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Hoad, SP

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Evaluation of new varieties for sustainable cereal production in Europe

Steve Hoad

SAC, Crop and Soil Systems Research Group, West Mains Road, Edinburgh EH9 3JG

Final Report on a Post-Graduate Study Award from the Farmers Club Charitable Trust

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Summary

This report presents a range of issues important to plant breeding and variety evaluation as they relate to sustainable farming. In future, priorities for plant breeding will go way beyond established market criteria such as improving grain yield and quality. Wider social and environmental criteria (i.e. new market values) will become as important as economic considerations. Wide ecological adaptation – embracing tolerance to climatic stresses, enhanced genetic resistance to pests and diseases, and expansion of geographic adaptability – will be essential for future cereal crops. Sustainability criteria for breeders of new varieties include: (1) adaptation to, and mitigation against, climate change, (2) more resilient crops to ensure food security and (3) plant traits to reduce harmful environmental impacts of farming.

This study considers the role of cereal plant breeding in achieving sustainability criteria in arable farming. The value of a new variety depends on its combination of traits. At present, new varieties are defined according to their crop yield and grain quality, but they could also be rated in terms of their environmental or social value, which is notionally determined by the net value of financial return plus/minus the value of positive and negative external impacts. These impacts arise for example from the reduction of fungicide, herbicide and fertiliser use.

The main objectives in this study were:
1. to discuss with plant breeders their aims in developing new cereal varieties with wide ecological adaptation and attention to sustainability criteria,
2. to consider if sustainability traits with both established and new (public good) market values could be incorporated into future variety selection and testing,
3. to outline approaches for evaluating the cost-benefits of selecting new varieties and their subsequent adoption.

The public good role of agriculture is increasingly emphasised in discourse on sector sustainability including commitments on climate change mitigation, soil and water quality improvement and biodiversity conservation. In this context, the development of new varieties will increasingly face the challenge of demonstrating financial benefits while contributing to the management of good and bad external impacts.

This work was made possible through a series of meetings with plant breeders in Saaten Union in Germany (Saaten Union HQ; Strube Research, Nordsaat Saatzucht; Ackermann Saatzucht) and France (Saaten Union Recherche SAS). Prior to discussions, each breeder was presented with an outline of key topics and questions about their work and ideas on the future of variety selection and testing. The content of this report presents a broad view of plant breeding in Europe.

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Dr Günter Welz, Strube Research, Söllingen, Germany

Dr Ralf Schachschneider, Nordsaat Saatzucht GmbH, Böhnshausen, Germany

Dr Claus Einfeldt, Ackermann Saatzucht GmbH & Co. KG, Irlbach, near Munich, Germany

Dr Volker Lein, Saaten Union Recherche SAS, Estrées Saint Denis, near Paris, France

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The author has made all reasonable endeavours to ensure that any commercially sensitive information discussed with individual plant breeders has been treated with care and discretion to avoid disclosure. None of the content should be regarded as endorsement by Saaten Union of particular breeding methods or technologies.

1. Introduction

The need for increasing the sustainability of farming systems is widely recognised. On a global scale there is the challenge of increasing crop production to feed the needs of growing world population, whilst at the same time sustain the environment and natural resources. In 2009, the Royal Society published ‘Reaping the Benefits’ and highlighted the urgent needs for increasing security in food supply and how this might be addressed through scientific innovation and addressing constraints to crop production.

Agricultural sustainability includes the more efficient use of all resources such as energy and crop protection inputs, and much wider appreciation of the long-term consequences of farming on the natural environment. Plant breeding is of prime importance to the development of sustainable cropping and farming systems.

Plant breeding of new varieties has contributed to about half of the threefold increase in cereals yields recorded from the late 1940’s to the early 1980’s; with the other half coming from increased mechanisation and the use of fertilisers and agrochemicals. A recent study by NIAB, Cambridge, estimated that around 90% of the average cereal yield increase since 1980 can be attributed to innovation in plant breeding (Source: BSPB Plant Breeding Matters, Nov 2008).

Priorities for cereal breeders are driven by long established market criteria such as improving crop yield and grain yield. Breeders also seek wide ecological adaptation – embracing tolerance to climatic stresses, enhanced genetic resistance to pests and diseases, and expansion of geographic adaptability. Sustainability criteria for breeders of new varieties include:

- adaptation to, and mitigation against, climate change,
- more resilient crops to ensure food security,
- plant traits to reduce harmful environmental impacts of farming and promote diversity in the rural landscape.

In future, these criteria could be extended to towards wider social and environmental benefits or public goods, which may become as important as economic considerations.

Genetic diversity is a precious resource for plant breeders. A better understanding of how plant breeders and associated research activities create and utilise genetic resources would be of lasting value in developing new varieties in the context of policy and socio-economic outcomes. An appreciation of how plant breeding, and the introduction of new varieties, contributes to the long-term sustainability of agricultural systems would be of considerable value to the research and variety evaluation communities.

2. Methodology

This report is the outcome from a series of discussions with plant breeders in Saaten Union[1] in Germany and France during November 2009. Notes from these meetings were used to integrate different approaches to plant breeding including variety selection and evaluation, and relates this to sustainable farming and the challenges facing agriculture. The plant breeders/companies involved were, in Germany, Saaten Union HQ near Hannover; Strube Research in Söllingen; Nordsaat Saatzucht GmbH in Böhnshausen and Ackermann Saatzucht GmbH & Co. KG in Irlbach near Munich and, in France, Saaten Union Recherche SAS in Estrées Saint Denis, near Paris

Prior to the meetings, each breeders was presented with a series of questions about their approaches to breeding and an outline of the challenges being faced by the plant breeding, farming and scientific communities (see Appendix 1). This included question about the two main resources available to the plant breeder – genetic resources and the environments used in selection and development of new varieties. The main challenges considered related to climate change and the desire – of policy, public and farming – to make more efficient use of inputs and reduce the environmental impacts of farming. Further statements were used to prompt debate about wider social and environmental values which could be placed on new varieties and their traits.

The report is in three sections.

1) A synthesis of plant breeding approaches and priorities based on the questions posed to breeders of wheat and barley – with a focus on wide ecological adaptation and attention to sustainability criteria. The commentary is not concerned with endorsing approaches used by particular breeders or revealing intellectual property of individual companies. Rather it attempts to provide a broad overview of plant breeding in Europe. This section is constructed as a series of mini-reviews encouraged by breeders' insight to their own work and their views of how breeding might respond to the challenges mentioned above.

2) Examination of how sustainability traits in new varieties could be valued in terms of their established market values and new-market values towards wider social and environmental goods in future variety selection and testing.

3) Outline of methods for evaluating the cost-benefits of selecting new varieties and their subsequent adoption. This section introduces some different methods of economic valuation as they might be used in genetic or variety evaluation.

[1]The breeding company Saaten Union has its headquarters near Hannover in northern Germany. This organisation is in fact an alliance of seven plant breeders, with pan-European

expertise in cereal (and other crop) breeding. The Saaten Union group has a wide range of trial locations across Europe: with more than 20 breeding stations and over 100 testing sites in and outside Germany; including France, Denmark, Hungary, the Czech Republic and the UK. The breeding philosophy of Saaten Union is for development of cereal varieties with wide ecological adaptation and attention to a wide range of agronomic criteria. The latter could lend themselves following further scrutiny to wider sustainability criteria.

3. Plant breeding and sustainable farming

3.1. Is there good utilisation of genetic resources?

1. The source of genetic material in plant breeding depends on the long-term targets, or what can be gained by using a particular selection approach or technology. Crossing of elite cultivars as parents is well utilised i.e. classical plant breeding, though pre-breeding, in which a wider range of plant or genetic types are used, is under-utilised. This is partly because pre-breeding is beyond the scope of most practical breeding and largely in the domain of research institutes.

2. Crossing using elite lines may narrow genetic diversity though access to exotic material adds diversity and helps to avoid erosion of genetic resources. Although far from the goals of practical breeding, pre-breeding has potential for the longer-term development of genetic resources. For example, the use more unusual plant types such as longer ears (heads), or different ear types with potential for enhancing the size of the sink (the harvested portion of the crop i.e. grain).

3. Although there is good utilisation of genetic resources across breeding programmes, with increasing diversity in the material used, there is scope for improvement. What is most important is retaining a systematic approach to the screening plant material (the phenotype) in the field. New material can be created from crossings of novel parent plants or sourced from seed collections (or gene banks) or from old varieties and landraces. A further challenge is assess the extent to which novel genetic material including landraces could be adapted to current breeding methods.

4. Breeders can also source extra genetic variation from the use of technologies such as genetic mutations or genetically modified crops which introduce a greater range (or advancement in) desirable traits.

5. There is a large amount of genetic material conserved in seed (gene) banks. Worldwide these exceed 100,000 different lines. Although this provides a rich resource, there is a bottleneck in the description or phenotyping of these resources and identification of the best alleles (forms of each gene). Amongst the most useful traits that need further sourcing and evaluation are timing of developmental phases including the length to flowering.

6. Breeders continually create their own genetic resources including identifying new parents for new varieties. This will include introgressions (e.g. introduction of desirable genetic material from a wild relative). This enables the introduction of new genes conferring one or several benefits e.g. reducing or increasing plant height

whilst adding disease resistance. This enables more rapid breeding cycles. It can include introgression of desirable traits into adapted varieties, though some of this activity should be considered as pre-breeding as it is far from most current practical breeding.

7. Within a cereal species, there are different genetic pools that provide high levels of diversity. For example in barley there are three main genetic sources in *Hordeum* species: *H. vulgare*, *H. spoteneum* and *H. Bulbosum*. Genotypes in which there have been genetic mutations (where specific gene changes have occurred) and wider pools of genetic diversity in landraces can also be utilised.

8. Along with advancements in genetics there needs to be new approaches to phenotyping. This requires new methods or devices to assist high throughput assessment of trait and genotype performance. There is also a need for more understanding of difficult to measure traits such as the structure and functioning of root systems.

9. Genetic resources can also be enhanced by the use of techniques such as doubled-haploid (DH) production which can increase genetic diversity because individual lines are retained that might otherwise have been lost in a conventional cross in classical pedigree breeding. Furthermore, developments such as hybrid barley or wheat provide an opportunity to introduce multiple traits.

10. An important aspect in the early selection of new material is a focus on climatic and geographic adaptation. For example, in wheat, novel material is used to develop new varieties suited to different growing season lengths and sowing dates. This includes the breeding of ‘alternate’ wheats that have different adaptation to the typical winter or spring sown wheats. Exotic material sourced from outside Europe can have benefits as long as yield is not penalised or other undesirable traits are not linked with introducing the beneficial traits i.e. linkage drag.

11. In future, the identification of genetic resources will benefit from understanding the genetic basis of phenotypic or trait variation across environment conditions. This makes use of understanding quantitative trait loci (QTLs) or sections of DNA than are linked to genes controlling each trait. Once QTLs have been identified they can be used to map genetic sequences that contain genes linked, or specific, to a trait. Photoperiod genes that control the earliness of plant development are examples of a QTL’s of value in adaption to changes in the environment, especially climatic conditions.

3.2. Approaches crop adaptation – climate and site conditions

12. Adaptation is determined primarily by plant responses to regional variations in day length and temperate (both north to south and east to west), but also by sub-regional or local changes in weather or soil conditions. There is much debate about how best to understand and utilise the relative merits of wide and specific adaptation.

13. The relative benefits of wide or specific adaptation are influenced by the value and size of the intended market for each variety. There is a tendency towards breeding varieties with wide market appeal e.g. large regions in west Europe, and thus wide adaptation is important. Although wide adaptation is ideal in a commercial sense, specific adaptation can be beneficial for optimising crop performance under local conditions.

14. Generally, breeders will use a central site for their parental crossing and several core sites to identify plant lines (genotypes) with potential for wide adaptation. These core sites will vary geographically and climatically. In Europe, this includes evaluation from cool-wet maritime conditions in the west and north-west to cool (winter) and hot (summer) continental in the east. In some regions there will be selection locations of interest only to the breeding strategy of particular companies, whilst other locations will have generic appeal.

15. The capacity of the breeding programme to develop wide adaptation depends on how well yield and phenotypic information at a limited number of core locations can be extrapolated to performance in other regions. Core locations also provide the first opportunity to select parental material or potential varieties with traits for specific use. Producing a variety that is specifically adapted can be more costly than one with broad adaptation. Commercially, this type, by definition, will have a lower market share.

16. Some traits can be selected for use across a wide region, whilst others will have more specific value or a narrower geographic range. Days to maturity and vernalisation requirements (in winter cereals) are traits considered on a regional basis and some grain quality traits (in wheat or barley) can also have broad appeal. Other traits such as early plant vigour and tillering ability are also important in conferring buffering capacity across regions e.g. across a wide range of environments. Whilst traits such as disease resistance that offset a local threat, or provide a local opportunity, may need to be considered on a sub-regional basis.

17. Information about wide and specific adaptation is useful when providing advice about how to grow a new variety on farm. A breeding company that is able to ‘network’ with

farmers will have the best opportunity to supply new varieties suited to their local conditions. For example, there is considerable value in understanding how speed of plant development can be used to optimise sowing dates.

18. The performance of new varieties across different sites is determined by genotype by environment interactions (*G x E*). The analysis of *G x E* is complex as it relies on accurate and very detailed assessment of each variety and selection environment, often over many years, as well good characterisation of subsequent growing conditions to optimise a variety's performance on farm. Furthermore, adaptation depends on *G x E* at both regional and sub-regional levels. Yield benefits from a particular selection strategies, using either a few regional sites or many sub-regional sites, will depend on the relative sizes of genotype and environmental variation.

19. Breeders will typically aim for wide adaptation at high yielding sites. This type of variety will have above average yield across sites. However, a widely adapted variety is often out-yielded by varieties that are specifically adapted to local conditions, as described by Ceccereli (1989). Therefore, a challenge to breeders it to balance the need to produce a variety to perform well over a large region with that of selecting different genotypes that may be better adapted to smaller regions.

20. A shift to more specific adaptation in a selection programme will be of value if *G x E* at the sub-regional level is large, and as long as genotype and environment are well defined. The commercial value of an increase in the number of selection sites or the number of varieties released will depend on market size.

21. Climate change could increase *G x E*, but at different scales. More extreme, but relatively stable, weather and soil conditions would mean commercial value in identifying varieties with specific adaptation. However, if growing conditions become more variable, then selection is likely to favour more resilient varieties in which stability in yield is preferred to maximising yield.

3.3. How are selection environments optimised?

22. Breeders continually review the most appropriate selection sites and revisions to the range of selection and testing sites are made to be competitive in the market place. The choice of site depends on the stage of the selection process. For example, at the early stages of selection after initial crossings, core sites are used to assess potential across large regions. This is possible because core sites are chosen to provide information on essential or priority traits including resistance to important (or widespread) diseases such as mildew in wheat and barley or rusts and *Fusarium* in wheat, as well as days to maturity and vernalisation requirements. Thus, breeders

work towards types of variety characterised by particular strengths or desirable features.

23. Regional differences related to potential for wide or specific adaptation are identified at an early stage. For example, the potential for early and late sowing, or the time to maturity (i.e. early or late ripening varieties). Initially, field assessments are based on acceptance or rejection of easy to visualise traits such as disease resistance. Early selections (at core sites) can also include potential for use elsewhere.

24. Direct selection or decentralised breeding refers to selection under a specific target environment or cropping system. In theory, this results in better adaptation to local conditions (e.g. Brancourt-Hulmel et al. 2005).

25. Indirect selection or centralised breeding uses well characterised core sites to identity material that is widely adapted across a range of conditions. Indirect selection also refers to the use of genetic markers to select for the genetic background to a desirable trait e.g. disease resistance or tolerance to stress, which might confer a degree of wide adaptation (from that trait). Traits with high heritability can be centralised, whereas other traits such as disease resistance for pathogens such as yellow rust need be assessed at specific locations.

26. Breeders have to decide on the most appropriate balance of direct or indirect selection depending on the value of specific traits or their market demand or aspects of variety management. The choice of locations will also need to balance priorities for increasing yield and improving disease resistance ratings. As selection becomes more de-centralised or more direct then potential benefits on farm have to be valued against a likely reduction in market size. A positive aspect for the grower is that crop management can be targeted much better following direct selection.

27. Direct selection at a target environment is most useful when it reveals more information about a desirable trait or traits. For example, drier or drought-prone sites can be used to improve phenotyping and assessment of traits for tolerance e.g. differences in rooting patterns. In some cases, breeders would like to undertake more direct selection, or at least to exploit this type of information, but this approach requires more resources and is best linked to complementary research activities.

28. In practice, indirect selection for some specific traits or specific use is carried out core sites, though this requires a great deal of understanding of potential value for specific environmental or cropping conditions. For example, how poorer yielding varieties at high yielding sites might have value under less fertile sites or more stressful conditions.

29. The basic strategy is to select for varieties that will have high yield potential across farming systems i.e. widely adapted varieties. That is, breeding for a wide range of different farms and farmers. Extrapolation from central or core selection is possible and successful. However, high *G x E* can limit the adoption of new varieties, especially when the environmental component includes a high level of seasonal variation.

3.4. Is there value in increasing genetic diversity within a crop?

30. Crop structure comprises both genetic and physical (phenotypic) components. Genetic diversity or complexity relates to the use of single or multiple genetic types (genotype) in the same crop. This will affect phenotypic diversity which includes structural and physiological attributes (for which there is a need for better understanding and faster methods of evaluating).

31. Most current plant breeding is based on single pure lines and varieties with uniformity in their structure and consistency in quality and agronomic characteristics of value to market demands i.e. a single genotype. However, crop structure can also include increased genetic or phenotypic diversity in the form of blends (or mixtures) of individual varieties i.e. multiple genotypes or through the creation of more complex plant populations, for example in a composite cross of many parents.

32. At present, breeding for diverse or complex crop structure remains of limited value (or use) as it lies outside of mainstream agriculture. However, crops made up of variety blends can be of value in participatory plant breeding (e.g. Sperling et al. 2001) in which breeders are involved with other stakeholders (e.g. farmers and researchers) in the development of novel or highly adapted crops in niche areas such as farming on marginal land or for specific uses in organic farming.

33. The development and use of cultivar blends or more complex plant populations is considered as an approach to farming, not necessarily a target for plant breeding. Under experimental conditions it has been observed that cultivar blend provide enhanced stability in yield across locations. For blends to be adopted in variety testing they be required to out-yield the best cultivars, or least the mean yield of the individual components.

34. The enhanced yield stability provided by blends could have value as a control when evaluating breeding material or new varieties. They also provide potential for reducing disease levels because the increased diversity in crop structure and resistance genes reduces infection and spread of disease. However, this is not compatible with breeding for maximum yield.

35. To a large extent the type of crop structure is determined by end use. Many processors require a supply of grain of specified quality provided by one or several varieties of their choice. For example, the malting barley industry is based predominantly on growing elite genotypes of established and reliable grain quality. Adding diversity in the growing crop is not considered beneficial by many cereal sectors, though variety blends have been grown in the past in some parts of Europe, and the future use of more diverse crops would need to be considered against a wider range of sustainability drivers e.g. economic and environment.

36. Changes in crop structure effect the ways in which a crop is managed. Adding diversity, whether it is through mixtures of different genotypes or changes in crop rotations, reduces the reliance on pesticide inputs. However, plant breeding for increasing diversity on farm is not well developed because there has not been a strong market or end user demand.

37. An issue to address is whether breeding for increased diversity *per se* would detract from current breeding objectives in raising yield, grain quality and disease resistance. Where adoption has been most successful is in participatory plant breeding (PPB), which involves farmers in decision making about genotypes and complex mixtures on their own farms.

38. Some breeders do evaluate different crop genetic structures (e.g. variety blends), but this tends to be at the near market of the selection process, rather than breeding for diversity. In future, breeding for diversity could develop as a useful activity in understanding adaption, or at least increasing genetic resources; this is most likely to be undertaken in partnership with the wider research community.

39. In terms of grain quality variety mixtures may have some use quality or even complementary quality. The role of diversity is a neglected area of research. New research on complex plant populations is attracting interest, at least for potential to provide novel genetic material or desirable traits that could be pulled-out for use in plant breeding.

40. Diversity (or complexity) can also be considered in terms of the range of crops in the farming rotation, as well as changes in the area of other major crops or minor crops such as oilseed rape and forage maize. The use of minor crops such as legumes need to be considered in relation to benefits of increased rotational diversity and offsetting problems such as disease build-up or poor nutrient cycling which occurs in short rotations that are common across much of Europe. Such changes also need to be placed in context of market demand.

41. To a large extent, the cereals industry has become driven by large markets dominated by relatively few commodities and there has been loss of other beneficial crop species in the rotation e.g. peas, beans, lupins and sunflower and the benefits they bring for on-farm diversity. However, even without the introduction of other crop species, cereals could become an important part of more diverse crop rotations, with benefits in disease and pest control conferred over time.

42. Plant breeding could make significant improvement in other crops that diversify the cropping rotation. However, this could only be achieve in the context of market support and consideration of how home-grown alternative crops such as legumes would replace cheaper imported crops such soya.

3.5. Coping with climate change

43. Many cereal breeding programmes in Europe will not need to make major changes in variety development as genetic improvement would keep pace with general trends predicted for climate change e.g. those predicted for north-west Europe. Techniques such as doubled-haploid production and single-seed descent, which speed up the breeding cycle, enable breeders to be more responsive to gradual changes in climate.

44. Some aspects of climate or environmental variation will have more impact on plant breeding than others. To improve adaption it would be appropriate to extend the environmental range outside of testing sites in current programmes to include areas matched to ‘future’ climates.

45. Response of plant breeding to changes or a shift in climate is well accounted for by existing diversity in breeding material, and the potential for additional novelty or diversity. However, any sudden (10 to 20 year) shifts in regional climate will become an issue. A better understanding of *G x E* is essential to improve adaptation to both site and seasonal variations. This includes better characterisation of selection sites genotype and trait testing, especially when targeting wide adaptation in traits such as resistance to disease (e.g. viruses or rusts).

46. Climate change is likely to extend environmental variation with extremes of temperature, precipitation and soil moisture occurring more frequently. This will increase the need for appropriate levels of adaptation. Thus, the debate for wide or specific adaptation will become more prominent. Even in the short-term seasonal variability in weather and developments such as resistance to drought or frosts in winter or spring.

47. Increase in volatility in seasonal temperature and precipitation will impact on current strategies for wide adaptation. At one extreme, drought tolerance would become more important, whilst coping with cold winters without snow cover would expose winter cereals to frost damage.

48. Improving resistance to diseases and insects pests will continue to be a high priority. Many diseases are already present within the wider variety selection areas, though some e.g. rusts would become more prevalent depending on changes in temperature and rainfall. Generally, the threat from insects is expected to increase.

49. In regions where coping with climatic variability becomes more challenging, more emphasis could be given to diversity in relation to the number of varieties grown, including an increase in variety numbers on national Recommended Lists.

50. ***Coping with a 1-2^{o}C rise in mean temperature in the next 30-50 years:*** This level of temperature change is well within the current rate of variety development. Plant breeders would consider the choice of current selection sites for the crops and varieties of tomorrow. Although this degree of shift could lead to a gradual change in the type of agriculture and crop rotation practiced, plant breeding cycles have been speeding up which helps with adaption.

51. ***Coping with a 2-4^{o}C rise in mean temperature in the next 50-80 years:*** Higher levels of temperature change would mean the need for very different types of variety. Coping with variability in climate alongside such a temperature shift will become the limiting factor to success. For example, plant breeders would need to introduce much more genetic diversity in plant responses to day length to optimise plant development, especially under extremes of temperature and soil moisture.

52. In regions faced with large changes or fluctuations in temperature and moisture, agriculture will need to consider if should attempt to grow the same crop species, or the same proportion of winter and spring cropping e.g. spring and winter barley. Thus improving crop rotations to sustain agricultural production will become much more of a political issue within and between regions or countries

53. To address a temperature change of 2-4^{o}C breeding must be supported by other research, with better understanding of temperature on crop development, leaf canopies and yield creation, and also the effects of changing soil temperature and moisture on root growth.

3.6. Adapting to reduced fertiliser (nitrogen) inputs

54. Politically this is being driven by the environmental impacts of fertilisers, as well as their availability and energy or production costs. In the longer term, the availability of phosphate will become a more important issue than availability of nitrogen. The former is a finite supply, whilst the latter can be produced providing a source of energy is available (e.g. fossil fuel-base or biological energy).

55. Policy directives, or economic drivers, to reduce significantly nitrogen fertiliser to cereal crops would impact on both yield and grain quality. The key issues for changing fertiliser management will be the amount by which nitrogen (and other inputs) might be reduced and the timeframe over which changes are made.

56. A shift towards reduced fertiliser use in plant breeding programmes will depend on the future of agricultural practice, including new technologies and improvements in precision farming.

57. Applications of nitrogen fertiliser are essential to achieving high yields. Yield and grain quality are both strongly influenced by crop nitrogen uptake and utilisation (i.e. partitioning of nitrogen within the plant). Research in the 1990's established that wheat crops achieve half of their yield as result of applied nitrogen fertiliser (e.g. Sylvester-Bradley 1993).

58. Any changes in fertiliser use will affect grain quality and yield, at least in the short term until breeding can respond. For example, nitrogen fertiliser is required to increase grain protein content – which is an industry standard measure of baking quality in wheat. In cereals there is negative correlation between grain yield and grain protein. Therefore, large changes in nitrogen and fertiliser management must be considered in relation to market value and use.

59. There is a need for much wider debate about which changes in grain quality specifications or measures (requirements) would be acceptable to industry (users of grain) or appropriate for use under farming with lower fertiliser or nitrogen input.

60. Modern varieties are much more efficient at using nitrogen fertiliser than those of just 30 or 20 years ago. This is observed as significantly higher yields in modern varieties compared to older varieties at current levels of fertiliser inputs. Breeding for further improvements in nitrogen or fertiliser use efficiency is expected to continue. This should develop as improved nitrogen uptake into the crop and/or improved nitrogen partitioning to the grain.

61. The use of nitrogen fertiliser must be placed in context of all fertiliser use in agriculture and the need to supply food of the appropriate or desired quality. This should include wider debate on energy use. Research – outside of plant breeding – is required to support development in fertiliser use efficiency: this includes identifying genes that confer better use of N, P and K.

3.7. Breeding for reduced energy use and increased efficiency

62. To a large extent this is a political issue and changes in energy use in agriculture must be considered in relation to food security and input/production costs across the whole supply chain, especially when targeting or adopting large reductions in energy use. Likewise, policy and technologies to reduce energy use and improve energy efficiency are being addressed across all industrial sectors.

63. In agriculture, reducing carbon and energy inputs and improving efficiency is not about adopting a single technology. It will encompass a wide range of approaches across the whole supply chain from plant breeding to farming, processing and consumption. For example, the more efficient use of soil management and inputs and waste reduction on farm, and the recycling of energy during grain processing.

64. Agricultural production costs vary by region, country and farming system according to farm structure, production methods, equipment and crop rotation, as well as food supply and demand. They also depend on farmers' own personal perspective of costs and production levels in relation to risk of not meeting the desired output. Some important costs such as labour or energy can be considered as global costs that are relatively high compared to agronomic costs or the cost-benefits of adopting a new variety.

65. There is a role for plant breeding in improving farming efficiency. This is most applicable when breeding companies and advisory or extension services work with farmers. Plant breeding is also part of the food supply chain and would respond according to market or policy demands.

66. The impact that a plant breeding programme has on subsequent energy use across the supply chain is not easy to quantify. However, it would be possible to evaluate new varieties in relation to measures of farm inputs or processing efficiency e.g. flour or malt yield per tonne or per unit of time or energy.

67. Plant breeding could include a wider range of different selection environments and selection criteria. The priority for each breeding company would depend on their

target markets. This may necessitate adjustment to crop management conditions at different stages of variety selection.

68. Soil cultivations and fertiliser use are major sources of energy use on farms. Breeding could select under different soil management for example minimum tillage or systems using lower fertiliser e.g. nitrogen as a response to lowering energy inputs in agriculture. However, such development would need to put into context of a major shift in agricultural production towards these practices. Furthermore, changes in fertiliser use must be considered in terms of benefits across the whole cropping rotation, rather than the current season. There is scope for using novel types of fertiliser such slow release nitrogen.

69. Changes in soil management or inputs can be costed to give an estimate or margin over costs for each new variety. For example, changes in inputs or costs could include soil management (e.g. ploughing versus minimum tillage), changing the number of spray timings or the use of novel fertiliser applications (e.g. slow release nitrogen fertilisers).

70. Public investment in plant breeding could be a strategic way to improve carbon and nitrogen balances in agriculture. For example, private-public partnerships across plant breeding and the scientific community to identify if varieties (for different farming systems) should be selected directly under specific conditions to indicate improved efficiency e.g. reduced inputs.

71. A view from the farming community (about reducing energy inputs and improving on-farm efficiency) would be the availability of more cost-effective varieties with good disease resistances or enhanced nutrient use efficiency which allows for fewer pesticide or fertiliser applications and fewer passes by tractor.

3.8. Reducing the reliance on plant protection products

72. Changes in the use of plant protection products in the EU will have a significant impact on the control of many pests and diseases. Revisions of Directive 91/414 are likely to reduce the range of pesticides that can be used in agriculture. Consequently, growers, plant breeders and the arable sector will need to adjust to changes that might occur in particular groups of fungicides, insecticides and herbicides. Whilst there is likely to be no sudden change in plant breeding programmes there could be a more gradual shift to the development of more pest or disease resistant varieties.

73. Breeding for yield improvement has often resulted in disease resistance being of secondary importance, though good resistance ratings across different disease are

targets in variety selection. To some extent the balance of yield and disease resistance will depend on the breeding programme and the objectives of individual breeders.

74. Breeding towards varieties for reduced agrochemical inputs, and improvements in disease resistance would have a significant impact on yield, at least in the short term. This is because breeding for high yields relies on removing limitations from diseases, pests and weeds. In terms of yield potential, fungicides in plant breeding have been invaluable in reducing worst cases of poor genotype performance. That is, yield and other traits such as grain quality are preserved by crop protection.

75. Although plant breeding has made significant advances in improving resistance to many of the major diseases, varieties with the highest yields rely on high inputs to achieve their potential. Untreated yields (i.e. yields without fungicides) will continue to improve, but an important question for agriculture is the extent to which breeding under reduced levels of crop protection inputs will affect the annual improvements in the yield.

76. Improving disease resistance and reducing the reliance on fungicides requires more public-private collaboration to understand the biology of pathogens and how this can be applied to crop protection and plant breeding. Although the idea of developing long-lasting (or durable) resistance to disease is not new, it will become a higher priority if there is less reliance on pesticides for high yields.

77. For some diseases, for example yellow rust, breeders are some way off in developing a durable or stable resistance. This is because new disease strains develop rapidly. A further complication is that healthy leaves, conferred by resistance to a specific disease or range of diseases, provide a substrate for other micro-organisms that might otherwise be absent. Another priority will be development of resistance to viruses which are spread by insect pests that may not be controlled in future because of proposed changes in insecticide use.

78. Breeding for disease resistance has occurred alongside the use of fungicides (in most programmes) so that selections can be assessed for yield potential. Breeding for improved disease resistance can also carried out alongside altered management. For example, selecting for yield improvement could be made at a critical level of resistance that allows for reductions in the number of fungicide applications.

3.9. Yield potential and the challenge to increase yield on farm

79. Plant breeding of new varieties contributed to about half of the threefold increase in cereals yields recorded from the late 1940's to the early 1980's; with the other half coming from increased mechanisation and the use of fertilisers and agrochemicals. A recent study by NIAB, Cambridge, estimated that around 90% of the average cereal yield increase since 1980 can be attributed to innovation in plant breeding (Source: BSPB Plant Breeding Matters, Nov 2008).

80. There is high expectancy of continued yield improvements. It is possible for cereal yields to increase at 1% per year, though this might be higher e.g. 1.5% in some cereal species such as maize or other crops such as sugar beet. Cereal hybrids might offer more than 1% improvement. Investment (from other research) is needed to sustain yield improvements at the highest level, this includes public sector involvement. Continued yield improvements depend on a better understanding of the genetic controls of yield components and traits.

81. In practice, yields on farm have increased only slowly, or even stagnated, compared to the achievements made in plant breeding. Although difficult to quantify, the discrepancy between genetic improvement or improvements in variety trials and yields on farm are likely to be the result of much less control of the main limitations to yield on farm compared to the more controlled conditions under which cultivars are selection and tested. Control of limiting factors – especially variation in soil conditions, diseases, pests and nutrient deficiencies – through precision farming would complement genetic improvements.

82. Differences in crop rotation on farms and high variability in soils across fields and farms tend to reduce the potential of a new variety selected and tested under more controlled conditions in breeding programmes. For example, in some regions continuous cereals are common on farm or there is at least an increase in second wheat crops.

83. Soil conditions and diseases are not as well controlled on farms as they are in breeding programmes. Thus, soil improvements on farm would raise yields. Diseases such as barley yellow mosaic virus (BYMV) or the fungal rusts are likely to have more limiting effects on farm than in breeding programmes. Generally, the variability or patchiness in soil conditions and crop health will impact on farm yield more strongly than in variety selection trials.

84. Yield improvement must also be considered in relation to other factors e.g. policy or technologies that impact on farm productivity. Policies that resulted in reduction of

fertiliser use would also set revised limits for yield potential. Likewise, reducing agronomic inputs, such as fungicides, will compromise selection for very high yield.

85. End user requirements, especially any changes in the grain protein specification will impact on progress with yield improvement. For example, yield increases are traded-off against raising grain protein levels i.e. the negative correlation between these two characters.

86. Yield Improvements need to be considered in relation to changes in land use or land types and potential productivity per unit area of land. This includes different soil-climatic types or even farming systems. This is important for policy (government) and industry for estimating changes in total production.

87. Yield improvements in cereals must be considered in relation to both human and livestock use – an appropriate balance between these two sectors will determine if cereal production can meet the demands of growing populations.

88. For breeders, the benefits of improved yield (and quality) must be considered in terms of value capture and the size of the seed market in a new variety. It is important for economic sustainability of plant breeding not to separate these two factors.

3.10. Scope for improving grain quality

89. Since the 1950's plant breeding has made significant advancements in grain quality across the different cereal sectors. Grain is already high, and continues to improve. The main issue today is how further improvements can help to maintain food supply chains and human and animal health.

90. Quality improvements are continually demanded, especially with traits to help processing and quality of the end product. This is important in highly competitive, mature or saturated markets.

91. Improvements in some crop characteristics are traded off against others – this poses a significant challenge to plant breeders. For example, there is a trade-off or negative correlation between grain protein content and yield. This has implications for producing high yielding bread making varieties.

92. The milling sector has several criteria for assessing grain quality. These relate to the quantity and quality of protein to meet requirements for different milling and baking processes. As yield improvements tend to reduce grain protein, a question for

sustained yield and quality improvement is what is the lowest level of protein required to achieve the market requirement?

93. Changes in grain quality need to be considered in context of the supply chain including the farmer, processors and consumers. To a large extent, sufficient quality is already present to supply major sectors of milling, brewing, distilling and feed. However, nutrient balance in relation to dietary requirements and health for humans and livestock can be considered as targets for future plant breeding. Any changes in grain nutrient composition need to be considered against trade-off with major grain constituents such as starch and protein.

94. Grains with added nutritional value, improved processing ability or other functionality such as starch or energy value can be targeted in future plant breeding. Likewise, developing special traits such improved starch in barley for human health and food & drink markets or increasing mineral content in milling wheat.

3.11. Increasing production by breeding crops for marginal land

95. This is less relevant to current plant breeding in the context of European agriculture because improvements in production (and supply) is expected to be made in the more fertile areas or under the best soils rather than more marginal areas. However, research into crop adaptation to meet predicted changes in climate and soil conditions e.g. requirement for drought tolerance that would be of value in some parts of Europe.

96. In Europe (or elsewhere) investment in breeding for more marginal land would be feasible if a these crops or varieties are of high value or sufficient market share. In other parts of the world where there is less productive land or a high proportion of degraded soils then breeding for more extreme or marginal condition is more important e.g. in parts of Russia, India, Brazil, Australia and across Africa. In Europe, this issue could become more pressing if climate change results in significant changes in rainfall and soil moisture which impacted on land capability across the continent.

97. There is scope to use hybrids. These are produced from a cross of two parents each with uniformity in the form of their genes (homozygous). The resulting cross produces a uniform population of hybrid plants. Hybrids have relatively good performance on less productive or more marginal land. Some of their inherent strengths of high tillering ability confers good all-round adaptation to adverse conditions.

98. There is a need for wider debate about arable cropping on less favourable land. In particular, the use of farm-saving of seed (to reduce farmers input costs) which needs to be properly accounted to protect breeders' royalties, which are essential for maintaining breeding programmes.

99. Breeding programmes are located in areas where the breeder expects most benefit and uptake from crop and variety development. This includes adoption of varieties across different types of farm or farming system. The debate about the value of direct or indirect selection environments can also be considered here. Generally, for most plant breeders, the most successful approach to variety adoption has been to use good sites and alter conditions at these sites rather that focus on less marginal conditions.

100. Direct selection under a specific environmental condition e.g. soil types is of value if there is a key specific trait to be introduced or if there was sufficient value in a niche type of variety, or if the direction of variety development was to change from a saturated (mature) market to an emerging (young) market. If land considered as marginal is re-evaluated as having potential in future then plant breeding is more likely to place resources in this area.

101. Use of new or marginal land for agriculture depends on the balance of agricultural production and other uses of land. This is a political question and depends on wider issues about land use; for example the role of forestry or agro-forestry within food supply or for other industrial (raw) materials or wider issues such as landscape resource management and conservation.

3.12. Breeding and public sector research

102. Plant breeding operate within a market place in which the main breeding targets are for improvements or differences in yield and quality requirements. Plant breeding would benefit from areas of research into genetic understanding of traits, genetic tools to speed up breeding and high throughput phenotyping. Much of this research is outside the capability of breeding companies, but could be of value given appropriate partnerships.

103. Science direction has not always been in the same direction as that of breeders. Science has been good at delivering tools, but less so at providing applications. Publically funded science has made significant advances in understanding the genetic basis of plant growth and developmental processes, especially in model species e.g. *Arabidopsis*. However, new funding is needed to extend (or apply) this to practical plant breeding. Likewise, publically funded crop science that has helped to

understand crop responses to changes in climate and soil conditions needs to be developed further with plant breeders.

104. Improving links between the plant breeding and industry depends on more relevant work being funded in the public sector such as pre-breeding for desirable characteristics or a clear route to the application of genetic understanding of plant growth and development and other traits in crops or model species, such as *Arabidopsis*. Addressing major issues such as the trade-off between grain yield and grain protein in cereals requires investment in crop research at Institutes and Universities with partnerships between breeding companies and academic partners.

105. Research has also provided benefits in new techniques such as the use of doubled-haploids in which development of a pure line is speeded up compared to convention pedigree breeding. Advances in biotechnology such as the use of transgenics (or GMO) are likely to improve grain quality and the efficiency of resource use e.g. fertilisers, though the application of some technologies must be considered in terms of wider agricultural and society needs.

106. Partnerships between breeders and the public sector research vary across Europe. The benefits to plant breeding of public investment in plant genetics also varies, though overall progress in applying such work has been limited. Some successful partnerships between plant breeding companies and Universities and Institutes have developed e.g. the Wheat Genetic Improvement Network in the UK. The value of Networks should not be underestimated in the development of applied research in genetics and crop physiology to benefit plant breeding. Plant breeding companies also play a key role in the application of new methodology or technology such as the development and application of molecular markers for desirable or undesirable traits.

107. Wider debate about the role of public-private partnerships to support plant breeding should be encouraged. In a UK context, plant breeding was once motivated by strategic concerns relating to food security. The Plant Breeding Institute (PBI) was established in 1912 devoted to the breeding of improved varieties of wheat. Over the years, the PBI established four crop sections in: Cereals; Potatoes and Brassicas; Sugar Beet; Forage and Grasses.

108. Until the early 1960’s plant breeding in the UK remained largely publicly funded. Today the majority of plant breeding takes place in the commercial sector. Since the 1970s, new areas of knowledge in biotechnology have brought together major agrochemical companies with the seed companies. In 1985 the PBI was sold to a private company under the government's privatisation policy.

109. Privatisation precipitated a market structure that s today dominated by only a few firms with the majority of breeding in the major arable crops dominated by several companies. This essentially means that public good objectives are delivered through a bottleneck of commercial firms whose motives are potentially at odds with the use of traits for sustainable farming.

110. A future model for developing private-public partnerships in Europe could be based on the historical workings of the PBI or at the very least expansion of initiatives such the Crop Genetic Improvement Networks supported by Defra in the UK or the BBSRC's Crop Improvement Research Club, also in the UK.

4. New varieties and sustainability traits

4.1. Characterisation of cereal varieties for established market values and public goods (new market values)

At present, successful varieties are characterised by high yields in response to fertilisers, fungicides and plant growth regulators and without competition from weeds. In future, agriculture could consider new sustainability criteria for the variety testing system such as reducing the reliance on high inputs (AEBC 2005; FOSSE 2001).

EU Directives require testing for Value for Cultivation and Use (VCU) as part of National Listing (NL), based on yield, resistance to harmful organisms and quality characteristics, which are primarily market-led drivers. Although EU Directives do not preclude additional criteria, the NL testing system is almost entirely funded by applicants (i.e. plant breeders), and consequently assessment of traits with possible environmental benefits is limited to disease resistance.

Breeding for improvements in traits to increase resource use efficiency e.g. use of fertilisers needs to be placed into context of other priorities such yield improvements and increasing disease resistance. This is to avoid the risk of varieties being limited to a niche market or a site-specific improvement (e.g. locally adapted nutrient use efficiency) with limited scope for wide-adaptation and weakness for diseases.

For farming to benefit from varieties with new market values traits would need to have quantifiable environmental benefits as well as continuing to meet the long established market value. Addressing several important questions is fundamental to the adoption of wider sustainability traits or other public goods:

- What is the added-value placed on traits that go beyond yield and agronomic benefits?
- Who pays for the extra costs incurred by breeders and the variety testing systems when assessing other public goods that are attributed to new varieties?
- What is the trade-off between yield and quality improvements and other new traits with wider public-good value?

There has to be a balance between producing food and impacts on the environment. The former includes nutritional value and cost to the consumer. To some extent, the production of inexpensive food and environmental benefits of agriculture appear to be in conflict because of the high input nature of modern agricultural production. However, these aspects could converge over time, if the whole of agricultural production, including plant breeding and variety testing, embraced a more holistic approach.

A proposal for a more holistic approach to agriculture – in which new varieties will be a key aspect – is presented in Østergård (2008) This highlights a more ecological based production system for agriculture, though it requires a shift towards embracing more diversity in arable production which may not match current requirement of breeder and end users. ,

New variety evaluation procedures, especially in national testing systems, would also need to be robust i.e. quantifiable and repeatable. This is feasible as long as the market demand is present and fully represented in the evaluation process. The risk is that introduction of a new criteria would tend to take selection towards niche types of very specific use. New traits need to become part of varieties marketability and not simply a niche commodity.

New criteria would require more assistance in variety registration, especially as part of VCU testing. Returning to the question of who pays? Would farmers, processors or consumers pay for additional public good or environmental benefits? Who rewards breeders and farmers when they deliver wider public goods? This is a supply chain issue, extending to processors and consumers. Should *both* breeders and farmers be rewarded for the added benefits?

Recommended Lists for cereals vary by country, but some traits are common to all such as the importance placed on fungicide-treated yields (i.e. an indication of yield potential) and grain quality measures, as well as a series of agronomic traits which include disease resistances, resistance to lodging (i.e. crop standing power) and plant maturity. Of more interest in the context of this report is the potential for variety selection and testing and recommended list to include wider sustainability criteria. Table 1 presents a list of plant or crop traits that are in current use for variety recommendation (i.e. established market values) or could be used in the future (i.e. new market values). Each trait has a scored for current market or future (new market) use or value; ranging from 1 the highest value to 5 the lowest value. A score of 0 denotes not included in variety recommendation. The scores are not a definitive survey of industry-wide views, but reflect a broad opinion of breeders, farmers and agronomists from recent discussions. As such they are hypothetical and would merit further testing.

The traits in Table 1 are grouped into the familiar ‘yield/quality’ and ‘agronomic features’ sections: these are common to most cereals recommended lists. ‘Crop rotational’ features also recorded in some lists, but ‘new crop features’ are not used at present. Note that most of the traits with a current market value are expected to retain this value or increase it in future. This is because traits such as untreated yield and disease/pest resistance are likely to become more important. Treated yield have been given a slightly lower future values because of more importance placed on yield with lower inputs.

Table 1. Variety traits according to their current and new (future) market value. These are included in current cereal recommended lists or have potential to be included in future. Scores are hypothetical and represent a broad industry view of how traits are perceived. The relative value is as follows: 1 = very high; 2 = high; 3 = moderate; 4 = low; 5 = very low; 0 = not considered or included at present.

Traits	Current market value	New market value	Comments on new market value
Yield and quality			
Yield (fungicide treated)	1	2	Important, but other yield traits increase in value
Yield (untreated)	3 or 4	2	Increase in value
Yield at reduced pesticide inputs	4 or 0	1	Increase in value
Yield at reduced fertiliser inputs	0	1 or 2	Likely to become a key driver in yield selection
Yield stability	5 or 0	1 or 2	Very important in the face of climate change
Grain quality[1]	1	1	Essential now and in the future
Agronomic features			
Disease resistance[2]	1 to 4	1 or 2	More or different diseases becoming important
Pest resistance[3]	1 to 4	1 or 2	More or different pests becoming important
Competitiveness against weeds	5 or 0	3	Could become part of more integrated farming
Resistance to lodging	3	3	Similar value in future
Ripening (days to maturity)	3	2	More important in the face of climate change
Resistance to sprouting	3	2	As above
Resistance to frost	3	2	As above
Resistance to drought	4	2	As above

Notes: [1]Grain quality currently comprises 4-10 different traits depending on cereal species and end use.
[2] Disease resistance currently includes 2-8 entries depending on cereal species.
[3] Pest resistance currently includes 1 or 2 entries depending on cereal species.

(**Table continued overpage**)

Table 1 continued

Traits	Current market value	New market value	Comments on new market value
Crop rotational features			
Position in crop rotation	2 or 3	1 or 2	More value in new crop rotations
Sowing date	2 or 3	1 or 2	Important response to climate change
Soil type	2 or 3	2 or 3	About same importance, but links to local needs
Other new crop features			
Increased nutrient use efficiency[4]	5 or 0	1 or 2	Likely to be a key part of future selection
Benefit in a variety blend	5 or 0	3	Provides option to growers seeking yield stability
Added health value (human/animal)	5 or 0	2	Important to breeders and new markets

Notes:

[4]This is related to yield at reduced nitrogen fertiliser input, but could include other nutrients e.g. phosphorous

4.2. Understanding how new traits could be included in VCU testing

This depends on how open-minded the testing of varieties becomes and will vary between countries. For example in Germany, some VCU testing does consider special traits e.g. in Germany. There is also a cost-benefit to consider in that addition measures mean more cost to the testing system and more data to process and interpret in the decision making stage. To a large extent, the official variety testing systems need not undertake more trials or assessments. Instead, it will be on-farm assessments that will place value on public good and environmental benefits.

Examples of traits that would have new market value include those with general use in terms of lower inputs. For example, a requirement for less fertiliser, high untreated yields (without fungicide), improved disease resistance ratings (FOSSE, 2001), high weed suppression characteristics (Hoad et al. 2008), early crop vigour and widening of sowing dates to offset weed, pest and disease build-up (FOSSE, 2001). Traits of value for reduced fertiliser requirement, improved disease control etc need to be high-lighted for positive and/or negative interactions within the whole character set for each new variety. This may include trade-off between different desirable traits and the different ways each variety might need to be managed to optimise its use on farm.

It is important to ask the question: Do farmers make the best use of traits such as disease resistance ratings? To some extent, a variety with improved resistance to all diseases would be valued by a farmer or agronomist as a low-risk crop, rather than a low-input crop. Higher economic value would be placed on disease resistance if it was shown to be more lasting across sites and seasons. This durability would add value to resistance ratings and change the approach to pesticide application to a more targeted (to weaknesses) and supportive role, rather than a reliance or dependency role.

Poorly defined or "soft" values add cost but risk no benefit. The success of new criteria is how they rate under different conditions. This would require additional support to widen the trials system. Plant breeders have their own preferred range of climatic and soil conditions. National List testing provides a wider range of sites e.g. change in soil quality. To improve understanding or benefit of broader soil or input criteria testing would need to be carried out at the same sites in each year to account for seasonal variation.

Although there is no added-value to plant breeding (in terms of continued variety selection) after the official VCU stage, it would be feasible to extend variety evaluation to specific situations after its official recommendation. Thus, adding value in terms of marketability of a new variety. This would be the role of extension services including agronomists and advisors – not the official testing system.

When evaluating varieties under a wider range of environment or inputs it is important to consider genotype by environment interactions (*G x E*). Good performance at low inputs is not always precluded or predicted by testing at high inputs or *vice versa* (Abeledo et al. 2003; Hasegawa 2003; Sinebo et al. 2002). However, a reduced yield gap (between varieties) becomes important when trying to discriminate between varieties when inputs are reduced also (e.g. Sinebo et al. 2002).

4.3. Placing value on new traits in VCU testing or recommended lists

Evaluation of new varieties for wider public goods starts with the premise that the value of a genotype depends on its combination of traits. New varieties are normally defined according to their established market value which is current determined by yield and grain quality, but they can also be rated in terms of their public good value, which is notionally determined by the net value of a financial return in adopting the variety plus or minus the value of positive and negative external impacts when growing the variety. These impacts arise for example from the reduction of fungicide, herbicide and fertiliser use.

A new variety always needs to be better than the current best in its sector, or when compared to other control varieties. Genotype screening may be carried out (by breeders or research groups) to assess genetic diversity in measures such as nutrient use efficiency, competitiveness against weeds and establishment under different soil conditions. Breeding companies vary in their approach to testing new crop features or how they use extension work to evaluate their new varieties. Some will test the ways farmers will use their varieties. However, this is not easy to undertake as variance about variety performance on farm (even under the same management) is wide. To add new values to a variety or additional criteria to a cereals recommended list it is essential for environmental and ecological features to be integrated, with much better understanding of cultivar and environmental or ecological interactions.

As stated already, varieties are evaluated against the current best. The main driver is the need to suit the market demands e.g. processor and consumer. Typically, end users such as millers, maltsters and farmers will decide the market, particularly in relation to quality requirements. This is the direction to market. This could perceived as variety development in one direction. For this to change towards new market values or public goods then another drivers e.g. environmental and public good would must be built into the market value. That is, the environmental, ecological or processor benefit becomes a requirement for the food supply chain, including consumers. In this way, a wider group of stakeholders play a role in deciding why crops are grown and what their value is. Hence agriculture, and plant breeding, respond more explicitly to society needs.

Official variety testing would need to be clear about definitions of environmental or social value. These could be based on an index or ratings system as used for agronomic characteristics in recommended lists, with clarity about minimum standards or thresholds. It should be feasible to define an ideotype (even for regional use) with traits for end user benefits, this would include the current value (or ratings e.g. 1 to 9) placed on disease resistance as well as new agronomic traits such as good yield at low fertiliser input or high fertiliser use efficiency.

If new traits are in sufficient demand, especially from growers and end-users then new criteria could be adopted by breeders' selection and official variety testing systems. When considering new criteria for variety evaluation it is important to understand how environmental or even social valuation may be sensitive to change year to year or region to region. Crop traits must be what farmers need to meet market specification and be robust in the sense that they can be measured with precision year by year and region by region. Without a high level of stability new traits or selection criteria cannot be evaluated in a testing system. Therefore, new criteria need to be of generic value.

Crop traits also need to be understood and valued in terms of how they impact on farm management. New plant breeding targets such as competitiveness against weeds and increased vigour, along with improved disease resistance ratings, would provide opportunities for cost savings and reduced inputs on-farm. Integration of new market values with well-established values such as those presented in Table 1 will enable plant breeders and the variety selection and testing systems to understand the context within which genetic improvement takes place and the potential mechanism for prioritising further trait development.

This approach extends to an externality quotient or 'footprint' of each genotype. Direct and indirect inputs and outputs will include economic value, energy balance, nitrogen budgets and waste. This type of evaluation would allow the industry and testing authorities to estimate the marginal effects of any explanatory variable (i.e. traits) on the value of the genotype. Finally, it is most important to maintain a reliable evaluation system and to decide what is a priority or really important to evaluate. If new selection and testing criteria require additional or different trials then costs and value for money become increasingly important.

5. Methods to evaluate new varieties

5.1. Considerations for variety trials

The use of established market and additional public good criteria (i.e. new market) within VCU testing, as well as in National List (NL) and Recommended List (RL) trials require experimental designs with appropriate variety and environmental controls to differentiate genotype responses across additional trials series and growing systems.

This might include low-input and organic field trials to put material under the severest test (e.g. Hoad et al. 2006) and new methods to assess both current and new market values. Such an approach should include cost-benefit analysis of aggregate returns to the costs of selecting new varieties and their subsequent adoption, and methodology such as hedonic pricing (assigning value to characteristics of goods) to value individual traits.

The response of genotypes (and their traits) to crop inputs or management factors remains important in assessing their new-market benefits at both development and testing stages. Seasonal and site differences mean that the environmental component in *G x E* is highly variable: this can make analysis of management effects difficult. A new approach would be to clarify both 'environmental' and 'management' factors within the trial design. Systematic trial development using specific environments and well-defined management options would enable the 'environmental' component in *G x E* to be sub-divided into environmental by management components (*E x M*). Thus, providing more reliable outputs for assessing cost-effectiveness of new genotypes.

Much of this relates to data analysis and interpretation, and a key step will be to identify additional partners in the variety selection and evaluation process to help understand the extra complexity of information within *E x M* and *G x E x M*. This should complement other methods e.g. yield sensitivity analysis to changes in site conditions that are routinely carried-out by plant breeders or research. Sensitivity analysis itself e.g. variety response to changes in site fertility could be widened to include other traits such and quality or new sustainability traits e.g. in Table 1.

5.2. Towards socio-economic analysis of new varieties and their traits

Some new varieties set a new benchmark for yield or quality or other traits. These represent steps to the next level of crop improvement or potential e.g. introduction of the Rht reduced height genes or the 1b/1r translocation, which has improved the efficiency of light conversion and biomass accumulation. Genetic benefits in each new cultivar may appear to be small.

However, these benefits are cumulative and thus large over time. Furthermore, new varieties will often have additional benefits such as dietary improvement, though currently these aspects are not be examined in detail.

Economic analyses should include comparison of the relative costs and benefits of new varieties and their trait combinations with alternative methods that could deliver the same public good; for example comparison with growing a different crop species or a different approach to farming. This could also other policy levers such as market-based changes or legislation for achieving specified objective outcomes. This approach lends itself to demonstrating the extent to which the introduction of new varieties may contribute to the delivery of environmental benefits. Hedonic valuation (Evenson et al.1988; Gollin and Evenson 1988) may be useful in valuing the wider environmental benefits of plant traits. In its simplest form, one such procedure is described by:

$$V_{ij} = F(T_{1ij}, T_{2ij}, ..., T_{nij}, Z_{ij})$$

Where V_{ij} is some measure of the economic value of a variety *i* in location *j*. T_{1ij}, T_{2ij}, ..., T_{nij} are indexes of traits *1*, *2*, ..., *n* of the variety in location *j*. Z_{ij} is a further measure of economic or ecological factors or benefits associated with variety *i*.

For any given social, environmental or policy objective (e.g. mitigation or adaptation to climate change, protection of biodiversity or reduce pollution and waste) it is possible to determine whether there is an alternative method of delivering the output equivalent to that delivered by the new variety or varieties.

Although a cost-effectiveness comparison between varieties or a variety and alternative methods of achieving the same objective can be complex, it is possible to conduct an "incremental cost effectiveness analysis" to compare additional variety or trait benefits to the current best, or currently implemented intervention, for achieving specific outcomes. New varieties may offer a cost-effective option to address specific policy objectives with the advantage that benefits of genetic improvement are permanent and cumulative. Even if the present value of the costs of alternatives (e.g. changes in crop rotations or policy-led reduced inputs) is low, a genetic approach is still favoured providing assumptions about levels of adoption by farmers and end users hold. This is influenced by the timeframe of plant breeding and subsequent adoption by farmers or even policy change. For example, the BYDV virus in cereals spread by aphids can be controlled by expensive seed treatments or through genetic resistance, but in a lower yielding variety. This evaluation requires a cost-benefit analysis.

Present value costs of adopting new genotypes can be assessed by comparing values of the variety and alternative approaches with the expected future benefits derived from the variety and alternative options in delivering the desired objective e.g. reducing fertiliser or pesticide inputs. For example:

PVg = Present value of new variety/s

PVc = present value of the alternative strategy

Qg = quantity of improvement or benefit under new variety option (within a time frame)

Qc = quantity of improvement or benefit under alternative strategy

An incremental cost-effectiveness ratio can be considered as:

$$\frac{PV_g - PV_c}{Q_g - Q_c}$$

By substituting various options for the costs and benefits of the alternatives to introducing the new variety/s. The use of this comparison is in terms of comparing the unit cost of incremental benefits delivered by the variety/s. In some cases we may be only interested in the strategy that delivers a greater quantity of social or environmental or market benefit. If this numerator is negative, then there is an incremental saving from not introducing the new variety/s, unless the specified alternative strategy delivers less benefit over a different and specified time period. The net present value (*NPV*) can be derived by a discounting procedure. The following equation summarizes the procedure:

$$NPV = \sum_t \sum_i \frac{B_{it} - C_{it}}{(1+r)^t}$$

where NPV is the net present benefit, B is a measure of monetary benefits (element *i* at time *t*), C represents the monetary cost, and r is the discount rate.

When all the established market and new market costs and benefits of a new variety are measured in monetary terms, the aggregation is simple: the discounted value of the total costs over time is subtracted from the total benefits also discounted over time. Positive *NPV* (i.e. benefits exceed the costs) indicates that the new variety is superior to the current best or 'do nothing' situation in terms of overall value. If the *NPV* is negative (i.e. the costs are larger than the benefits), then the new variety would not be expected to have significant benefit, unless there were other strong non-monetized benefits to consider.

6. Concluding Remarks

The public good role of agriculture is increasingly emphasised in discourse on sector sustainability, and most countries with the Organisation for Economic Co-operation and Development (OECD countries) are now locked into a range of commitments on climate change mitigation, soil and water quality improvement and biodiversity conservation. In this context, the development of new varieties will increasingly face the challenge of demonstrating yield and quality improvements with financial benefits to breeders, growers and the rest of the supply chain, while at the same time contributing to the management of good and bad external impacts on the agricultural landscape

An important question to address is who pays for the added benefits from plant breeding. The cost-benefits to breeding, agriculture and society in developing a variety that is widely-adapted (to geographical or climatic regions) needs to be compared to that of, for example, several other varieties that have more specific adaptation to smaller regions.

Governments are bound by a range of environmental and rural policy objectives, some of which are evolving through time. For example, policy targets are set out in the UK Government Sustainable Development Strategy, as well as more specific targets such as compliance with the Water Framework Directive and the Emissions Ceiling Directive. The wider aspiration of farming making a positive net contribution to the environment leads to the consideration of how new varieties might be assessed for their contribution to the wider policy drivers. However, the important issues – of yield and quality in response to needs of a growing population and climatic challenges – should not be lost amongst poorly defined, though well-meaning, criteria.

The big picture is what society wants from agriculture and plant breeding. Breeders respond to the needs of society, working via the official testing system. Consumer demands decide on varieties of the future, the official testing does not. That is, society decides what cereals are used for. To achieve the multiple benefits desired from agriculture, breeders need to be better supported by publically funded research and to collaborate with the science community to help deliver new varieties for a sustainable farming future.

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Appendix 1

Discussion Paper for meetings with Saaten Union - Evaluation of new varieties for sustainable cereal production in Europe

Discussions with breeders in Saaten Union will explore the role of plant breeding in achieving sustainable cereal production in Europe. These discussions will become part of a study carried out by Steve Hoad (Scottish Agricultural College) funded by the Farmers Club Charitable Trust, London UK. This paper outlines some ideas for discussion during a series of meetings proposed over the period 9th to 21st November 2009.

The starting point for discussion with breeders is a set of questions that ask about their aims in developing new cereal varieties e.g. towards wide ecological adaptation and with attention to a range of sustainability criteria. Subsequently, wider sustainability traits with both market and non-market values for new cereal varieties could be devised along with a scheme to evaluate the cost-benefits of selecting new varieties and their subsequent adoption.

Three sections below outline possible areas for discussion.

1. 'Priorities for plant breeding' is a series of questions for general discussion about the way ahead for variety selection.

2. 'Development of new cultivars and traits' is a series of general statements that should be considered in terms of their <u>relevance</u> and <u>use</u> in variety development.

3. 'Future evaluation of new varieties and traits' is a series of general statements that should be considered in terms of their <u>relevance</u> and <u>use</u> in variety evaluation.

1. Priorities for plant breeding – a series of questions related to future breeding objectives

1.1. Which genetic resources are appropriate?

1.2. To what extent is there under-utilisation of genetic resources?

1.3. Should genotypes be selected for wide or specific adaptation?

1.4. What are the most suitable selection environments?

1.5. Is there value in decentralising plant breeding i.e. in favour of more direct selection within the target environment?

1.6. What are the most appropriate crop structures e.g. single cultivars, cultivar blends, populations or landraces?

1.7. Climate change is likely to extend environmental variation – increasing the need for appropriate levels of adaptation. To what extent are adaptation to, and mitigation against, climate change incorporated into current breeding programmes?

1.8. How is plant breeding addressing, or responding to, the following aspects related to climate change?

1.8.1. A 2^{o}C rise in mean temperature in the next 30-50 years?

1.8.2. A 4^{o}C rise in mean temperature in the next 50-80 years?

1. Priorities for plant breeding … (continued)

1.8.3. A future policy directive to reduce carbon/energy inputs by 50%?

1.8.4. A future policy directive to halve nitrogen fertiliser?

1.9. To what extent is the delivery of plant breeding targets dependant on findings from public sector research?

1.10. Over the next twenty years, what are the estimated contributions and benefits from plant breeding in terms of the following?

1.10.1. Increasing production through improvements in yield?

1.10.2. Increasing production through use of marginal land?

1.10.3. Increases in grain quality?

1.10.4. Reducing the reliance on pesticides for disease and pest management?

1.10.5. Reducing costs of production e.g. costs per tonne?

1.10.6. Reducing energy inputs and use?

1.10.7. Reducing carbon emissions?

1.10.8. Increasing diversity and biodiversity in the landscape?

2. Development of new cultivars and traits – a series of statements for further discussion

2.1. Characterisation and evaluation of cereal varieties for both market and environmental values would be a significant step towards developing more sustainable farming systems.

2.2. New varieties are normally defined according to their market value e.g. yield and quality, as well as agronomic attributes but they could also be considered in terms of their environmental or social value.

2.3. EU Directives require testing for value for cultivation and use (VCU) as part of National Listing (NL), based on yield, resistance to harmful organisms and quality characteristics, which are primarily market-led drivers. European farming would benefit from varieties (and their traits) which provide quantifiable environmental benefits as well as high market value.

2.4. Future evaluation should broaden the range of selection criteria and the genotype *x* environment interactions under test by integration of data from trials undertaken across different input levels.

3. Future evaluation of new varieties and traits – series of statements for further discussion

3.1. The value of a genotype depends on its combination of traits, especially those related to yield and quality. Could new varieties be rated in terms of their environmental or social value? For example, these impacts arise for example from the reduction of fungicide, herbicide and fertiliser use.

3.2. Each new genotype will have an externality quotient or 'footprint' which relates to direct and indirect inputs and outputs. This includes economic value, energy balance, nitrogen budgets and waste.

3. Future evaluation of new varieties … (continued)

3.3. A market and non-market evaluation will also enable plant breeders and the variety testing authorities to understand the context within which genetic improvement takes place and provide a mechanism for prioritising further trait development.

3.4. Economic analyses should include comparison of the relative costs and benefits of new genotypes and their trait combinations with alternative methods for achieving specified objective outcomes e.g. mitigation or adaptation to climate change, protection of biodiversity or reduce pollution and waste.

3.5. It is possible to conduct an "incremental cost effectiveness analysis" to compare additional variety or trait benefits to the current best, or currently implemented intervention, for achieving specific outcomes.

3.6. New varieties may offer a cost-effective option to address specific policy objectives with the advantage that benefits of genetic improvement are permanent and cumulative.

3.7. Present value costs of adopting new genotypes can be assessed by comparing values of the genotype and alternative approaches with the expected future benefits derived from the genotype and alternative options in delivering the desired objective e.g. reducing fertiliser or pesticide inputs.