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Cereals for bioethanol: quantifying the alcohol yield of UK hard wheats and the grain yields and N requirements of triticale in the second cereal position

by
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ABBREVIATIONS USED

ANOVA	Analysis of Variance	RL	HGCA Recommended Lists
AY	Alcohol yield	RV	Residue viscosity
CEL	Crop Evaluation Ltd	SED	Standard Error of Difference
DM	Dry matter	SWRI	Scotch Whisky Research Institute
ha	Hectare		
hL	Hectolitre	t	Metric tonne
L	Litre	SF	Suffolk (field trial site)
LSD	Least Significant Difference	Spwt	Specific weight
N	Nitrogen	TO	Towthorpe (field trial site)
NUE	Nitrogen Use Efficiency	TT	Terrington (field trial site)
PGR	Plant Growth Regulator		

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CONTENTS

1. ABSTRACT

This project is the first to consider the performance of hard wheat varieties for bioethanol production in the UK. It is also the first to describe a series of experiments in which modern winter wheat and triticale varieties have been studied under comparable conditions of nitrogen (N) nutrition and crop management. This latter work was carried out in the context of identifying the best cereals for bioethanol production, particularly in the second position in the rotation.

In the first part of the study, 10 wheat varieties were taken from six HGCA Recommended Lists sites in 2009 (56 samples in total) and analysed for alcohol yield (AY) and residue viscosity (RV) using a method previously applied to distilling wheats. There were significant differences between hard wheat varieties; Conqueror and Oakley had particularly high AY and Ketchum had low AY. Glasgow as a soft wheat reference variety demonstrated superior AY, outperforming all the hard wheats. There were no differences in RV between hard wheat varieties, indicating that they are equally amenable for bioethanol processing. The higher AY of Conqueror and Oakley was principally due to their lower grain proteins, which probably reflect a yield dilution effect, rather than underlying genetic differences in grain composition. The combination of high AY and high grain yield meant that Conqueror and Oakley had the highest yield of alcohol per hectare.

With regards to alternative feedstocks for bioethanol, the results point to a substantial opportunity for the use of triticale to displace wheat. In five out of six trials carried out between 2007 and 2010, triticale out-yielded wheat when studied in the first or second cereal position on high yield potential 'wheat land'. At the sixth site, triticale matched but did not out-yield wheat, only because of post-maturity lodging at the higher N rates. Within these experiments, where full N response trials were carried out, triticale had a lower N optimum than wheat in one experiment, and the same optima as wheat in another two. In a fourth experiment, there were two triticale varieties with lower optima and two with similar optima to wheat. N optima for triticale appear to be higher than stated in the Defra Fertiliser Manual. Given the higher grain yield with the same and/or less N, and higher straw yields, these results clearly indicate that triticale has higher N use efficiency than wheat. The report makes recommendations for further work on wheat and triticale for bioethanol production, and to identify more N efficient cereal species.

2. SUMMARY

2.1. Introduction

2.1.1. Objectives

1. To determine alcohol yields of current Group 3 and Group 4 hard wheat varieties
2. To evaluate the grain yield, alcohol yield and N requirements of triticale in relation to wheat

2.1.2. Background

With the opening of the Ensus bioethanol plant on Teeside in spring 2010 and the Vivergo plant on Humberside scheduled to open in 2011, growing grain for bioethanol is now a reality, with up to 2 million tonnes of grain expected to be used from the 2011 harvest. Both variety and agronomy can affect the value of grain to the processor, mainly through the alcohol yield achieved per tonne of grain. In addition, through Carbon Reporting in the Renewable Energy Directive the Greenhouse Gas (GHG) savings of the biofuel are also important to the processor. Given that over 67% of the GHG costs of bioethanol are due to crop production, reducing these GHG costs will ultimately be important, and will be part of specifications to the grower.

The keys to maximising the GHG savings associated with bioethanol production include maximising grain yields, and minimising Nitrogen (N) inputs. Nitrogen fertilisation constitutes over 70% of the GHG and 20% of the economic cost of production of wheat.

In a first wheat position, to maximise both profitability and GHG savings, variety choice will be driven primarily by a high grain yield (as reported in the HGCA Recommended Lists), but processing performance and alcohol yield will still be important to the industry. In a second wheat position the situation is different because yield tends to be lower due to build-up of diseases such as take-all, because N applications are generally higher, and because grain protein is generally higher (hence reducing alcohol yields). All of these factors (especially low yield and higher N inputs) reduce the profitability of the crop and the potential GHG savings of the biofuel. It is possible that alternative cereals may have similar or higher yields than wheat in the

second or later rotational positions, and have a lower N requirement. Of the likely candidates, barley and oats are unlikely to be of use due to their husked grain and hence relatively low starch content, and rye has low yields. This leaves triticale, a hybrid of rye and wheat.

Varieties in HGCA Recommended List trials are tested for their alcohol yields by the Scotch Whisky Research Institute (SWRI) and there are some indicators of the best varietal types suitable for distilling (see HGCA Information Sheet 11, 2010). These tests are currently restricted to soft wheats, however, with the existing distilling industry experiencing problems in processing hard wheats. In contrast, the new bioethanol plants inevitably take in a range of wheat varieties including hard endosperm types. However, little is known about the performance of hard wheat varieties for alcohol production in the UK. Clearly some hard wheat varieties may be useful for bioethanol production, particularly those with high yield potential and lower grain proteins than milling wheat varieties (e.g. Oakley). However, further work is needed to determine the AY and processing characteristics of the Group 3 and 4 hard wheats to guide variety choice in the developing bioethanol industry.

Carbon reporting for the RED now applies at farm level and a GHG incentivisation scheme is likely. Early work has demonstrated that the ideal wheat variety for bioethanol is high-yielding with low protein content and low N fertiliser requirements. However, wheat varieties showing big improvements in N use efficiency are not currently available within elite germplasm. Initial investigations have suggested that triticale could deliver comparable yields at a lower N input, and moreover that this species was being used in Sweden for bioethanol production.

Agronomy trials carried out around 5-10 years ago indicated that modern triticale varieties could yield up to 9 t/ha as a first cereal and 8 t/ha as a second or third cereal when grown on sites with high yield potential and managed according to best agronomic practice for wheat (e.g. good disease and lodging control).

Given the potential displayed by triticale in a ‘look-see’ study in 2007, a dedicated trial funded by breeders was subsequently designed to compare wheat and triticale in a second cereal position on good wheat land in 2009. Importantly, the design incorporated an N response trial, with identical N rates for each variety, to allow curve fitting and determination of economic N optima. Based on the fitted optima, triticale

yielded approximately 10% more than wheat, with *ca*. 20% lower N optima. Even with a discount applied to the value of triticale grain (relative to wheat grain), triticale still showed a greater financial margin over N inputs than did wheat.

Clearly, these are very important results, both in the context of improving profitability of cereal production, but also in terms of reducing GHG emissions, assuming that modern triticale varieties could find a ready market in the bioethanol industry today. Based on this one N-response trial, there are insufficient data to take a conclusive message to the industry, and further work is needed to validate the potential of triticale to wheat in the second or third cereal position. Therefore the work outlined in the current project aimed to repeat the study described above at two sites in 2009/10. The results of an additional breeder-funded study are included, to bring the number of N response data sets from 2010 harvest to three.

2.1.3. Summary

The aims of this project were to: (i) provide information on the suitability of hard Group 3 and 4 winter wheat varieties for alcohol production, and (ii) investigate the performance of winter triticale in the second cereal position as a potential low-input, high yield feedstock for alcohol production. An additional commercial trial harvested in 2010 is also reported for wheat and triticale in the first cereal position.

2.2. Materials and methods

2.2.1. Hard wheat samples for alcohol yield testing

Fifty-six wheat grain samples were provided by Crop Evaluation Ltd (CEL) from the 2009 winter wheat Recommended List trial series. The ten varieties selected were Glasgow, Warrior, Oakley, Duxford, JB Diego, Ketchum, Panorama, Grafton, Conqueror and KWS Sterling. Alcohol yield and residue viscosity was tested in the laboratory based on the 'wheat-cook' method of the Scotch Whisky Research Institute, using samples of soft wheats Glasgow and Warrior as reference varieties.

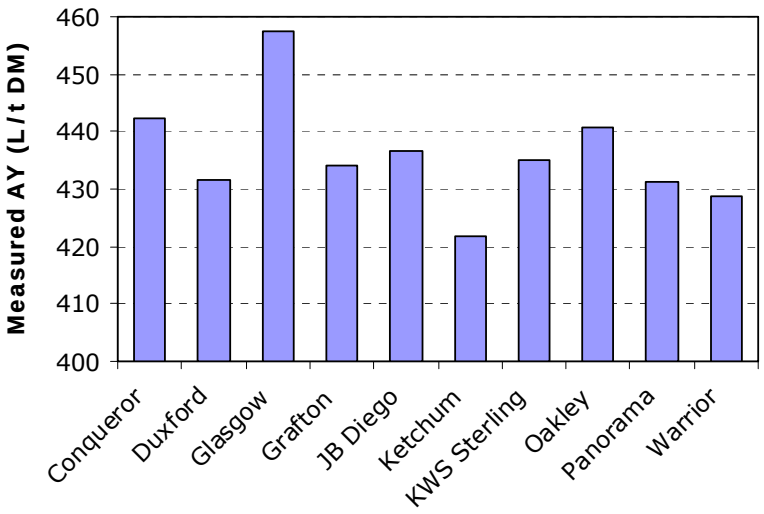
2.2.2. Wheat-triticale N response experiments

Two wheat-triticale N response experiments were carried out in the 2009/10 field season in the second cereal position. The first was at Towthorpe, Near Malton, East Yorkshire and the second at Terrington St Clement, King's Lynn, Norfolk. At each site, two winter wheat (JB Diego and Viscount) and two winter triticale (Benetto and Grenado) varieties were each tested at five nitrogen (N) rates. A third wheat-triticale experiment funded by breeders was carried out in the 2009/10 growing season within a larger species trial comparing winter wheat, triticale, barley, oats and rye. This experiment was located at Cransford in Suffolk on a clay loam soil, also in the second cereal position. Grain yield was determined at harvest, and grain protein and specific weight determined in all experiments, and the economic optimum N rate determined by curve fitting. In individual trials, assessments were made of lodging, incidence of take-all, and pre-harvest grab samples taken for determination of total biomass.

2.3. Results

2.3.1. Alcohol yield of hard wheats

The wheat samples selected were all feed types, with relatively low grain protein contents. There were significant variety differences in protein content, with Conqueror, Glasgow, Duxford and Oakley having lower protein contents than Grafton, Ketchum, Panorama and Warrior. Measured alcohol yield (AY) for the hard wheats, compared to the reference varieties of soft wheat; Glasgow (high AY) and Warrior (low AY) averaged across sites are shown in Summary Figure 1. Variety had a significant effect on AY whereby Glasgow was confirmed as the superior wheat, having significantly higher AY than the other varieties. However, Conqueror and Oakley also had significantly higher AY than the worst varieties Ketchum and Warrior.

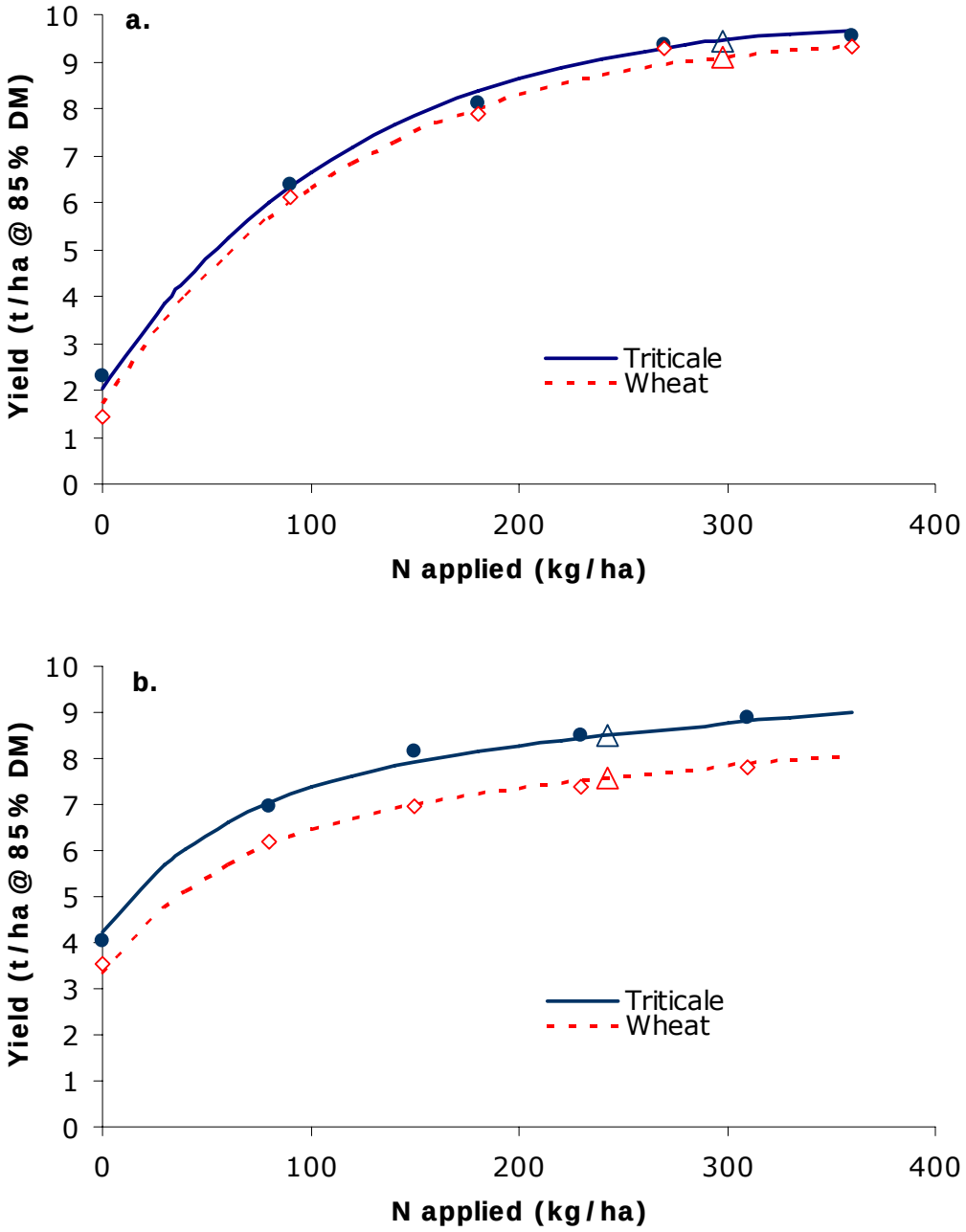


Summary Figure 1. Alcohol yield of ten wheat varieties from the 2009 Recommended List.

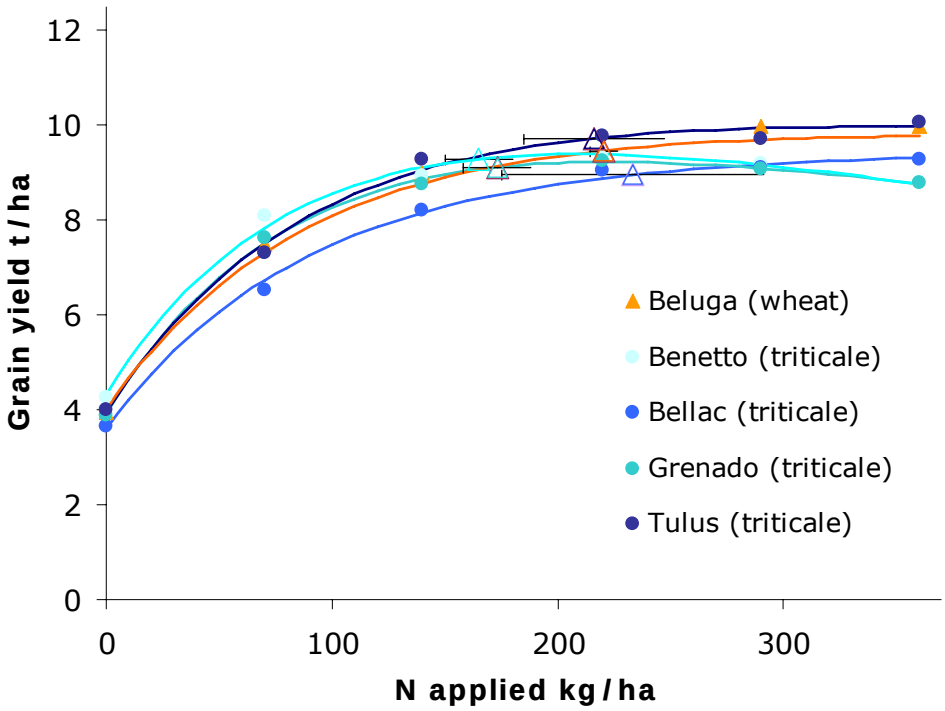
The good performance of Conqueror and Oakley was in part due to their lower protein contents. When the protein effect was removed by standardising AY at 11.5% protein, only Glasgow was shown to be significantly different to the rest. The hard wheats were very similar in AY at a fixed protein content. When combined with grain yields to estimate alcohol yields per hectare, Conqueror and Oakley were seen to be the best performing hard wheats. Residue viscosity was significantly influenced by variety, with Warrior having the highest residue viscosity (indicative of problems during processing). However no other hard wheat variety was significantly different to the others in terms of residue viscosity.

2.3.2. Grain yields and N requirements of wheat and triticale

In both the Towthorpe and Terrington N response experiments, the triticale varieties significantly out-yielded the wheat varieties (Summary Figure 2). A third N x species experiment in 2010, where four triticale varieties were compared to a number of wheat varieties, showed that triticale matched, but did not exceed, the yield of winter wheat (Summary Figure 3).



Summary Figure 2. Effect of N on yield of triticale and wheat (data points and fitted curves), including yields at optimum N rates (triangles) at a) Towthorpe, and b) Terrington in 2010.



Summary Figure 3. Effect of N on yield of triticale and wheat (data points and fitted curves), at a second cereal site in Suffolk in 2010, including yields at optimum N rates (triangles).

Over two field seasons (2009 and 2010) where full N response experiments were carried out, we have therefore shown that on high yield potential land in the second cereal position, triticale has out-yielded wheat on three occasions and matched wheat in the fourth. In 2009 triticale had significantly lower N optima, but in 2010 it had the same N optima as wheat at two sites (Terrington and Towthorpe), and an N optima that varied between varieties at the third site (Suffolk); two triticale varieties having lower optima than wheat varieties (albeit associated with greater lodging at higher N rates), and two others having N optima similar to wheat. The N optima in these experiments (Suffolk, 199; Terrington, 243; Towthorpe, 298 kgN/ha) were higher than those that would be recommended in the Fertiliser Manual where the highest recommendation is currently 150 kgN/ha for triticale.

Overall, grain protein contents and likely alcohol yields of triticale can be expected to be similar to wheat, with variation between cultivars, as is the case for wheat.

Some measures of take-all were made on the Suffolk trial and its incidence was shown to be significantly lower in triticale than in the wheat varieties tested (8% and

19% respectively). Further work over a wider range of seasons is required to quantify the true take-all resistance of modern triticale varieties, and to distinguish this from traits such as a faster rate of root expansion, which could enable the crop to overcome pathogen attack and give increased ability to capture N.

Better nitrogen use efficiency (NUE) is also an important trait in triticale. In 2009, better grain and straw yields (i.e. greater total biomass) than wheat were observed, with less applied N. The resources were not available in 2010 to examine N partitioning and total biomass in all these experiments, but it was confirmed that triticale in the Suffolk trial had greater straw biomass (particularly for the variety Benetto). Nevertheless, with the Towthorpe and Terrington crops, it is clear that triticale produced more grain with the same amount of N applied, i.e. better NUE. However, the basis for this better performance remains unknown. It seems to be due to a combination of greater recovery of soil N (i.e. higher nil-N yields) and greater recovery/utilisation of fertiliser N; analysis of dry matter and nitrogen harvest indices is required to understand the better NUE of triticale.

One disadvantage of triticale in the 2010 experiments at two sites was lodging at the highest N rates, although the variety Tulus was fairly resistant to lodging and gave the highest yield of both species. The results suggest that if lodging could be better controlled in more of the triticale varieties, yields could be even higher. This warrants further work, both on plant growth regulators, and in understanding inherent lodging risk and how triticale relates to wheat in terms of root plate spread, stem strength etc. It should be noted, however, that there was no lodging at the Towthorpe site in 2010.

The ADAS work to date has focussed on triticale in the second cereal position as it is believed this is where the main advantage of triticale will lie, by making better use of its inherent take-all resistance and NUE when roots are compromised. In the first cereal position, we may not expect triticale to outperform wheat, which has had more sustained breeding effort in the UK. Despite this, a 0.5 t/ha yield advantage of triticale was seen in first wheat experiment in 2007 compared to 40 wheat varieties. Also in 2010, Agrovista carried out a trial at Eryholme, Nr Darlington, where wheat and triticale followed oilseed rape, where the two triticale varieties out-yielded the wheat average by 1.83 t/ha, and out-yielded the top yielding wheat (Robigus) by 0.47 t/ha.

These results point to a substantial opportunity from the use of triticale to displace wheat for animal feed as well as bioethanol use; in five of the six trials we have studied, which have compared wheat with triticale over the past four years, triticale has significantly and substantially out-yielded wheat, whether in first or second cereal positions. At the other site, triticale did not out-yield wheat only because of post-maturity lodging at the higher N rates.

2.4. Discussion/Conclusions and implications

This report is the first to publish actual alcohol yields and residue viscosities of hard wheat varieties from UK Recommended List trials, and to compare them to reference varieties of soft wheat using a laboratory method. It is also the first to describe a series of N response experiments in which wheat and triticale have been studied under truly comparable conditions with respect to fertiliser N, with assessments made of both grain yield and quality.

With respect to the alcohol yield of hard wheat varieties grown on a number of Recommended List sites in 2009, the conclusions are as follows:

1. There are significant differences in AY between hard wheat varieties, with Conqueror and Oakley having particularly high AY, and Ketchum a particularly low AY.
2. Glasgow as a soft wheat reference demonstrates superior AY, outperforming the hard wheat varieties.
3. There were no significant differences in residue viscosity between hard wheat varieties, and none with the undesirable character of high residue viscosity, as demonstrated by the soft wheat variety Warrior.
4. The higher AY demonstrated by Conqueror and Oakley were most likely due to their lower grain protein contents (compared to the other hard wheat varieties grown at the same sites) and hence is more likely to reflect a yield (protein dilution) effect, rather a solely genetic effect.
5. The combination of high grain yield and high alcohol yield meant that Oakley and Conqueror had the highest alcohol productivity per unit area, indicating their value for maximising GHG savings.

Taking into account the three wheat and triticale N response experiments carried out in 2010, together with a previous experiment carried out in 2009, the conclusions are as follows:

6. Triticale out-yielded wheat on three occasions and matched wheat yield in the fourth when grown in the second cereal position and with similar N applications.
7. Relative grain protein contents and predicted alcohol yield between triticale and wheat are broadly similar, but differences are inconsistent between sites and protein measurement methods.
8. Triticale had a lower N optimum for yield than wheat in one experiment, had the same N optima as wheat in two experiments, and in one experiment there were two triticale varieties with lower N optima than wheat, and two with similar N optima to wheat.
9. N optima for triticale appear to be higher than stated in the Defra Fertiliser Manual, however this is the first series of experiments to study the performance of triticale on 'typical wheat' land of high yield potential.
10. Given the higher yield with the same and/or less N, these results clearly indicate that triticale can have higher nitrogen use efficiency than wheat.
11. These performance benefits of triticale could be greater in a year with a higher incidence of take-all.
12. Triticale also appeared to produce more straw and hence total biomass then wheat, which could be particularly valuable in the context of burning biomass for energy.
13. Significant lodging in triticale was seen in two trials, although if the crops had been harvested earlier, it is likely that triticale would have outperformed wheat to an even greater extent.
14. The results confirm that triticale tends to have lower specific weights than wheat, even in the second cereal position, although this may not be important for bioethanol production.
15. In an ADAS trial in 2007 triticale out-yielded wheat by 0.59 t/ha, and an independent commercial trial in 2010 showed that triticale out-yielded wheat by 1.83 t/ha, both trials being carried out in the first cereal position.

Recommendations for further work are described in the scientific report.