THE USE OF GPS IN AGRICULTURE FOR YIELD MAPPING AND TRACTOR IMPLEMENT GUIDANCE

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1. INTRODUCTION

Agriculture in the Federal Republic of Germany produces on a high level.Average yields of 69 dt/ha of winter-wheat, 546 dt/ha of sugar-beets and 490 dt/ha of corn-silage require exact scheduled fertilizing. Even if modern distribution techniques are used, over-fertilizing cannot be avoided. This is based on changing circumstances on the fields, on mistakes during calibration and on the more psychological tendency of the farmers to avoid possible nutrient shortcomings. As a summary of all these facts investigations show the real situation very dramatically. About 36 % of the phosphorus and about 42 % of the nitrogen in the surface water are coming from agriculture. In addition, chemicals and pesticides for plant protection have a high impact on nature. Besides this high - and not justifiable - environment pollution there are also high costs for agricultural products. For example, ISERMEYER 1990 calculates costs of over-fertilizing to be about 286 DM/ha for grassland-farms and 125 DM/ha for cereal farms in "Niedersachsen".

2. TECHNICAL OBJECTIVES FOR AN ENVIROMENTAL FRIENDLY AGRICULTURE

Therefore fertilizing and chemical application in plant production must be improved for environment protection. It will have an electronic basis with the possibility of including the variability of soils, their supplies of nutrients and their water-volume into the strategy of fertilizing. For all this a low cost, reliable and exact position detection of agricultural vehicles in the field will be the basis. Using these techniques a closed loop control of an environmental friendly fertilizing could be established (figure 1).

In this system yield detection in fields has to be the starting point. The withdrawals ofnutrients and their replacements by straw and roots give the initial potential for the following harvest. Position detection and yield will lead to a yield-map with different gridsizes or to an analysis of sub-plots with the same yield potential, called equifertiles (SCHNUG et al.). The same system could also be established for grassland, where the yield detection has to be included into the harvest vehicles (normally in self-loading-trailers).

In connection with the withdrawals, data from the weather, from soil nutrients analyses, and from soil maps (together with knowledge systems) can be used to calculate predictions for the needed seed and fertilizing amounts. Position detection is again necessary for planting and fertilizing to put on every sub-plot the predicted amounts exactly and local specific. The use of GPS, probably DGPS, is thereby needed in nearly all sub-steps (table 1).

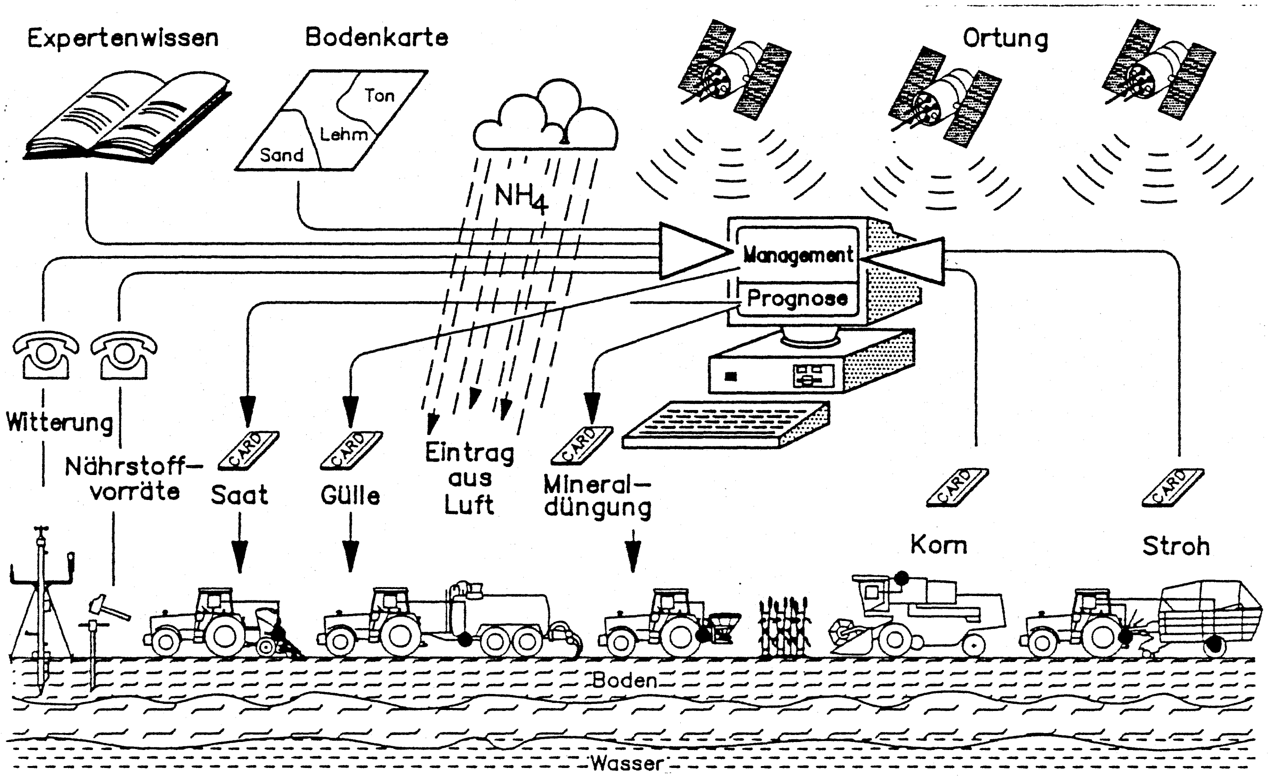


Figure 1: Closed loop system for environmental friendly any yield oriented fertilizing.

In this system again the harvest will be the initial point. With suitable detection techniques in sieves of combines, and especially with a welldeveloped image analyzing system, the weed amount in cereals could be detected and with position detection shown locally. Weed-maps, in connection with weather-data and expert-systems, could then lead to predictions of treatment date, type of chemical and the amount of chemical input. About 60 to 70 % of the input could be saved by such a system compared to whole covering treatment. If in a further step the system could be extended to band spraying in rowcrops, then a reduction down to only 15 % against the whole covering treatment could be reached.

A similar system could be used also for the weed control with very heavy reduced use of chemicals (figure 2).

Then the guidance of tractor and implement will be the main problem. A high performance with a fairly good hoeing-success and small amount of working time can only be realized, if the guidance of vehicles will be automated. In any case completely automation is required for the guidance of implements (e.g. hoeing-machine), that in a high working speed a good cut, tear and coverwork of the tools will be possible.

To avoid chemicals for weed control totally then mechanical control must be taken as an alternative (figure 3).

step	task	sensors / actors	positioning	data transfer
yield detection and mapping	cereal harvesting grass and straw harvesting	paddle wheel; x-ray sensors strain gage sensors load cells	DGPS GPS	chip card [3] or RAM-box
weather and soil monitoring	local weather conditions soil sampling [1]	rain fall; wind speed 2 air and 2 soil temperatures humidity; radiation hydraulic driven drill or tube with cartridge	--- DGPS	video text network
controlled distribution	liquid organic manure [1] mineral fertilizing with - weight control - tramline guidance - variable-rate fertilizing	hydraulic driven positive displacement pump and slip control slip control together with strain gages in 3 point linkage --- [2] centrifugal mixing unit	DGPS DGPS + dead reckoning	chip card [3] or RAM-box

[1] not under examination [2] future activities [3] DIN and ISO standards under preparation

Table 1: Activities, sensors, actors, positioning detection and data transfer in a closed loop system of "environmental friendly and yield oriented fertilizing"

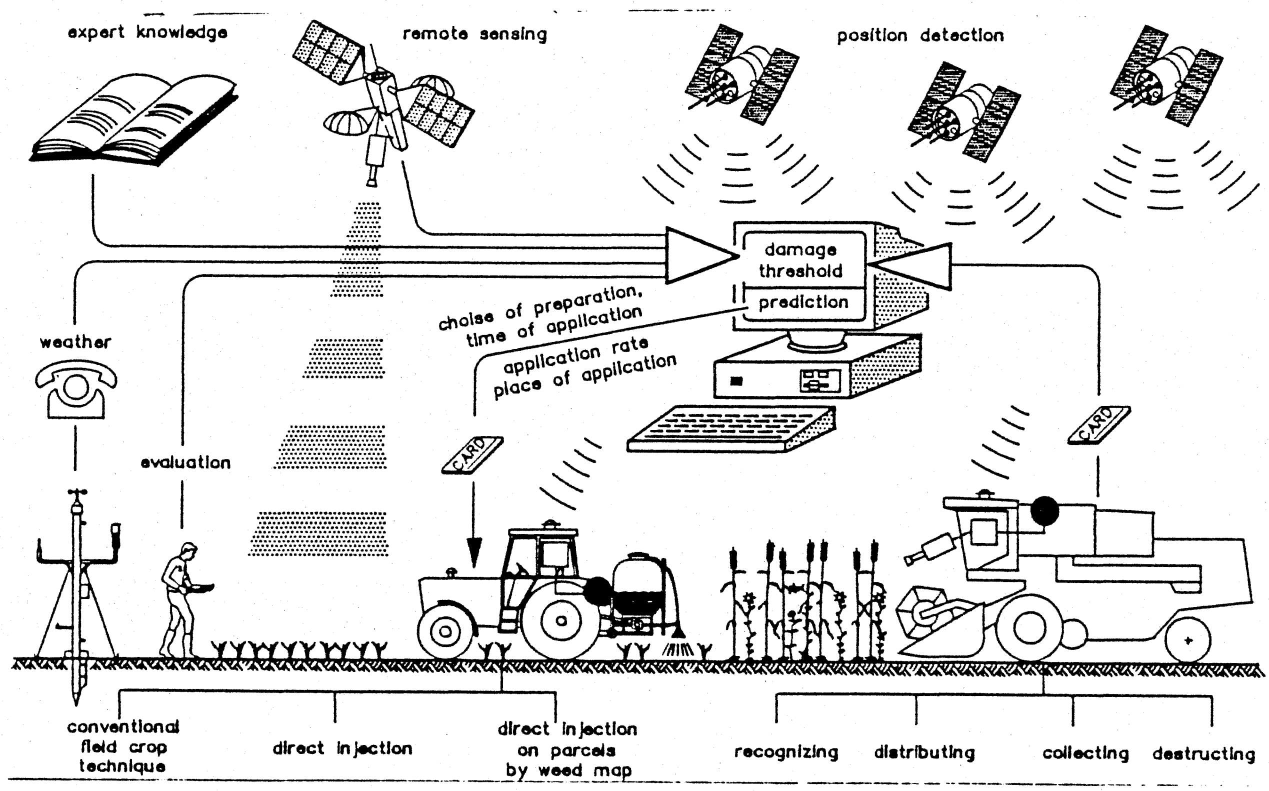


Figure 2: The use of electronics for reducing the chemical input in weedcontrol.

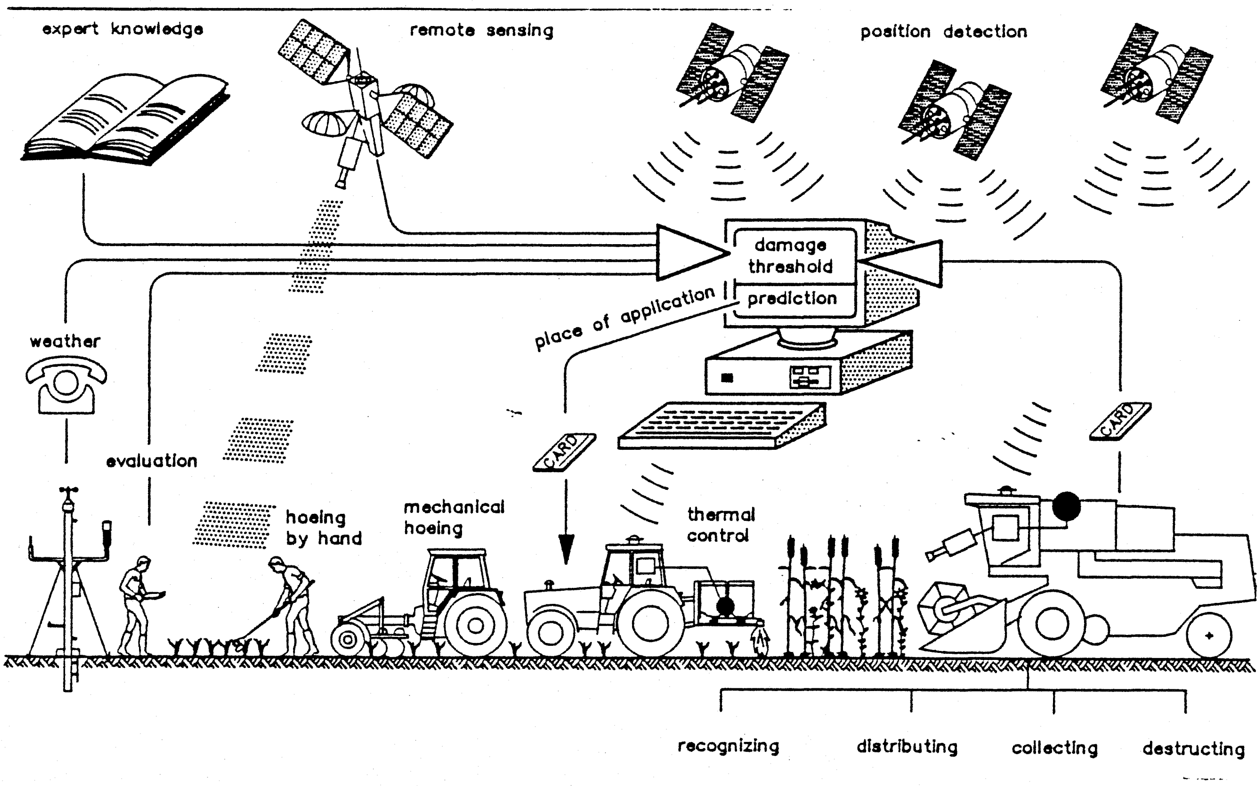


Figure 3: The use of electronic in a closed loop of mechanical weed control.

3. YIELD MAPPING

Starting from the central importance of the yield detection during the harvest, comprehensive investigations for yield mapping in combines have been started.The used technique is based on a modern but normal combine, a yield-meter, and a position detection system based on GPS (figure 4).

The data acquisition was carried out with two specific laptop computers for the yield and the position detection. Starting both computers time-synchronous and putting the time into the datafile, the data-connection was guaranteed. The data acquisition was done in time intervals of 0.33 or of 1 sec. Together with an average working-speed between 4 and 5 km/h this leads to the following data (table 2):

Table 2: Collected data from the investigations in 1990.

Type of crop	in ha	frequency of yield and position	position-detection total 'Figure of Merit' <= 4
Winter-wheat	17,1	0,3	15,393
Whinter-wheat	7,2	1,0	10,149
Corn	8,5	1,0	4,615

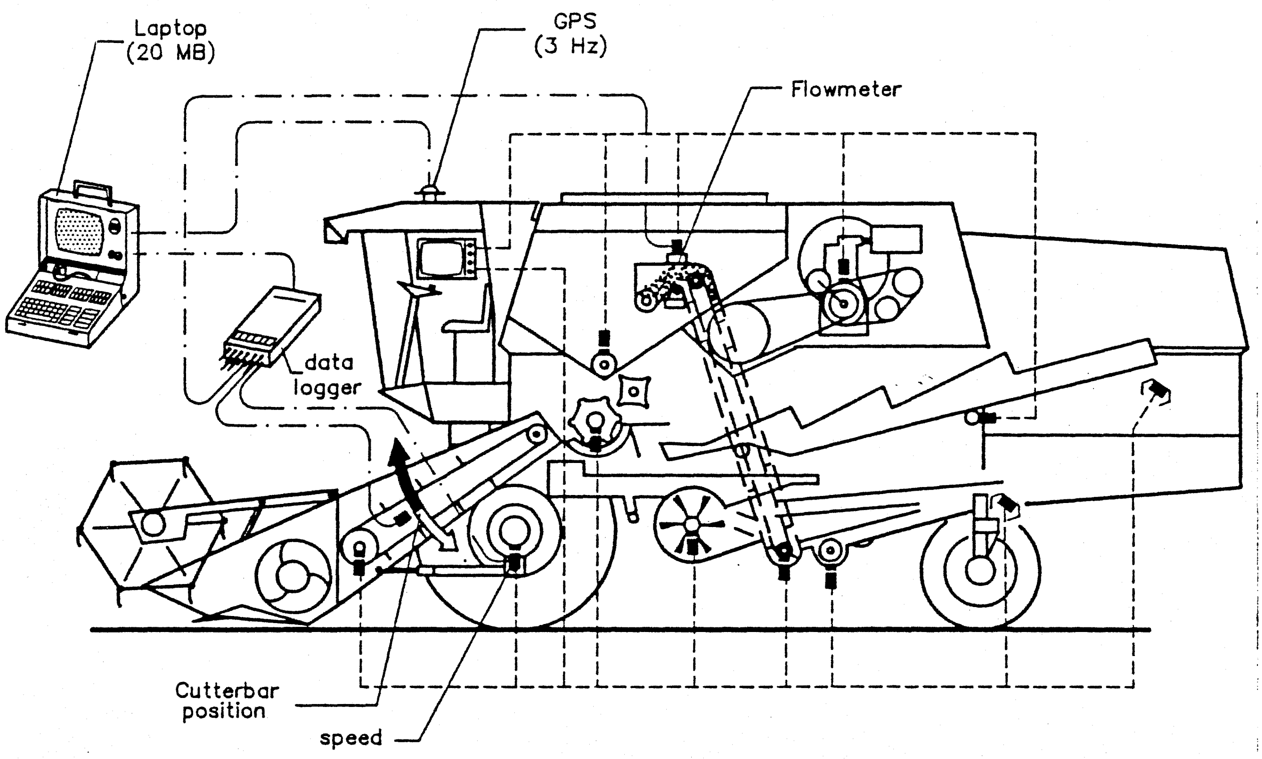


Figure 4: System of data acquisition in the test-combine in 1990.

The data analysis was done with the geographic information system ARC/INFO on a 386SX-personal computer. It offers together with a specific data filter program in the programming-language "C" a direct input of the data and a matching of the yield values to the position detection data. Using a gridsize of 5 by 5 m (equal to the header width of the combine) the usable position detection values with their corresponding yield data can be seen in figure 5.

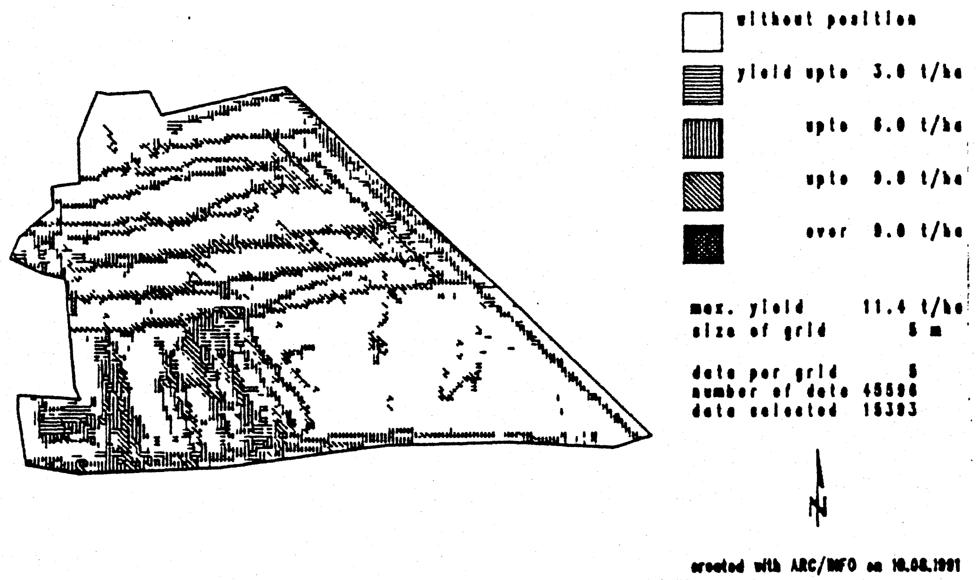


Figure 5: Yield-map for winter-wheat on the experimental farm Scheyern 1990 (Flachfeld; 17.1 ha; gridsize 5 by 5 m)

It is apparent that the quality of position detection on the field borders is very high. Therefore it can be concluded that all other position detection data are of equal accuracy. Nevertheless, it is easy to see that for a large area no position could be detected under the given circumstances.

For a more practical oriented use the previous chosen gridsize is not very helpful. A gridsize corresponding to the usual working-widths of 12, 16, 20 or 24 meters would be better. Therefore in the following map the gridsize was increased to 12 by 12 m to meet the standard spreading width of distribution implements (figure 6).

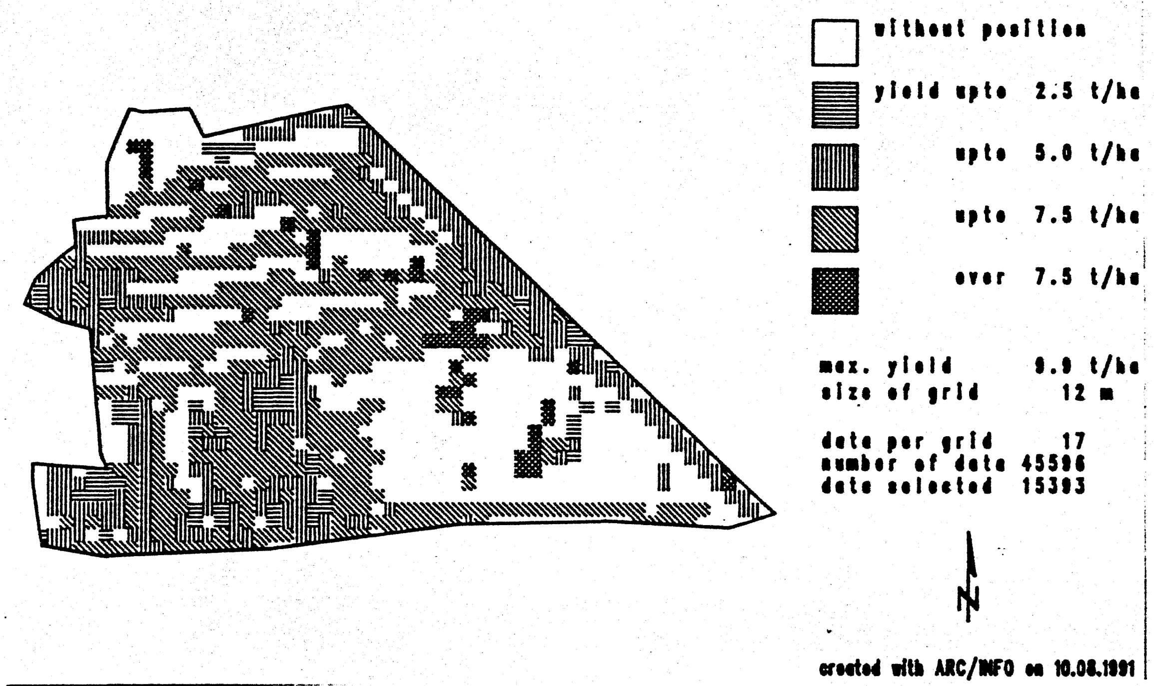


Figure 6: Yield-map for winter-wheat on the experimental farm Scheyern 1990 (Flachfeld; 17.1 ha; gridsize 12 by 12 m).

Based on the higher gridsize, now the areas with missing position detection are less noticeable. Also a very good classification into 3 yield levels can be done. These advantages will be even higher, if the gridsize is expanded to 24 by 24 m (equal to 2 working-widths, see figure 7).

If finally the gridsize is increased to 50 by 50 m (equal to 4 working-widths)then a directly transferable yield-map for a controlled fertilizing can be gained (figure 8).

Based on last year investigations a very comprehensive investigation program will be performed this year (table 3).

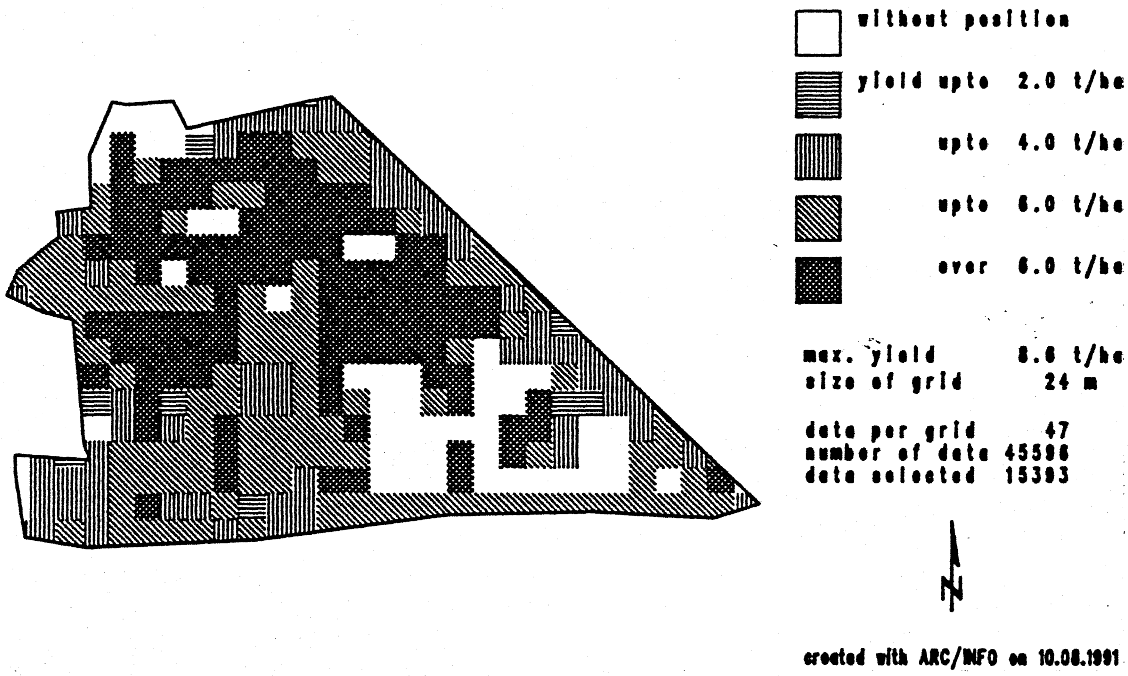


Figure 7: Yield-map for winter-wheat on the experimental farm Scheyern 1990 (Flachfeld; 17.1 ha; gridsize 24 by 24 m).

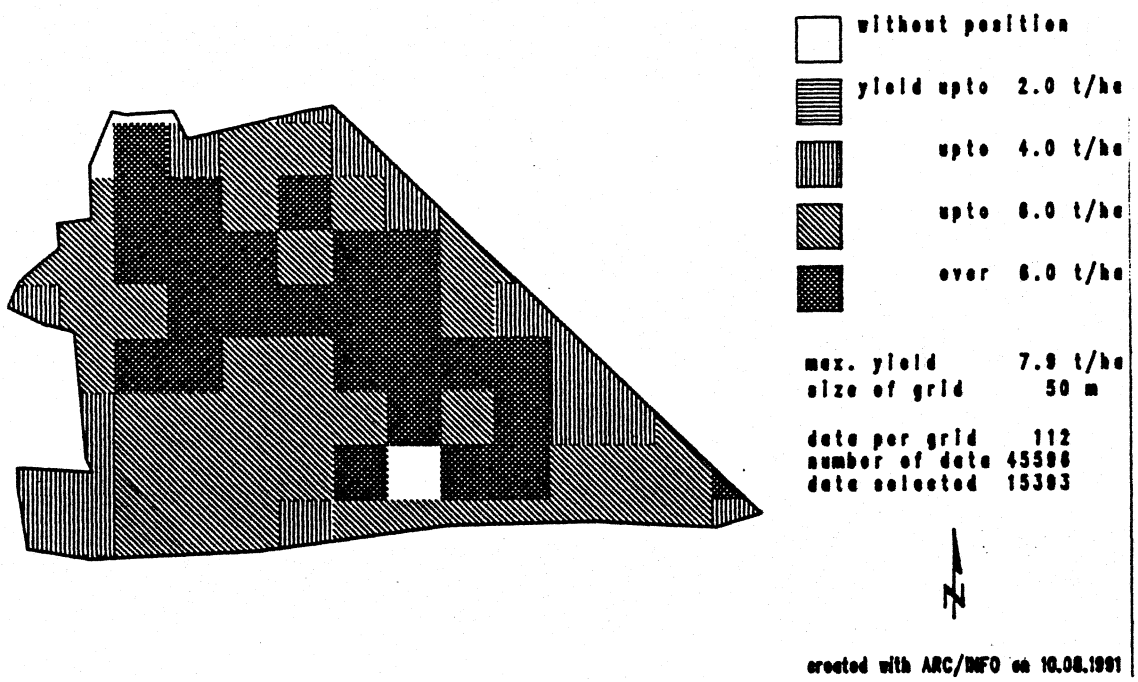


Figure 8: Yield-map for winter-wheat on the experimental farm Scheyern 1990 (Flachfeld; 17.1 ha; gridsize 50 by 50 m).

Table 3: Investigation areas for yield mapping in 1991

Crop	Place of investigation	Type of terrain	Harvest area in ha
Winter-barley	Wittenfeld	hilly	35
Winter-wheat	Wittenfeld	hilly	5
Spring-barley	Freising	plane	3
Winter-wheat	Erding	plane	17
Winter-wheat	Scheyern	hilly	120

For these trials two combines from different companies re- transmits (online) the position detection errors to the combines and it is able to receive the data from the combines into the reference-station. The update-frequency will be 7 s when using one combine and about 10 s when using both combines simultaneously. The systems are identical with the system used during the harvest 1990. Besides the online-DGPS-usage, position data will also be calculated offline on the combines with a frequency of 1 s and with postprocessing, a DGPS is achievable. To get further information about the accuracy of the position detection a geodetical reference system will be used on one plot.

4. NAVIGATION OF AGRICULTURAL VEHICLES

Position detection alone is only applicable for monitoring. In agriculture nearly all harvesting jobs belong to this type of work, if the operator still controls the vehicle. However, if these jobs should be more automated then a navigational system is needed. This leads to the big task of all distribution works of fertilizing and chemicals. But it also leads to more automated tractor and implement guiding in form of an autopilot or a field-robot in the far future. The required accuracy for navigation in agriculture derives from these applications (figure 9).

A relatively rough navigation can be used for detecting predefined areas. For example, this is required for specific soil sampling (SCHNUG et al.). Also the detection of tramlines falls into this category. Thereby an accuracy of ± 1 m is needed and it must allow a speed from 6 to 8 km/h on the field. Then the driver has to follow manually on an equivalent display. DGPS with a minimum update cycle of 5 s (equals about 10 m of traveling) for error correction could be the best medium of aid.

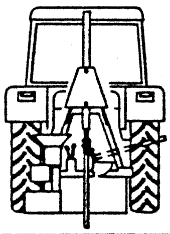
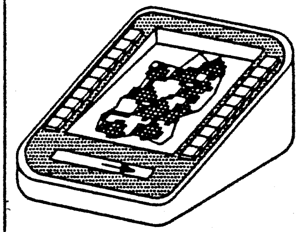
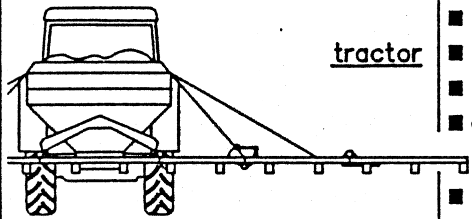
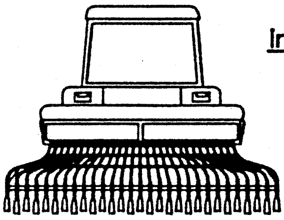
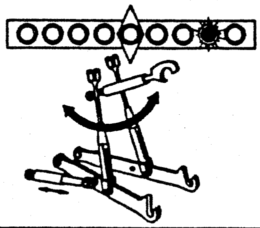
type	kind	examples	navigation aid	required accuracy
rough navigation	 vehicle	■ soil sample aquisition ■ detection of tram lines		± 1 m
fine navigation	 tractor	■ mineral fertilizer spreading ■ liquid manure spreading ■ solid manure spreading ■ application of pesticides ■ soil cultivation		± 10 cm
precise navigation	 implement	■ drilling ■ hoeing ■ plowing		± 1 cm

Figure 9: Requirements for navigation in agriculture.

Much more higher requirements are coming from tractor-navigation during distribution work and from the navigation of harvest-machines. Their importance increases with increased working widths. The main task is to avoid skips and gaps during seed, fertilizer and chemical distribution. Aids of navigation must display the desired steering correction and must take over completely in an autopilot system. This form of navigation requires an accuracy of ± 10 cm. But it has to be taken into account, that while driving in a field a lot of uncontrollable influences will lead to a continuous drifting of the vehicle (longitudinal and latitudinal). Therefore, by using DGPS as a stand-alone-navigation-system, a very high update-cycle of less than 0.2 to 0.5 s is required. For practical use on farms therefore dead-reckoning in connection with DGPS seems to be necessary.

Finally, the highest precision is required for implement guidance. With amaximum deviation from ± 1 cm to the neighboring implement pass or to the single plant in a plant row, automate driving can only be solved by dead-reckoning. Main areas of usage are planting and hoeing. To eliminate the above mentioned uncontrollable influences on the tractor from affecting the implement, it seems that only a combined solution with a correction from tractor navigation could be a real alternative. Very short update-cycles for a DGPS are required.

5. CONCLUSIONS

Based on the investigations during the last year for yield mapping in cereals and on the fundamentals to navigation of agricultural vehicles, "global positioning system (GPS)" will have a central role in an ecological oriented agriculture.

In a lot of cases for monitoring machines and implements and for data acquisition a simple GPS will be adequate. Accuracy in position detection from ± 22 to ± 50 m (in exceptional cases ± 100 m) should be sufficient.

For yield-mapping (as an initial point for an environmental oriented fertilizing) DGPS must be used. Thereby the required accuracy of position detection should be in a range from ± 1 to ± 5 meters. The investigations during the harvest in 1990 pointed out that this will be possible. This leads to minimum gridsizes of 12 by 12 or maybe 5 by 5 m. Also plots with equal yields (equifertiles) on a field can be derived.

The requirements for the navigation of agricultural vehicles are much more higher. Position detection from ± 10 cm to ± 1 cm makes in all cases the use of dead reckoning besides GPS and DGPS necessary.

In agriculture the unshaded reception of GPS and DGPS-signals will be rare. Continuous changing surface angles, hedges and forests near fields will disturb the signal reception. Therefore with GPS and DGPS only multi-channel-implements can be used. In consideration of the financial situation of farms, these systems must be inexpensive.

If this happens, then GPS and DGPS for position detection and navigation of agricultural vehicles on the field will take over a central role. Only with it today's and future farming will be economical and ecological in the same way.

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