The impacts of tractor exhaust injection on wheat growth and yield in South Western New South Wales.

Participating farmer Daniel Linklater standing in the trial on the 8th of September 2009

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By

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Executive Summary

Landholders in the low rainfall Mallee region of southern New South Wales are looking for new technologies that will reduce inputs and costs while delivering improvements in crop production. BioAgtive Emissions (BAE) is one technology of interest to the region's farmers. In 2008 Mallee Sustainable Farming worked with a local landholder to demonstrate and evaluate this technology. The 2008 project result did not provide any conclusive results and therefore a more rigorous trial was implemented in 2009.

The 2009 trial tested four treatments:-

1. control - no fertiliser and no exhaust
2. no fertiliser and exhaust injected
3. fertiliser applied and no exhaust and
4. fertiliser applied and exhaust injected

Large scale treatment plots (25 x 200 meters each) were sown and harvested with commercial equipment. The trial was measured throughout the season for shoot biomass production, tiller numbers, grain yield and grain protein content.

Due to the large scale design of the trial site, inherent soil variability needed to be accounted for in the statistical analyses. Both Colwell potassium and soil pH were shown to significantly correlate with some experimental measurements. Therefore initial crop production data was also assessed using an analysis of covariance and the Colwell potassium and pH soil parameters as co-variates.

The analyses indicated that the injection of exhaust did not improve or compromise crop production relative to the control. However, injecting exhaust while simultaneously applying fertiliser did initially reduce crop growth. In this season and on this soil, the crop was unresponsive to the application of fertiliser except for a small, significant increase in grain protein.

Further research is needed on this issue to better inform farmers who are implementing or considering this technology. It is unknown how the BAE performs over the long term, in different soil types and seasons

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1.0 Introduction

In the low rainfall Mallee Region of South Western New South Wales, Australia, landholders are seeking to identify farming methods that can increase crop yields and improve soil health whilst reducing the costs of production. One approach that farmers in this region are investigating is recycling tractor exhaust emissions into the soil seedbed with the hypotheses of catalysing biological activity to mineralise nutrients which are immobilised in the soil organic matter (MSF, 2009).

A Canadian company, N/C Quest Inc., has been researching and developing the technology to capture exhaust gasses emitted from the seeding tractor and inject them into the soil. The technology is named BioAgtive Emissions (BAE). With funding from Lower Murray Darling Catchment Management Authority (LMDCMA) in 2008, Mallee Sustainable Farming with Ian, Daniel and David Linklater undertook a project to examine and report the effectiveness of the BAE technology on plant growth and sustainable agricultural production (MSF, 2009). There is no existing scientific literature on the effectiveness of this technology.

The 2008 project used four non-replicated trial strips to demonstrate the technology. Trial strips were monitored throughout the year for plant growth, yield and grain quality. Soil samples were also collected and the chemical and biological properties analysed. The outcome of this project was that results were inconsistent, with no crop production benefits from using the technology identified. Furthermore, as the first project was a demonstration activity, no statistical conclusions could be drawn from the results.

A project funded by LMDCMA was implemented in 2009 to more rigorously investigate the effect of tractor exhaust injection on the growth of cereal crops in the Mallee region of southern New South Wales. This report outlines the methodology and results of a trial that was implemented over a one year period using large scale treatments in a replicated trial design.

2.0 Methodology

2.1 Trial design

In 2009 a paddock scale, replicated experiment was established to test four treatments. The treatments were:

1. Control -No fertiliser and no exhaust (-Fert, -Ex
2. No fertiliser and exhaust injected (-Fert, +Ex)
3. Fertiliser applied and no exhaust (+Fert, -Ex)
4. Fertiliser applied and exhaust injected (+Fert, +Ex)

Each treatment was replicated six times in a randomised block design. Each plot was 200 metres long and 25 metres wide. A 25 metre buffer was established between plots and between replicates. Large buffer areas were required to allow commercial equipment t o manoeuvre around the site during seeding and harvest.

2.2 Soil sampling

Soil sampling was sampled in May 2009. Topsoil samples were collected from each plot and analysed for chemical properties at the CSBP laboratory. Soil analysis included organic carbon, available nitrogen, available phosphorus (Colwell), available potassium (Colwell), electrical conductivity and soil pH ($CaCl_2$ and H_20).

2.3 Sowing

Treatments were established on the 27/05/2009. Plots were sown with commercial seeding equipment that was fitted with the BAE technology. The BAE technology cools the exhaust gas and then directs exhaust into the pressurised seed cart. The exhaust is then distributed through the seed and fertiliser distribution network and injected into the seedbed with the seed and fertiliser. The seeder used knifepoint's and press wheels with 30 centimetre row spacing.

Each treatment was sown continuously so that all six plots were sown before the next treatment. The nil-exhaust treatments were sown before the with-exhaust treatments to minimise any possible residual exhaust effects.

2.4 Biomass measurements

Shoot biomass (dry matter) measurements were collected on the 14/07/2009, 8/09/2009 and 13/10/2009. These three sampling dates corresponded with the Zadoks crop growth stages of Z20, 47 and Z69. Ten random samples, each 0.5 metres by two crop rows cut to ground level were collected from each plot (Plate 1). Samples were dried in a fan forced drying oven at 70^oC until constant mass was achieved.

Plate 1. Collecting shoot biomass measurements

2.5 Crop yield and grain quality

Treatments were harvested on the 21st of December using a commercial harvester. The yield from each plot was physically measured using a weigh-bin (Plate 2). As the grain was augured from the harvester into the weigh-bin, multiple subsamples of the grain were collected and placed in a labelled plastic Ziploc bag. Samples were analysed for protein content by the Graincorp grain receival silo at Carwarp. Crop nitrogen removal was calculated from grain yield and protein on each plot using equation 1 below:

Equation 1: Nitrogen Removal (kg/ha) = Yield (kg/ha) x protein (%) ÷ 570

Plate 2. Measuring grain yield from a commercial harvester using a weigh bin

3.0 Results and Discussion

3.1 Soil Analysis

A summary of the soil test data is presented in Table 1. Analysis of the data shows that variation exists between treatment plots. Key indicators of soil fertility such as nitrogen, Colwell phosphorus (P), Colwell Potassium (K), sulphur and organic carbon (OC) all have coefficient of variations of greater than 10 percent. The soil electrical conductivity (EC 1:5) and soil pH ($CaCl_2$ and H_20) results also varied spatially throughout the trial site.

Table 1. Summary of trial site 0-10 cm pre sowing soil test data.

Test	Units	Average	Minimum	Maximum	cv (%)
Ammonium N	mg/kg	1.79	1.00	5.00	46%
Colwell K	mg/kg	522	430	634	11%
Colwell P	mg/kg	31.0	23.0	82.0	37%
EC1:5	dS/m	0.09	0.05	0.12	21%
Nitrate N	mg/kg	4.08	2.00	9.00	47%
Organic C	%	0.59	0.43	0.83	15%
pH($CaCl_2$)		7.52	6.90	7.80	4%
pH(H_2O)		8.30	7.60	8.60	4%
Sulphur	mg/kg	1.65	1.00	2.60	24%

Soil variability is a common problem when establishing trials of such a large scale in Mallee paddocks. Variability can be induced through past management practices, but more commonly it inherently exist within the paddock. The variability in the soils chemical properties observed at this trial site could also be an indicator of other soil factors that may influence crop production. For example, changes in potassium may be a result of spatial differences in soil texture and variations soil pH can result in variable levels of phosphorus buffering capacity throughout the site.

3.2 Initial crop growth, yield and grain quality

The results for the shoot biomass production, tiller numbers, grain yield, grain protein and grain nitrogen removal are presented in Table 2. Statistical analysis using treatment only factors showed some irregularities, however some statistical differences were observed. The fertiliser only treatment had greater biomass production than the control at all three sampling dates. Grain protein and nitrogen removal was also greater than the control when fertiliser was applied. The treatment where both fertiliser and exhaust was applied simultaneously had reduced shoot biomass production at the first sampling time, reduced yield but greater grain protein than the control. Poor crop production in the fertiliser and exhaust injection treatment was also observed visually in the field (Plate 3). The with exhaust injection only treatment was not different to the control for any measurement throughout the experiment.

Table 2. Initial mean crop production data for each treatment. Letters indicate significant differences between treatments. LSD = least significant difference at p=0.05.

Measurement	Units	Control -Fert -Ex	-Fert +Ex	+Fert -Ex	+Fert +Ex	LSD
Shoot Biomass (Z20)	kg/ha	68 (a)	75 (ab)	80 (b)	46 (c)	11.7
Shoot Biomass (47)	kg/ha	1924 (a)	1906 (a)	2424 (b)	1585 (a)	370.4
Shoot Biomass (Z69)	kg/ha	3420 (a)	3467 (a)	3899 (b)	3134 (a)	389.7
Tillers (47)	m^2	55 (a)	54 (a)	60 (a)	48 (a)	10.18
Yield	kg/ha	1763 (a)	1628 (ab)	1761 (a)	1583 (b)	140.6
Grain Protein	%	12.27 (a)	12.45 (bc)	12.73 (b)	13.15 (c)	0.41
Grain N Removal	kg/ha	38 (a)	36 (a)	39 (b)	37 (a)	2.9

Plate 3. The +Fert-Ex treatment on the left and the +Fert+Ex treatment on the right at the second sampling. Notice the patchy growth of the +Fert+Ex treatment.

3.3 Correlation between soil analysis and crop production measurements

Due to the large variation in soil parameters observed in the pre sowing soil tests, an analysis was undertaken between the chemical soil parameters measured before seeding and the crop production measurements collected during the experiment. Colwell potassium was significantly correlated with yield, Z69 shoot biomass, protein and grain nitrogen yield (Table 3 & 4, Figures 1 & 2). Correlations with EC1:5 and organic carbon were also significant, however they were not as strong (Table 3 & 4). Soil pH (both in water and $CaCl_2$) was also significantly correlated with yield (Table 4 and Figure 3) and shoot biomass production at all growth stages (Table 3 and Figure 3). Soil pH was also correlated with grain nitrogen removal, but not with grain protein (Table 4).

The significant correlations between soil parameters and crop production measurements indicate that the observed soil variability is influencing the experiments results. For example, the plots with low topsoil potassium concentrations tended to have a higher yield than plots with higher potassium concentration. In Mallee soils, potassium content tends to be an indicator of higher clay content, which in low rainfall environments and years with a dry spring (such as 2009) can impact on crop yields.

The correlation between soil pH and crop production should also be noted. In Mallee soils, higher pH is usually an indication of higher soil buffering capacity. Soil pH is likely to relate to the phosphorus buffering capacity, and the degree of fertility. Therefore, in this experiment where + and – phosphorus was applied through fertiliser application, spatial variability of plant available phosphorus throughout the experimental site may have compromise the experimental results.

Table 3. Linear correlations between pre-sowing soil tests and crop production measurements (shoot biomass (growth stage Z20, 47 & Z69) and tillers). Significance of correlation is indicated: ***p<=0.001, **P<= 0.01, *p<=0.05.

	Shoot Biomass			
Soil Parameter	**Z20**	**47**	**Z69**	**Tillers**
Nitrate N	-0.097	-0.238	-0.086	-0.323
Ammonium N	+0.169	-0.019	+0.134	-0.219
Colwell P	-0.030	+0.178	-0.078	+0.253
Colwell K	-0.336	-0.383	-0.536**	-0.288
Sulphur	-0.113	-0.216	-0.189	-0.192
Organic C	-0.251	-0.275	-0.342	-0.220
EC1:5	-0.311	-0.411*	-0.495*	-0.181
pH($CaCl_2$)	-0.504*	-0.627***	-0.673***	-0.401
pH(H_2O)	-0.601**	-0.633***	-0.679***	-0.412*

Table 4. Linear correlations between pre-sowing soil tests and crop production measurements (grain yield, grain protein and grain nitrogen (N) yield). Significance of correlation is indicated: ***p<=0.001, **P<= 0.01, *p<=0.05.

	Grain Yield	**Grain Protein**	**Grain N Yield**
Nitrate N	-0.257	+0.402	-0.090
Ammonium N	+0.174	-0.339	+0.020
Colwell P	-0.069	-0.044	-0.099
Colwell K	-0.724***	+0.675***	-0.497*
Sulphur	-0.208	+0.284	-0.093
Organic C	-0.533**	+0.448*	-0.382
EC1:5	-0.521**	+0.457*	-0.368
pH($CaCl_2$)	-0.544**	+0.032	-0.629***
pH(H_2O)	-0.520**	+0.068	-0.582**

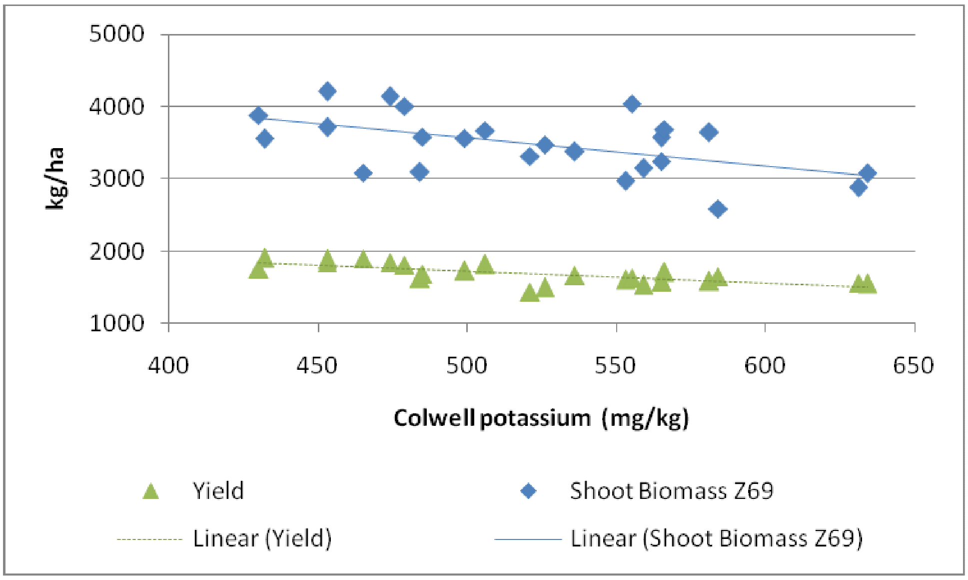

Figure 1. Linear correlation between pre seeding Colwell potassium concentration and the crop production measurements of shoot biomass accumulation (Z69) and yield.

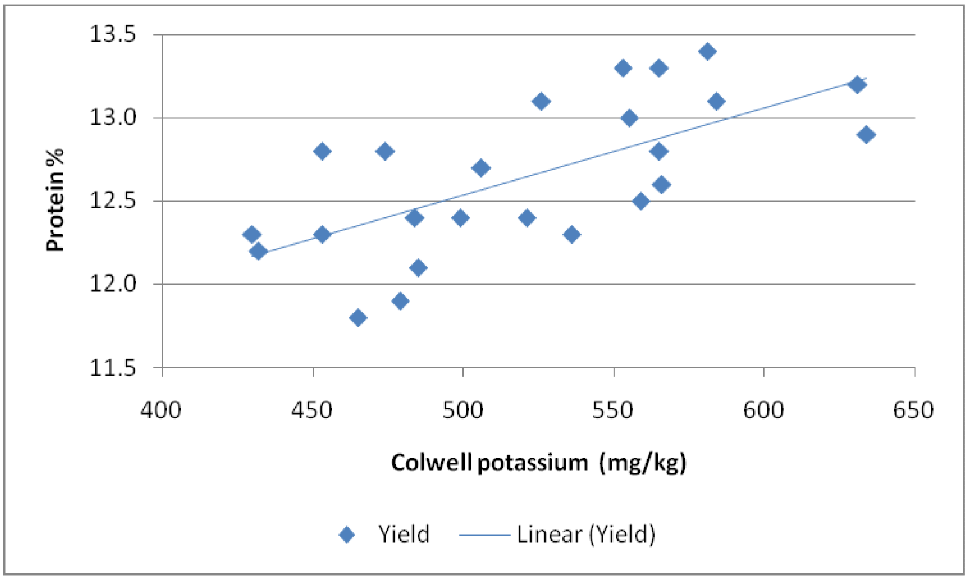

Figure 2. Linear correlation between pre seeding Colwell potassium concentration and grain protein

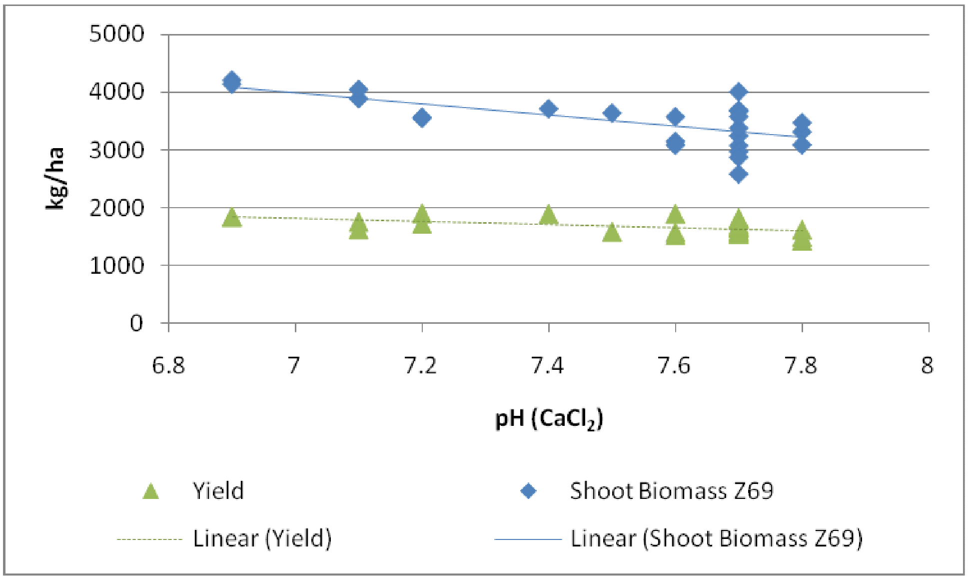

Figure 3. Linear correlation between pre seeding soil pH and crop production measurements of shoot biomass accumulation (Z69) and yield.

Given the significant correlations between soil parameters and crop production, an analysis of variance was taken between pre sowing soil test values and the replicate and experimental treatments (Table 5). The analysis of variance shows that there was a significant relationship between the Colwell potassium and soil pH and the placement of treatments. This suggests that the location of at least some of the treatments in the experiment was biased towards soil types with either high or low Colwell potassium or soil pH values. However no statistical relationship between soil test values and the replicates was observed. This confirms that the experimental design and location of the treatment plots did not eliminate the impact of spatial variability.

Table 5. Analysis of variance between pre sowing soil parameters and replicates (Rep) and treatments (Treat).

	p-value (Rep)	p-value (Treat)	Adjusted R-Sq.
Nitrate N	0.641	0.564	
Ammonium N	0.612	0.439	
Colwell P	0.729	0.686	
Colwell K	0.499	0.014	33.0
Sulphur	0.583	0.409	
Organic C	0.474	0.712	
EC1:5	0.261	0.133	
pH($CaCl_2$)	0.745	0.001	52.2
pH(H_2O)	0.648	0.001	55.8

3.4 Revised crop growth, yield and grain quality

Given the linear correlation between measurements on crop production and pre sowing soil tests, the initial crop production data was reanalysed using an analysis of covariance (ANCOVA) with Colwell potassium and soil pH as the co-variates. These two soil parameters were chosen as they were best related to crop measurements and other soil variables, but are relatively orthogonal (not correlated) with each other. The blocking factor was also ignored in the analysis.

The revised means of the treatments are shown in Table 6. Both exhaust injection and the application of fertiliser alone had no significant impact on crop growth (biomass and tillers) and crop yield when compared to the control. However, when applied in combination (exhaust and fertiliser), early shoot biomass production was reduced. This treatment recovered after the first sampling date as no significant difference was observed between this and other treatments for 47 and Z69 shoot biomass, tiller number or yield.

Grain protein was significantly increased in the treatments where fertiliser was applied. Injecting exhaust resulted in significantly lower levels of grain protein than both of the treatments where fertiliser was applied, however grain protein in this treatment was not significantly different from the control. Furthermore, all four treatments had a comparable grain nitrogen removal.

Table 6. Revised mean crop production data for each treatment using Colwell potassium and soil pH as covariates. Letters indicate significant differences between treatments. LSD = least significant difference at p=0.05.

Measurement	Units	-Fert -Ex	-Fert +Ex	+Fert -Ex	+Fert +Ex	LSD
Shoot Biomass (Z20)	kg/ha	71 (a)	75 (a)	76 (a)	46 (b)	14.3
Shoot Biomass (47)	kg/ha	2005 (a)	1935 (a)	2278 (b)	1622 (a)	519
Shoot Biomass (Z69)	kg/ha	3434 (a)	3553 (a)	3628 (a)	3305 (a)	500
Tillers (47)	m^2	56.6 (a)	53.9 (a)	59 0(a)	48.4 (a)	12.5
Yield	kg/ha	1763 (a)	1672 (a)	1627 (a)	1673 (a)	148
Grain Protein	%	12.5 (a)	12.4 (a)	12.9 (b)	12.9 (b)	0.4
Grain N Removal	kg/ha	38.6(a)	36.2 (a)	36.6 (b)	37.8 (a)	3.1

4.0 Conclusion

This project aimed to assess the impact of exhaust injection on the growth of a cereal crop in the Mallee region in Southern New South Wales. The experiment investigated this approach against only applying fertiliser and applying fertiliser and injecting exhaust simultaneously. All three treatments were compared to a control where neither exhaust was injected or fertiliser was applied.

The experiment utilised large experiments plots (25 m x 200 m) and therefore the trial was considered to be of a paddock scale. This resulted in inherent soil variability within the paddock compromising the statistical design of the experiment. Statistical analysis showed that some soil parameters (particularly potassium and soil pH) were significantly correlated to crop production measurements. Furthermore, spatial variability of potassium and soil pH was significantly related to the placement of treatments and therefore treatment means needed to be revised using an ANCOVA.

The ANCOVA showed that the injection of exhaust did not improve or compromise crop production relative to the control. However, injecting exhaust while simultaneously applying fertiliser did initially reduce crop growth. In this season and on this soil, the crop was unresponsive to the application of fertiliser except for a small, significant increase in grain protein.

5.0 Further research

Conducting a replicated trial using such large scale plots increases the chance that natural site variability influences the observed differences. Therefore, if any future effect of the treatments is to be measured, a clearer understanding of the soil variability that underlies the site is required. The grower attempted to generate a yield map of the buffer areas surrounding the treatments to obtain data that could indicate how variable the site was, however there was a problem with the harvester's data card and therefore no yield mapping data was available for 2009. Yield mapping, electromagnetic mapping and additional soil sampling could be used to determine any underlying site variability.

The landholder will continue to implement the same treatments on this trial site with the aim of trying to experiment with the BAE technology over the longer-term. Data collection will however be limited to grain yield and quality due to limited resources. A greater understanding of the site variability is required to make any further data collected from this site useful, particularly as the initial results suggest that any future treatment effects are likely to be small. A new experimental design or a change or trial location may be needed once the site conditions are better understood.

Further research is needed on this issue to better inform farmers who are implementing or considering investing in this technology. It is unknown how the BAE performs over the long term, on different soil types and in better or worse seasons. Furthermore, scientific laboratory-type experiments are required to determine what effect the injection of tractor exhaust has on soil chemical and biological proprieties.

6.0 Acknowledgements

This project was funded by the Lower Murray Darling CMA. Thanks go to the landholders - Daniel and Ian Linklater for supplying the land, equipment and inputs for this experiment. The landholders also provided significant labour support for data collection.

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Finally, Dr Ben Jones of Mallee Focus has provided support to this project by undertaking statistical analysis of the data.

7.0 References

Mallee Sustainable Farming (2009). *CO_2 Exchange 'Examination of the effectiveness of recycled tractor exhaust for use on dryland cropping soils on yield, grain quality and soil health' Final Report.* Mallee Sustainable Farming, Mildura, Victoria.