sum \lambda_i \leq 1$, which now fits a non-increasing returns to scale frontier. If the TE scores are identical for the VRS and the NIRS versions of the model, decreasing returns to scale apply and if they differ, the firm faces increasing returns to scale. We used DEAP 2.1 to calculate pure technical, scale and overall efficiencies (<http://www.uq.edu.au/economics/cepa/deap>).

In this study limited sample size precluded the use of the joint estimation of the stochastic frontier (\mathbf{x} , \mathbf{y}) and its inefficient effects (\mathbf{z}) as proposed in Battese & Coeli (1995). The standard remedy for this kind of problem is to conduct a series of simple statistical tests like ANOVA or χ^2 across categories of interest (D'Haese *et al.*, 2001; Gaspar *et al.*, 2003). We tested for differences across frontier and other farms, as well as across the two sites of production.

Results and Discussion

The efficient frontier

This section compares the nine frontier farms to the 24 inefficient operations in the sample, as identified by DEA's total efficiency measure. Four of the nine frontier farms came from 2012 and five from 2013. Just one farm was efficient in both years. The average characteristics of each group are presented in Table 2 with the relevant statistic to indicate if the difference in means is significant across efficiency groups or not. These findings show that best-practice farms are on average 332m² in size, compared to the overall average of 592m² (not shown) and 690m² for inefficient farms. Efficient farms generate approximately R34 of gross income per square meter over the course of one year, while inefficient farms achieve just R22 per square meter per season. All financial values are in constant 2014 Rand. The only respect in which efficient and inefficient farms are identical is labour; each on average employs 3.3 workers. This means that the labour absorption rate of efficient farms is one worker per 100m², while inefficient farms use 0.48 workers per 100m². These results show that the efficient frontier is comprised of relatively small farms, suggesting that efficiency is lost as greater quantities of inputs are combined in the production process.

Table 2: DEA results - frontier vs. inefficient farms

	Non-frontier /	Frontier /	
Variable name (units)	inefficient (n=24)	efficient (n=9)	Chi2 or t
Output (Rands)	15,420	11,305	1.3067
Compost (Rands)	6,242	3,067	2.1524**
Seedlings (Rands)	2,081	933	2.8721***
Land (m ²)	690	332	2.3994**
Labour (workers)	3.33	3.33	-
Experience (years)	9.25	10.56	-0.5827
Mulching D (% yes)	88	89	-0.1055
Windbreaks			
None (%)	21	22	
Some (%)	37	78	
Elaborate (%)	42	-	5.9461*
Pure technical efficiency	72	100	-3.9957***
Scale efficiency	87	100	-2.8751***
Overall technical efficiency	62	100	-6.0670***

* $p \leq 0.10$, ** $p \leq 0.05$, *** $p \leq 0.01$

Table 2 shows that amongst non-frontier farms the average operator was slightly but not significantly less experienced than his counterpart from the frontier group. There was no difference in the prevalence of the practice of mulching across efficiency groups. Surprisingly non-frontier farmers were more likely to have elaborate windbreaks. This finding suggests that wind damage could be a significant determinant of a farm's productivity which the types of windbreaks that these farmers have access to are unable to overcome.

Further analysis of the efficient frontier reveals that only three of the nine frontier farms serve as either a primary or secondary peer to 83% of non-frontier farms. Farms 10, 24 and 26 have peer counts of fifteen, sixteen and twelve respectively. This means that Farm 10 serves as a model to fifteen other farms in the sample, with which it shares a set of factor ratios. Inefficient farms can have a number of peer farms using a similar ratio of inputs and outputs in a more efficient manner. In terms of characteristics, these three farms vary quite substantially in land size. Farms 10, 24 and 26 cultivate areas of 676m², 101m² and 349m² respectively. Only Farm 10 is thus above the mean farm size (592m²) and therefore could serve as benchmark for the majority of non-frontier

farms in the sample. Although the frontier farms are distributed equally across the two production sites, farms 10, 24 and 26 are all located in Khayelitsha, which might make them more accessible to Khayelitsha farmers than to farmers from Nyanga. At the very least communication between farmers is required for inefficient farmers to learn from best-practice approaches. In the context of *Harvest of Hope*, it is clear that communication does exist between the farmers. Not only were farmers highly knowledgeable concerning other farms, but they also collectively attend workshops at the PBO's offices in Philippi where communication and learning are facilitated. This is promising for future efficiency gains, as there is potential for best-practice methods to be shared amongst the farming community.

Efficiency breakdown: overall, technical and scale

It is now suitable to draw attention to the actual efficiency levels as uncovered with DEA. The average overall efficiency across all farms was 72%. The average technical and scale efficiencies were 80% and 91% respectively. These results imply that the same level of output could be achieved with approximately 30% fewer inputs. There is therefore clear potential to use scarce urban land more productively, which could alleviate local food insecurity.

It is also clear that farms tended to be more scale efficient than technically efficient. This illustrates that there is greater room for efficiency gains in terms of overall input management, than by adjusting farm size. This is promising, as the researchers believe it difficult for farmers to adjust their farm size upwards. Almost 60% of scale-inefficient farms exhibit increasing returns to scale, where scale efficiency can be improved through farm expansion. Constraints manifest themselves through few farmers having sizeable areas of unused land on their plots. Furthermore, many farms are located on school property where permission to take up more land is not always forthcoming. A clear example of this is the case of one farmer who has been waiting for over 6 months to expand farm size, yet negotiation with the school principal has been unsuccessful. The implication of these land rigidities is that many farmers can expect to obtain more immediate gains in efficiency by focussing on overall input management.

Comparing overall efficiency with that of the literature, one finds that it is substantially higher than Piesse's (1996) finding of below 50% in the Northern Transvaal. Nyariki (2011) similarly reported an average overall efficiency of 42% in the most efficient of three seasons analysed. These findings support the notion of a wide range of efficiency, which is less prevalent in the present study. This may be explained by the fact that *Harvest of Hope* farmers have received homogenous training from the NGO. Farmers are thus likely to demonstrate a

similar production process and input usage, contributing towards smaller departures from best-practice efficiency.

Of greater interest are the significant pairwise correlations obtained for compost, seedlings and land. The Pearson's correlation coefficients for these inputs with the overall efficiency scores obtained from DEA are -0.379 ($p=0.0294$), -0.384 ($p=0.0272$) and -0.522 ($p=0.0018$) respectively. Land thus exhibits the strongest correlation of all inputs considered. The most striking finding here is the negative sign for these correlation coefficients. This indicates that overall efficiency declines as compost, seedling use, and farm size increases. These results serve to confirm that farms on the efficient frontier are below average in size. The implication is that as farmers increase the scale of their production process (both in terms of land and other inputs) they are unable to maintain their previous levels of efficiency. A possible explanation is that larger production processes are more complex to manage. The reason is probably that larger farms require additional labour. A t-test of overall efficiency across a dummy variable indicating whether a farmer works alone (=1) or with other people (=0) resulted in a t-statistic of -1.7286 ($p=0.0938$). The three farmers working alone achieved an overall efficiency of 94%, while the thirty farmers, who have to organise other labour in addition to their own, achieved just 70% efficiency.

Our findings are in keeping with those from other researchers. Lipton (2013) points to the inverse relationship between farm size and efficiency. This relationship is further supported locally by Kirsten & van Zyl (1998), who reported efficiency declines with farm expansions. In developing countries the reason for the inverse relationship is probably that labour tends to be relatively abundant while capital tends to be scarce. Thus in low-income and many middle-income countries, small-scale farms represent the most efficient use of resources (Cornia, 1985; Lipton, 2013). Given that the farming environment of Khayelitsha and Nyanga is defined by widespread poverty, the negative relationship between scale and efficiency is congruent with the literature.

Apart from the scale effect we wanted to know if operator experience or the adoption of particular practices resulted in significant differences in the overall efficiency scores obtained from DEA. The efficiency scores were uncorrelated with operator experience ($r=0.0987$, $p=0.5848$), perhaps due to a lack of variation in farming experience amongst these farmers. Alternatively this lack of difference in efficiency attributable to experience indicates the *Harvest of Hope* production system is so prescriptive that it does not matter whether a farmer has experience of the production process or not.

The practices of mulching and planting windbreaks form part of a suite of water-wise gardening practices promoted by a variety of PBOs which work in the urban agriculture space. Both practices are aimed at overcoming the unfavourable production conditions of the Cape Flats, and should therefore result in higher yield. In the discussion above we asked if there was a difference in the prevalence of the practices across frontier and non-frontier farms. The question here is how the DEA overall efficiency scores of adopters compared to that of non-adopters of the practice. There was a difference for mulching; farmers who mulch were 70% efficient on average, while those who do not mulch were 88% efficient. While mulching should result in higher yields, it also costs money and is labour intensive, and it is through its additional labour use that adopters of this practice were shown to be marginally less efficient than non-adopters ($t=-1.4651$, $p=0.1530$). The situation with respect to windbreaks was more complicated than that. A single variable ANOVA test showed that the average efficiency of farms without windbreaks was 73%, compared to 83% for farms with a basic windbreak and 55% for farms with an elaborate windbreak. The F-statistic of 5.76 was significant ($p=0.0077$). A Bonferroni multiple comparison test (Hochberg & Tamhane, 1987) revealed that the 10% efficiency gain obtained from adopting a basic windbreak was not statistically significant ($p=0.897$). Comparing the efficiency of non-adopters to that of the adopters of an elaborate windbreak, we observed an 18% difference in mean efficiency, this time with the adopters being less efficient than the non-adopters; clearly elaborate windbreaks only get built when wind is a serious problem. However, the Bonferroni test also showed that the difference in this pairwise comparison was not significant ($p=0.245$). The only pairwise difference that was significant ($p=0.006$) was between the adoption of an elaborate versus a basic windbreak, thereby confirming the earlier conclusion that even the best windbreak cannot overcome adverse growing conditions.

Differences between Khayelitsha and Nyanga

Table 3 considers the differences that exist between farms in the Khayelitsha and Nyanga regions. The results of χ^2 and t-tests indicate significant differences. Nyanga farms demonstrate a significantly higher average technical efficiency (approximately 12% higher than Khayelitsha). By contrast, Khayelitsha significantly outperforms Nyanga in terms of scale efficiency by about 8%. Given that neither region dominates in terms of both efficiencies, it is unsurprising that the differences in overall efficiency are insignificant. These findings show that farms are of a more optimal size in Khayelitsha, whilst overall input management is better in Nyanga. Scale differences are relatively intuitive, as they simply imply that Nyanga farms are less adequately sized. Reasons for differences in technical efficiency are harder to pinpoint, although

input use explains some of the deviation. Nyanga farms tend to be smaller, although not significantly smaller than farms Khayelitsha. Nyanga farms also use more labour and are run by managers with more experience than Khayelitsha farms. Table 3 reveals that farms in Khayelitsha buy significantly more seedlings from *Abalimi* than in Nyanga, where farmers tend to be more self-sufficient. It would be interesting to know if Nyanga farmers, on account of being more centrally located, have found cheaper suppliers or whether being more experienced they have learnt to save their own seeds. It is also interesting to note that the average Nyanga operation uses compost more economically (although not significantly less so) than the average farm in Khayelitsha, and does so without negatively affecting output. There are also statistically significant differences in the use of mulching as a water saving technique and windbreaks to improve the productivity of the land. These two factors play directly into technical efficiency as it can be seen that Nyanga farmers tend to have more extensive windbreaks and that they universally employ mulching whereas a certain section of farmers in Khayelitsha tend to avoid these practices, no doubt to save labour.

Table 3: Farms in Nyanga vs. farms in Khayelitsha

Variable name (units)	Khayelitsha (n=20)	Nyanga(n=13)	Chi ² or t
Output (Rands)	15,916	11,808	1.4387
Compost (Rands)	5,480	3,215	0.1837
Seedlings (Rands)	2,103	1,253	2.2342**
Land (m ²)	673	467	1.4350
Labour (workers)	2.55	4.54	- 4.4770***
Experience (years)	8.25	11.69	-1.7579*
Mulching D (% yes)	80	100	2.9586*
Windbreaks			
None (%)	35	-	
Some (%)	30	77	
Good (%)	35	23	8.4975**
Pure technical efficiency	75	87	-1.6966*
Scale efficiency	94	86	1.7726*
Overall efficiency	71	75	-0.5505

* p≤0.10, **p≤0.05, ***p≤0.01

However, differences in technical efficiency are unlikely to be fully explained by differences in these inputs. The researchers believe (through observation) that soil quality is driving a wedge between the technical efficiencies of the two townships. On average, soil in Cape Town's greater township area (i.e. the Cape Flats) is sandy and thus poor in quality (Battersby-Lennard & Haysom, 2012). However, local differences may still exist within this region. In terms of location, Khayelitsha borders the False Bay coastline, with the soil being largely comprised of sand as a consequence. On the other hand, Nyanga is situated a few kilometres inland with seemingly less sandy soil. Furthermore, Nyanga is situated adjacent to the Philippi Horticultural Area, which has a long history of being a food production area in Cape Town. Battersby-Lennard & Haysom (2012) indicate that various soil, climatic and water conditions have allowed the region to outperform other horticultural areas in terms of production. Nyanga's proximity to this area may help explain its higher technical efficiency. This report also indicates that soil quality varies substantially within the Philippi Horticultural Area. There is thus reason to believe that inherent soil quality differences can exist between two townships situated in different locations. The implication is that Khayelitsha farms may have to practice a higher degree of soil augmentation (e.g. through compost use), given a poorer endowment of soil quality. Currently, however, there is no significant difference in the use of compost between the two townships.

Conclusion

This research has revealed the characteristics and efficiencies of urban micro-farming in the townships of Khayelitsha and Nyanga. The overall efficient frontier is characterised by nine small farms with low input usage, relative to the average. Within the efficient frontier framework, three farms exist that serve as a benchmark for the vast majority of non-frontier farms. These farms are all situated in Khayelitsha, but are fortunately not completely isolated from their Nyanga counterparts. It is thus expected that their best-practice methods can be effectively disseminated to similar, but less efficient farms.

The negative correlations of land, compost, and seedlings, with overall efficiency, confirmed the initial finding that best-practice farms operate a smaller production process. These correlations are also supported by the literature, which indicates that in a developing context, increases in scale generate inefficiency. The farmers of Khayelitsha and Nyanga thus suffer inefficiencies when trying to increase the overall scale of their production. Ultimately, efficiency losses of this nature pose a challenge to farmers in the area. Though many might associate larger farms with higher incomes, there

needs to be a consideration of additional cost burdens that can result from new inefficiencies. Caution should thus be exercised when expanding the production processes of farms.

The present study demonstrates higher average efficiencies compared to other reports from sub-Saharan Africa. This may be the result of effective, homogenous training received by farmers in this study, causing a smaller spread of efficiency. The relatively high efficiency levels are promising, but there remains room for improvement. Importantly, greater gains can be expected from improving input management, as scale efficiency currently outstrips technical efficiency. Overall, there is thus potential to amplify the impact of urban micro-farming on food security and poverty, through efficiency gains.

A final consideration of efficiency differences between the two townships indicates that Nyanga excels technically, whilst Khayelitsha is superior in terms of scale. The recommendation is thus that Khayelitsha farms focus on input management whilst Nyanga farms attempt to adjust their scale. Differences in technical efficiency are somewhat explained by differences in input usage, notably seedling use and land. However, it is believed that underlying soil quality differences between the two areas are placing a heightened strain on farms in Khayelitsha. This is potentially as a result of its proximity to the coast, whereas Nyanga is situated adjacent to one of Cape Town's historical food production areas. A deficit in soil quality warrants greater emphasis on soil augmentation in Khayelitsha. This is a clear example of how regional differences may require different responses to dealing with inefficiencies.

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