

## PRECISION AGRICULTURE

### 2. Report on the TA Project “Modern agricultural techniques and methods of production – economic and ecological potentials”

In June 2003 the Committee on Education, Research and Technology Assessment decided to commission TAB with a TA project on the subject of »Modern agricultural techniques and methods of production – economic and ecological potentials«. Based on a proposal made by the Committee for Consumer Protection, Food and Agriculture as well as from suggestions made by TA rapporteurs, this TA project is to investigate what economic and ecological potentials could be achieved for sustainable agriculture through Precision Agriculture.

The report on »Precision Agriculture« forms the second part of the final report of the TA project on »Modern agricultural techniques and methods of production – economic and ecological potentials«. The partial report on »Alternative crop plants and methods of cultivation« has been presented.

### BACKGROUND

The investigation of modern methods of agricultural production should be carried out on the one hand on the basis of technological developments in the Precision Agriculture sector, and on the other hand in the light of new developments in alternative crops and methods of cultivation. The purpose of the investigation is to work out political options for action in research and technology policy, ecological policy as well as the agricultural policy conditions.

Whereas with the use of alternative crop plants and methods of production the emphasis lies on the contribution made to the preservation of agricultural biodiversity, Precision Agriculture focuses on the management of fields, adapted to sites and crops as well as the new potentials involved, in order to reduce the environmental burdens caused by agricultural management measures – in particular through the need-based application of pesticides and fertilisers.

## DEFINITION AND COMPONENTS

Precision Agriculture (PA) is an innovative information controlled management concept of crop production, based upon various new or advanced technologies. These include in particular satellite-supported positioning systems, sensor technologies for data collection and geo-information systems. Using PA the existing, locally varying soil conditions and properties of crops can be recorded within an arable area. Based upon this information, analysed with special assessment systems, and with suitable agricultural equipment, plant cultivation measures are spatially and quantitatively more accurately applied than previously. Depending upon the temporal relationship between the collection of data, decision-making and management measures, PA procedures always differentiate between offline procedures (mapping approach), online procedures (sensor approach) and the combination of offline and online procedures (sensor approach with mapping overlay).

- > In the off-line procedure there is no direct temporal relationship between collection of data, issuing the machine order and execution of the management measure. They can be implemented when the characteristics which the management measure is targeted to influence are relatively stable, such as fertilisation with phosphate. The collection of soil and crop data as well as their transformation into application maps has been extensively tested and is in principle ready to be put into practice. Limitations arise partially due to the work involved (e.g. when determining the incidence of weeds manually) or the costs incurred (e.g. for soil sampling and analysis). The decisive weaknesses of the off-line procedure lie with the extent of administration and analysis required for large amounts of data, with the interpretation of the data and making of decisions using rules or suitable models, as well as with the drawing up of application maps which are sufficiently accurate while remaining inexpensive to produce.
- > On-line procedures are used when dealing with rapidly-varying production factors (e.g. the nitrogen requirements of crop plants) and a real-time execution of work is required. Thus the relevant characteristics (e.g. the nitrogen supply of crops) are recorded indirectly on the field on the basis of the optical, mechanical or biochemical properties of the crop, and appropriate measures linked to this (e.g. the application of nitrogenous fertiliser) are carried out immediately. The fundamental weaknesses of the on-line procedures are the sufficiently accurate and cost-effective collection of data using sensors, which is still very much in the research and development phase in many fields of application, and the insufficient consideration to date of influences which are independent of measures taken (e.g. soil moisture levels) and disturbance variables (e.g. light conditions). A further weakness is – as with the offline procedures – the partially insufficient accuracy or lack of plant cultivation rules for the interpretation of the sensor data collected and for the derivation of solid decision-making algorithms for the (semi)automatic transformation of sensor data into management measures.

## FIELDS OF APPLICATION

Fields of application for information controlled crop production using PA can be found in all the main work stages of the agricultural production process. Other applications include satellite-supported automatic guidance systems with visual steering assistance or autopilot systems as well as the simplified, comprehensive and spatially as well as temporally differentiated documentation of measures carried out. For several work stages there are marketable procedures already available for implementing site specific management. These include site specific nitrogen fertilising with on-line approaches using optoelectronic sensors (e.g. Yara N-Sensor®) or the CROP Meter (also known as the pendulum sensor). The nitrogen sensor is used in Germany on about 400,000 ha – this is equivalent to approx. 3.4 % of the arable land – primarily in the new Federal States, however also to some extent in Lower Saxony and Schleswig-Holstein.

Initial procedures for selective weed control have been developed to practical maturity. An example of this is the »seeing« field spray, which can recognise the species and quantity of weeds and grass weeds and can differentiate between these and crops, and is able to spray up to three different agents simultaneously as well as adjusting the amount sprayed to the intensity of infestation. The CROP Meter is suitable for the site specific application of fungicides (and also of growth regulators), as it can infer the necessity of treatment on the basis of indirect characteristics (crop density). Further sensor supported approaches for the indirect and direct recognition of fungal diseases are in development.

In the field of satellite-supported automatic guidance systems, various visual steering guidance as well as autopilot systems are on the market and further new developments are on the way. The large number of providers indicates that the advantages created by the thereby greatly reduced load on the driver, the additional work assignments possible (e.g. in the fog) as well as the potential reduction in costs (e.g. by avoiding overlapping when cultivating the soil) are of great interest to farmers.

Yield mapping is currently one of the most widely spread PA procedures; however it is more of a procedure for the extraction of site specific information rather than an actual application. It represents – in particular, if in future this is supplemented by the on-line ascertainment of the quality of the harvested crops by means of near infrared spectroscopy – a quality control system, which in combination with site specific management can make an optimisation of the production process possible. Positive effects can be achieved for classical row crops (e.g. maize) and high seed costs by using yield potential maps for site specific sowing. The widespread implementation of site specific sowing of grain – apart from in dry locations – is however rather doubtful due to its ability for tillering. Yet manufacturers of sowing machines still offer their machines equipped for PA.

Several other PA applications have also been developed to practical maturity, without a widespread implementation appearing likely to date. One of these is site specific basal dressing with phosphate and potassium. Sensor approaches currently being developed can contribute to the reduction of the current high costs required for soil sampling and soil analysis to a practical level. The advantageousness of the procedure is however difficult to evaluate due to the principle of stock fertilization applied to these nutrients. It could however gain in importance in future due to scarce and thereby increasingly expensive phosphate resources. Increasing interest could also derive from the use of PA for the regulation of soil acidification through site specific liming. There is a procedure for the site specific adaptation of the cultivation depth which is being marketed by a tool manufacturer. This PA technology has yet to play a role in practice, although it could well make significant fuel savings possible where the site heterogeneity is appropriate.

Organic farming also offers fields of application for PA. Of particular interest here are PA technologies for mechanical or thermal weed regulation and the site specific application of organic fertilisers – the site specific application of liquid manure is currently being tested in field trials financed by the German Environmental Foundation. The sensor controlled cycloid hoe is a PA application for weed regulation which has been developed to market maturity. On account of its high cost and inadequate striking force it has admittedly not yet achieved commercial production. The use of PA for site specific harvesting (e.g. of quality grain) as well as for the documentation of operational measures also presents attractive options for organic farming. Further statements on PA applications in organic farming can be found in TAB Background Paper No. 12 (»Status of and prospects for the use of modern agricultural technology in organic farming«).

## STATUS OF RESEARCH

Numerous universities and private companies are engaged in research on PA in Germany. Various successful integrated projects have been completed over the past few years and several new projects started (e.g. the Federal Ministry of Education and Research integrated project preagro II). Projects on PA have also been sponsored over the past few years on a European level; however the resources deployed were on the whole relatively modest. Outside Europe intensive research with varying emphases is conducted on occasion. Whereas in the USA a reduction in the use of pesticides and fertilisers has been in the foreground, in Japan the expectation is that PA will contribute to correcting structural problems in agriculture.

## ECONOMIC ASPECTS

PA applications are considered to be efficient when the additional proceeds brought about through savings in capital and higher yields exceed the additional expenditure necessary

for the acquisition and use of the PA technology. While the costs for the collection of data and decision models as well as the application and navigation technology are known and can be relatively accurately calculated, the benefits of PA procedures can only be roughly estimated, as they are dependent upon various factors, some of which cannot be influenced (e.g. weather patterns) and the effects to be expected turn out differently according to the cultivation step, the field internal site heterogeneity, the crop cultivated and the intensity of production.

Through site specific nitrogen fertilising, the mineral fertiliser expense on heterogeneous fields can be reduced by about 7 % or 14 kg N/ha on average, with yields remaining constant or up to 6 % higher. Savings in the application of fertiliser are also possible in the area of basal dressing and liming, however the effects on yield are not worthy of mention. The application of PA also brings about positive results in plant protection: When applying herbicides an average of about 50 % of the amount spread (a span of 10 to 90 %) can be saved. Likewise when applying fungicides using the CROP Meter, savings of the order of 10 to 20 % seem achievable; similar figures hold true for the application of growth regulators. There are indications of considerable savings to be made in fuel consumption with site specific soil treatment. Site specific sowing can produce positive effects (same yield with a reduced sowing intensity) with row crops (e.g. maize). There are no results so far available as to the economic effects of a visually supporting or automatic guidance system. It can however be assumed, that capital savings are possible through the reduction of commonly occurring overlaps when cultivating the soil and applying organic fertiliser.

As the efficiency of site specific measures is dependent on the respective conditions of production, they cannot easily be generalised. In principle however it can be said, that PA applications reach the efficiency threshold sooner, the larger the agricultural areas cultivated, and the more heterogeneous the site conditions are. Currently the site specific application of nitrogen und phosphate as well as of herbicides and growth regulators in winter wheat is only considered efficient, when notable capital savings are made or investment costs for PA applications (or data collection) are considerably reduced and areas of usage comprising several hundred hectares per year are achieved. In comparison to this the average agricultural farm in Germany encompasses an area of only about 50 hectares. For small operational agricultural areas the economical use of PA procedures is only possible if machine employment is organised at an extra-farm level.

## ACCEPTANCE

The PA procedures primarily used in practice are surveying, soil sampling and yield mapping, all procedures which serve the acquisition of information. In contrast to this, PA procedures which convert the information acquired into site specific management

measures (e.g. site specific nitrogen fertilising) are much less frequently used. Guidance systems based upon satellite-supported positioning systems are already used by every fourth PA user (with private contractors it is every second PA user).

PA is used in particular by young, well-trained farmers with above-average sized agricultural areas as well as in cross-farm forms of management (e.g. machinery co-operatives). The average PA user farm size is between 1,080 ha (2001) and 904 ha (2005). The fundamental reasons for use are expected gains in knowledge about the production sites and greater reliability when making decisions as well as economic motives. Most farmers do not however expect an increase in profits until after an induction and application phase of five to ten years. The vast majority of farmers do not currently intend to invest in PA, which is hardly surprising given the difficult and unstable business environment in agriculture, which in general does not provide a favourable climate for new investments. The negative attitude towards PA has its roots in insufficient knowledge of the effects of PA as well as in a lack of concrete recommendations for its implementation. Further acceptance barriers are a lack of technical norms for equipment interfaces, concerns regarding the functionality and reliability of the technology and misgivings as regards the time required for initial training, management tasks and further training. These insecurities give rise to the situation that when new acquisitions are made the choice falls first on those procedures and technologies with which the most powerful and rapid cuts in production costs are achieved with the least possible work involved. The additional proceeds in PA are in contrast rather difficult to estimate and initially linked to a considerable amount of management requiring a reasonably good understanding of information technology.

## ECOLOGICAL EFFECTS

Ecologically positive effects can be achieved with various PA applications. Fertiliser savings can be normally made through differentiated mineral nitrogen fertilising while achieving constant or even higher yields. Positive environmental effects can also be achieved through site specific soil treatment and sowing due to the associated reduction of fuel and seed consumption. The largest reductions in amounts used result from the differentiated application of pesticides. The amounts applied – particularly with herbicides – can be reduced by half on average. The use of PA for combating weeds and fungus infestations can also contribute to an improvement in the effectiveness of resistance management, as this would make a spatially differentiated application of agents possible within the fields.

In principle PA technologies can also be used to perform services to help protect species and biotopes in the agricultural landscape, for example through the targeted omission of sensitive areas when applying pesticides in order to protect local biotopes in the

agricultural landscape, the consideration of special habitat requirements and the compliance with restrictions in use (e.g. distance requirements near running waters).

## SUSTAINABILITY POTENTIALS

The classification of PA in the context of sustainable development in agriculture shows that PA can make certain contributions to the achievement of different ecological sustainability goals. Thus it is possible to reduce local nitrogen or phosphate surpluses through mineral fertilisation with PA. However consideration must be given to the fact that the area specific nitrogen and phosphorous balances of purely cropping farms are predominantly even whereas the problems of extremely high nitrogen and phosphorous levels occur particularly in areas with regionally concentrated livestock levels and large volumes of farmyard manure. PA procedures for applying organic fertilisers are still being developed and will not change the cause of the problem, which is in particular the result of regionally concentrated intensive livestock breeding.

The high reduction potentials when using PA for plant protection show that PA can contribute to the achievement of the goal decided upon by the Conference of Agriculture Ministers in March 2005 of reducing the expenditure on pesticides by 15 % over the next ten years. As the total amount of pesticides applied in Germany is determined by grain cultivation (on 59 % of arable land), this contribution may turn out to be relatively modest if PA procedures are not developed for the management of pesticides in grain. It is true that procedures have been developed in research for site specific herbicide applications in grain; these are however not yet ready to be put into practice.

Through the use of PA in soil management, fuel consumption and the risk of soil erosion or compaction could be reduced in principle, and thereby contributions made to the achievement of important sustainability goals. When compared with alternative procedures, such as conservative soil management, the effects of the use of PA on spatially differentiated soil management would however be significantly lower. However it is still unclear as to whether certain of the positive effects of conservative soil management (e.g. the enhancement of soil fertility) could be improved through the use of PA.

A further sustainability goal is the preservation of the diversity of species in the agricultural landscape. As the use of PA can be used to – in the sense of plot management also virtually – enlarge the fields, this could have undesirable effects on the preservation of flora and fauna in the agricultural landscape. It would be technically feasible to identify local areas in the agricultural landscape which are worthy of protection and to cultivate them restrictively using PA or to take them out of use completely. Using PA for protecting biotopes fails in practice, because it is methodically difficult to allocate specific protection goals to individual lots. Appropriate simple classification systems for

agricultural practice are currently being tested. The question which arises here however, is whether there are not simpler and less expensive ways (e.g. special agrarian environmental programmes) to achieve the goals of increased biotope diversity and occurrence of species in the agriculturally used landscape.

As far as the ecological dimension of sustainable agriculture is concerned, it can be summarised that PA does have various potentials for environmental relief, but that these are limited: First of all the PA technology necessary for extensive use is not yet available (e.g. PA procedures are missing for herbicide applications in grain, the most important crop plant in Germany); secondly PA procedures are in competition with other technologies (e.g. procedures for conservative soil management) or cultivation methods (e.g. organic farming); and thirdly the existing sustainability deficits in agriculture can only be partially remedied through the use of modern technology (e.g. nutrient surpluses due to regionally concentrated intensive livestock breeding).

If the economic effects of PA are considered, it can be viewed rather critically as regards sustainability, as PA applications – like so many technologies which improve efficiency – could well result in a long-term loss of jobs. As the use of PA becomes more economical with the increase in farm size, the increased use of this technology may also lead to an acceleration of the structural change in agriculture. Over the next few years PA procedures will lead initially to an increase in the amount of management required and thus in the medium-term to somewhat higher staff requirements, at the least on a level comparable with the standard cultivation of agricultural land. In addition the requirements connected with PA applications for vocational training and further training capacities as well as »IT support«, should result in positive employment effects both in agriculture and in the service sector.

The positive contributions to an ecologically sustainable agriculture and for the safeguarding and improvement of jobs in agriculture and in the rural area linked to the use of PA are likely to prove rather modest, if nothing changes within the business environment or no special incentives for the use of PA in practice are created, because otherwise only a rather low diffusion of PA applications can be assumed in future. How large the contributions are PA could make towards the achievement of a sustainable agriculture overall, depends among other things on the extent of the existing field internal site heterogeneities on the agriculturally used land, the crops planted and the intensity of production; no investigations have been made to date this however.

## POSSIBILITIES FOR ACTION RESEARCH AND DEVELOPMENT

In spite of previous research efforts there are still various unsolved technical, specialist and methodical challenges to the current developments in technology for site specific crop farming which are obstructing the rapid and widespread introduction of PA into practice. There is a particular need for research in the development of on-line procedures for

simplified soil analysis, because this would result in improvements in the efficiency of site specific basal dressing. As far as the further development of sensor systems for site specific nitrogen fertilising is concerned, it seems advisable to place the emphasis on the development of procedures for plant parameters which are ascertainable with sensors that take into consideration disturbance variables (e.g. light conditions) and other influences (e.g. soil moisture levels, fungus infestations). There is a need for research in the area of plant protection in order to develop suitable, cost-effective sensors, which on the one hand can differentiate between crops and weeds in the row and on the other hand between weeds and grass weeds sufficiently reliably. Suitable systems are currently being developed, but they are not yet ready as herbicide applications for the market. In order to also be able to use PA procedures for the selective combating of crop diseases in future, procedures for the explicit and cost-effective, automated recognition of fungus infestations in their initial stages and practicable decision models for the application of fungicides would need to be developed.

Organic farming will be able to profit in certain application fields from PA research, which currently is predominantly oriented towards the requirements of conventional agriculture. Conversely however, conventional agriculture could also benefit from PA research which takes into account the concerns of organic cultivation. This is particularly true in the case of PA applications for mechanical weed regulation and for the application of fertilisers.

To improve the transformation of the soil and plant parameters recorded using PA procedures into site specific management measures, the further development of models for decision-making and of algorithms for controlling the application technology would be desirable. There is a need for further research to determine whether PA is a suitable tool for meeting the comprehensive and continually increasing legal obligations of accountability and recording in agriculture efficiently.

## POSSIBILITIES FOR ACTION SUSTAINABILITY AND FOLLOW-UP ANALYSES

So as to be able to make more reliable statements as to the potential contribution of PA to achieving sustainability goals, analyses are necessary in order to assess in which regions of Germany PA could be practically implemented on the basis of field internal site heterogeneities and corresponding farm structures. There is also a need for research in the development of scenarios for the use of PA (in Germany and in the EU) under future agricultural policy conditions and for the assessment of the economical, agrarian structural, ecological and social consequences connected with this on a sectoral level. The fundamental problem with sustainability assessments of agricultural measures in contrast is non-PA specific and a general research desideratum: There is a need for further

development of appropriate parameters, goals and indicators to measure sustainable economic and social development in agriculture.

## INFLUENCE OF AGRICULTURAL POLICY ON THE DIFFUSION OF PA

The liberalisation of agricultural markets and the complete decoupling of direct subsidies from production tend to result in the prices for agricultural products falling and partly in lower operating incomes while at the same time the prices for resources are rising. In this increasingly difficult economic environment, farmers are interested in opening up new, more lucrative markets (e.g. the production of bioenergy) as well as in technologies and procedures which lead to reductions in production costs or an increase in output and thus to an improvement in efficiency. With this background many farms are currently refraining from investing in new technologies such as PA, as these require additional capital expenditure and initially an increase in management and can only conditionally contribute to a rapid improvement of the operating income.

However the use of PA as an IT-based agricultural management system may attract greater interest in future, because PA can be called upon for the fulfilment of ever more extensive and potentially ever increasing documentation obligations and because potentials for cost reductions and productivity increases can be identified and implemented using PA. In addition PA technologies could also be integrated in labour-saving, more extensive methods of production (e.g. site specific cultivation intensity or depth using conservative soil management), which could lead to economic benefits for large farms in particular if cost prices remain sufficiently low. If PA technologies were also offered in future, which guaranteed an automation of PA specific work processes as far as possible, these technologies could also be of interest from an economic viewpoint for more agricultural farms under increasing pressure to produce efficiently at the same time as the requirements relating to environmental protection and the documentation of agricultural production processes are growing.

## POSSIBILITIES FOR ACTION DIFFUSION OF PA

Knowledge of PA should be firmly fixed both in the Master Craftsman's training and in courses at colleges and universities. There is also a need for the promotion of knowledge about PA in the area of agricultural consultation and further training. The diffusion of PA could e.g. be promoted with an investment grant for innovative methods of production. Furthermore the propagation and long-term establishment of PA applications could be promoted both through measures to make environmentally harmful means of production (e.g. mineral nitrogen fertiliser) more expensive as well as through appropriate provisions on the handling of these resources or on the spatially and temporally differentiated documentation of measures carried out.