

MAPPING THE HETEROGENEITY OF AGRICULTURAL FIELDS
BY MEANS OF AERIAL PHOTOGRAPHY

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Abstract:

Field trials play an important role in plant breeding. However, the heterogeneity of fields is a serious problem since it severely influences the comparison of varieties of cultivated plants. The use of aerial photography for mapping the heterogeneity of a trial field with one barley variety was evaluated. By performing additional grain yield measurements at sample points it was shown that the infrared reflectance could be used for estimating yield (linear correlation coefficient 0.90). As a result the spatial pattern of infrared reflectance displayed the spatial pattern of grain yield. Results will be used for improving the experimental lay-out of field trials.

1. INTRODUCTION

1.1 Background to the present study

In plant breeding the accuracy of yield trials is often limited by heterogeneity of the field. The accuracy might be improved if it were possible to account for yield patterns, caused by heterogeneity of the field.

The traditional way for obtaining this information is to grow one crop and harvest the entire field in small units (blank experiment; Smith, 1938). However, this harvesting would mean an elaborate work. Data collection and handling would not be a sinecure either.

A survey of literature indicated that remote sensing techniques offer a possible alternative. The near-infrared reflectance can be used for estimating yield of crops (Aase et al., 1984; Pinter et al., 1981; Tucker et al., 1980). Aerial photography offers the possibility to obtain recordings of an entire field with respect to infrared reflectance (Clevers, 1986b).

In this study we investigated whether application of this technique in combination with computerized data analysis allows mapping the heterogeneity of a field with respect to yield.

1.2 Remote sensing and agriculture

During the past decades knowledge about remote sensing techniques and their application to areas such as agriculture has improved considerably. Among others, Bunnik (1978) described the possibilities of applying optical remote sensing in agriculture, particularly with regard to its relation with crop characteristics such as soil cover, leaf area index (LAI) and dry matter weight. In the literature there is a certain consensus that the near-infrared reflectance factor may be most suitable for estimation of leaf area index or yield. In the near-infrared region (700 - 1300 nm) of the electromagnetic spectrum, reflectance and transmittance of a green leaf are each about 50%, and there is hardly any infrared absorptance by a green leaf (Colwell, 1983). In this situation leaves or canopy layers underneath the upper layer (or soil underneath it) contribute significantly to the total measured reflectance. This causes the infrared reflectance factor to be a suitable estimator of e.g. leaf area index (up to LAI values of 6 to 8). Biomass may be regarded as being proportional to LAI. As a result, yield may also be estimated by the infrared reflectance factor.

If reflectance factors are required with high spectral and spatial resolution (as for this research) for crop monitoring, Clevers (1986a, 1986b) selected black and white multispectral aerial photography. Systems of aerial photography provide recordings of the reflected visible and infrared radiation. The spectral resolution may be high when adequate combinations of films and filters are used in order to achieve a multispectral photographic (MSP) system with narrow bands. The spatial resolution will primarily depend on lens type, altitude, film material and image motion. By using an appropriate densitometer with small aperture, quantitative measurements with high spatial resolution may be obtained. Moreover, the measurements on the photograph can be carried out at exactly determinable locations of an object. By using 70 mm film cameras, which can be installed in small planes, cost stays within acceptable limits. All these considerations render black and white multispectral aerial photography the most promising remote sensing technique for application to small areas.

2. MATERIALS AND METHODS

2.1 Test area

The research was carried out at the Department of Plant Breeding (IVP) of the Wageningen Agricultural University (the Netherlands). A field of 100 by 200 metres, which is used for trials once every four years, was sown with the commercial barley variety "Trumpf" on 26 April 1985. The row width was 19 cm and the sowing density was 150 kg/ha. Disease control and fertilizing were applied according to practical farm management.

2.2 Aerial photography

Black and white multispectral aerial photography was carried out by taking vertical photographs from a single-engine aircraft, equipped with Hasselblad cameras with Planar 100 mm lenses, at a height of 600 metres. As a result the recording scale was 1:6000. On 24 July 1985 a mission was carried out under cloudfree atmospheric conditions. In order to match an infrared band Kodak Infrared Aerographic Film 2424

was used in combination with a Wratten 87C filter. This resulted in an 840–900 nm spectral band.

Densities were measured by means of an automatized Macbeth TD-504 densitometer with a circular aperture of 0.5 mm. At a scale of 1:6000 this coincides with a spot of 3 metres diameter in the field.

Measured densities were converted into reflectance factors according to the procedure of camera calibration and atmospheric correction as described by Clevers (1986a, 1986b). This procedure requires reference measurements of reflectance factors. In this study reflectance factors of natural surfaces in the neighbourhood were measured by using a hand-held radiometer.

2.3 Field measurements

In order to ascertain the relation between the reflectance factors and yield, fifty plots of 3 by 3 metres were selected in the field, such that the complete range from dark to light of the infrared image was covered. At maturity (August 25) these plots were harvested with a small combine and the yield (kernel weight) of each plot was ascertained.

2.4 Data analysis

In order to visualize the heterogeneity of the field, reflectance factors were obtained by digitizing a photograph. Then a map could be created, in which reflectance factors were represented by symbols in a computer printout. It was also possible to apply digital image processing on the reflectance data by e.g. a personal computer and present the results on a colour screen.

The photograph was digitized by scanning parallel lines broadwise across the field. Between lines (i.e. lengthwise) the spot was moved over a distance equal to the diameter of the spot (corresponding with 3 metres in the field) so there was no overlap in this direction. Within lines (i.e. broadwise) the spot was moved over a distance about 1/9 of the diameter of the spot, so there was ample overlap in that direction.

For creating a map of reflectance factors the mean of three successive measurements (broadwise) was taken all over the field. These means were classified and printed out according to the field lay-out. The scaling of the map could be varied as one pleases.

2.5 Trial simulations

Six different trial lay-outs were simulated in order to get an indication of the most efficient way of blocking. The lay-outs differed in shape and direction of the blocks (see figure 1). Each trial consisted of 80 plots divided in four blocks of twenty plots and was randomly assigned to the digitized photograph. The corresponding reflectance factors were used as simulated yield data. For an analysis of variance the observations need to be independent, so there should be no overlap between the observations. Therefore the simulation was based upon each third mean of reflectance factors (broadwise). In this way there was hardly any overlap between successive values both broadwise and lengthwise. Each selected mean represented an estimate of the yield of a plot with a diameter of three metres.

For each selected trial simulation an analysis of variance was performed. The total sum of squares was divided into a sum of squares within blocks and a sum of squares between blocks (one-way analysis of variance; cf. Cochran & Cox, 1950; Snedecor & Cochran, 1980).

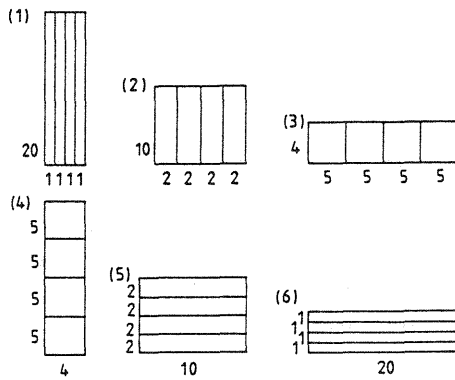


Figure 1: Six different trial lay-outs used for the simulation experiment. Each trial consists of four blocks of twenty plots each. Blocks within trials are drawn. The numbers at each side refer to the number of plots in that direction.

3. RESULTS AND DISCUSSION

3.1 Reflectance factors and yield

A regression analysis of yield on the reflectance factors for 50 plots was performed. In this study, the regression of yield on the infrared reflectance factor was satisfactorily described by a linear function (the correlation coefficient was 0.90). The results, as presented in figure 2, indicate that aerial photography can be a good alternative to the classical blank experiment. Because of the linear relation, maps of reflectance factors will be similar to maps of yield. In other words: the spatial pattern of infrared reflectance will display the spatial pattern of grain yield.

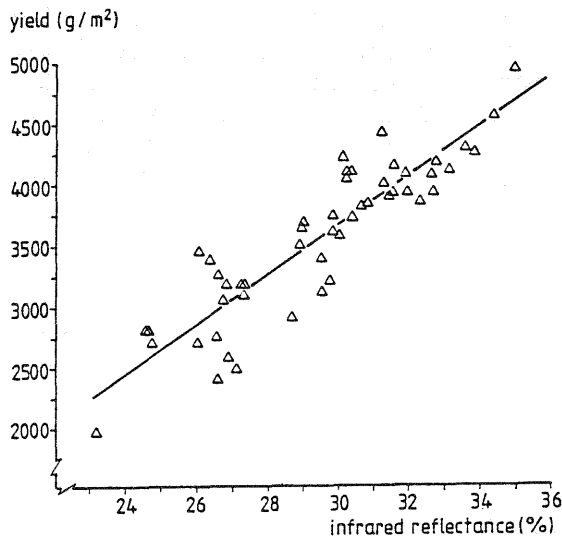


Figure 2: Linear regression of yield (Y) on infrared reflectance (X) of spring barley: $Y = -2446 + 204 \cdot X$ (correlation coefficient is 0.90).

3.2 Maps of the digitized photograph

As an example, a map of classified reflectance factors is shown in figure 3. Darker symbols represent lower reflectance factors. The original photograph is shown in figure 4. If several of these maps with different scaling are combined a good impression can be obtained of the pattern of the field. The field examined showed an obvious lengthwise pattern and it was evident that part of the field (the left half) did have higher reflectance factors than another part (the right half). The lengthwise pattern indicated that blocks (of a trial) situated lengthwise to the field are expected to be more homogeneous than blocks situated broadwise.

3.3 Trial simulations

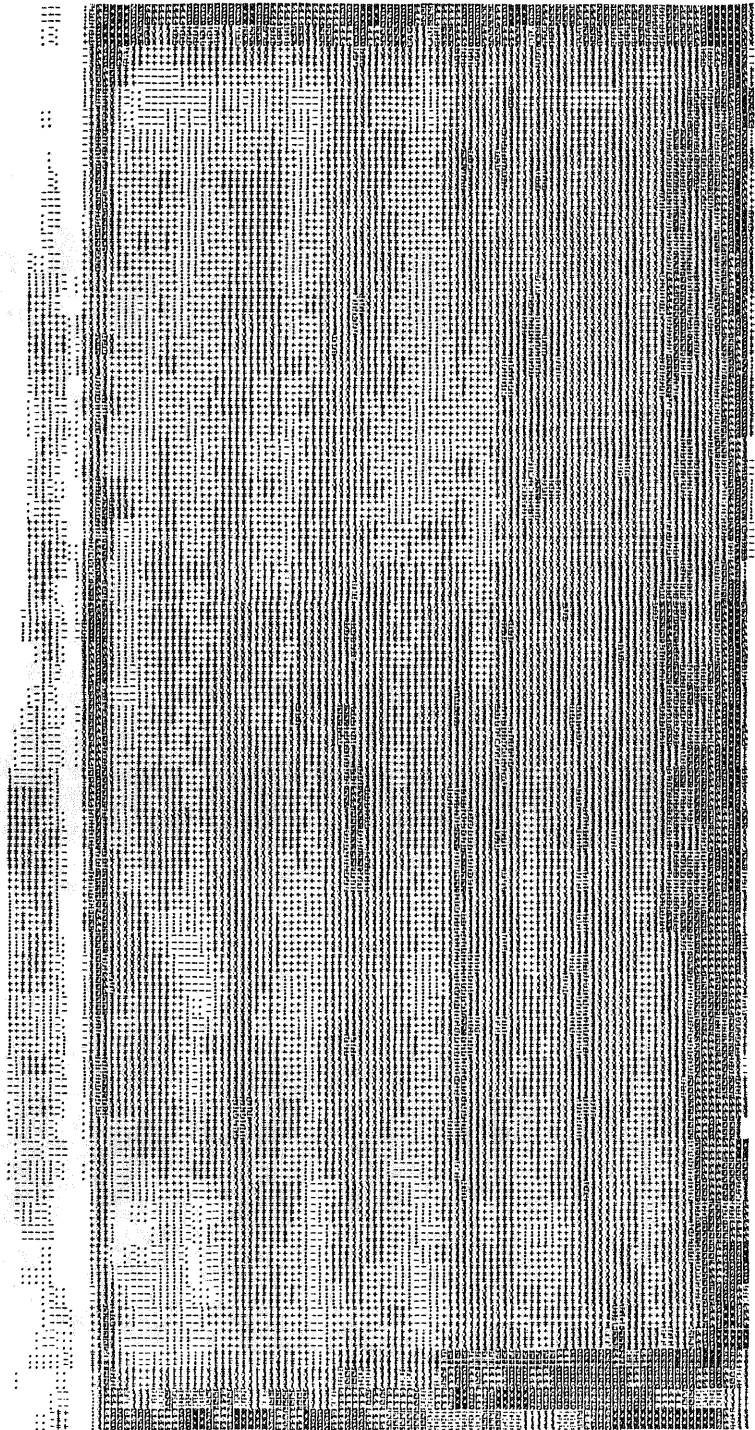
The assumption that (for this field) blocks should be situated lengthwise to the field was checked by simulations. To test the null hypothesis that there are no block effects against the alternative that there are, the ratio of the mean square between blocks and the mean square within blocks was used. If the hypothesis of no block effects holds, this ratio had an F distribution with (4-1) and (80-4) degrees of freedom under the assumptions of normality, independence and equal error variance of the observations. There is no reason to doubt these assumptions. Within the limitations of a more or less homogeneous field, a lay-out with (highly) significant block effects is preferred (mean square between blocks large in comparison to mean square within blocks). This means reduction of the error variance and therefore enhancement of the precision of the experiment.

In table 1 the range of the ratio for six different trial lay-outs (see also figure 1) is given together with the range of the critical levels. The critical level (often called P-value) is the smallest level of significance at which the observed result would just lead to rejection of the null hypothesis. Each range is based upon two to four simulations. The first two lay-outs show very significant block effects, whereas the last two do not have any significant block effects. Lay-out 3 and 4 are in between. The traditional lay-out for trials on this field looked more or less like lay-out 5 or 6. These simulations indicate that the unexplained variation should be largely reduced if another lay-out (such as lay-out 1 or 2) was used.

The simulation had to be restricted to one plot size, namely the size of the spot as measured by means of the densitometer.

Table 1: The ranges of ratios of mean square between and within blocks and the ranges of critical levels for six different trial lay-outs. Each range is based upon two to four simulations.

Block shape (see fig. 1)	MS(between)/MS(within)	critical level
1	24.6 - 44.5	<0.001
2	19.7 - 24.3	<0.001
3	4.5 - 5.5	0.001 - 0.005
4	0.2 - 3.9	0.011 - 0.896
5	0.1 - 0.5	>0.50
6	0.4 - 0.5	>0.50



LEGEND

- 20.9
- 21.6
- 22.3
- 22.9
- 23.6
- 24.2
- 24.8
- 25.5
- 26.1
- 26.8
- 27.4
- 28.1
- 28.8
- 29.4

Figure 3: Map of the infrared reflectance factors of the field. The reflectance factors are divided into classes and symbols are assigned to each class. Darker symbols represent lower reflectance factors.

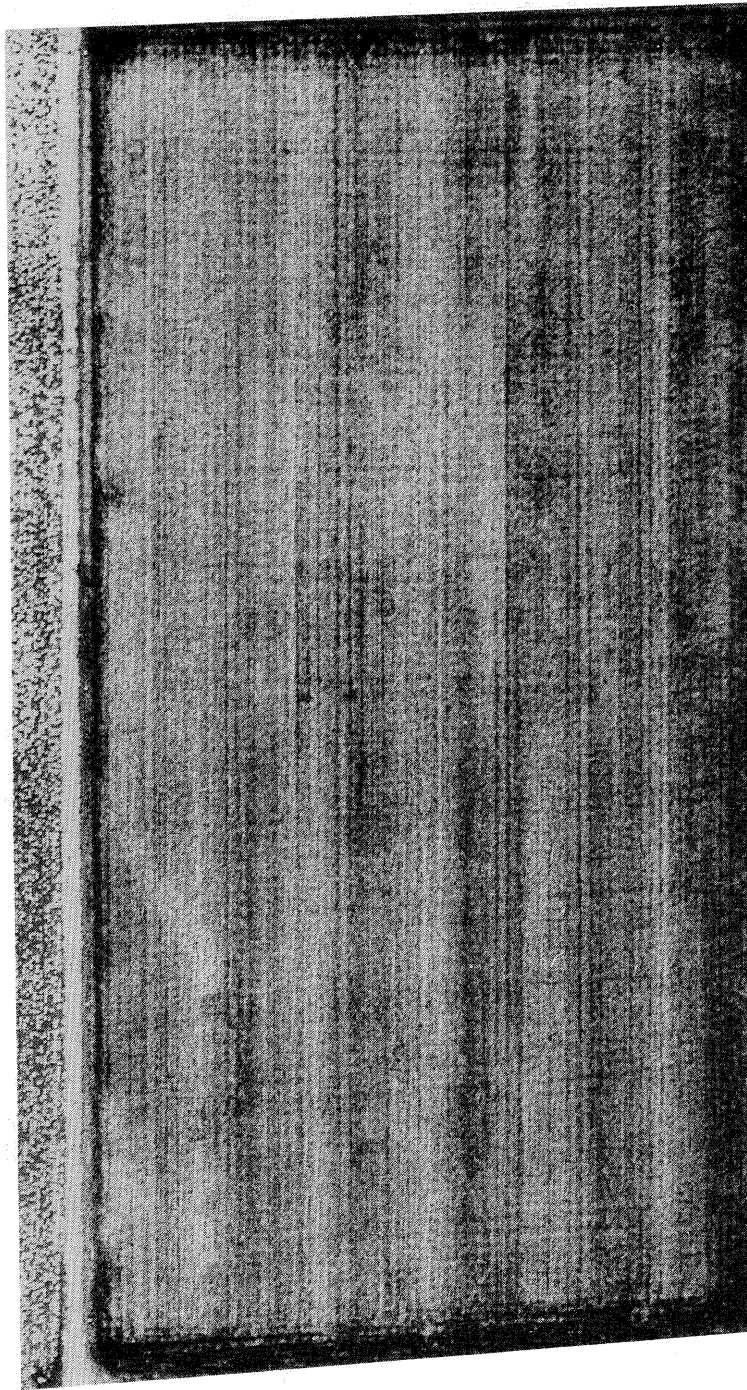


Figure 4: Original photograph of the field. Kodak Infrared Aerographic Film 2424 with a Wratten 87C filter.

4. CONCLUSIONS

Aerial photography seems to be a good technique to map the heterogeneity of a field with respect to yield of barley. It has several advantages in comparison with traditional blank experiments:

- It is a quick and easy way: the complete analysis can be done by one person within a few day's time. Traditional harvesting and data handling is much more laborious.
- The method is non-destructive; the crop remains intact.
- The chances of making mistakes are minimal, because data collection and handling are computerized.

Of course the method also has some disadvantages:

- It is weather dependent; photographs should be taken under a cloudless sky.
- Very specific equipment is required, such as equipment for aerial photography and a digitizing device.

Finally, it seems possible to use this technique for evaluating the suitability of arable fields for yield trials. For this particular field the pattern observed showed which part of the field seemed to be less suitable for yield trials. It also indicated that another way of blocking than practised might improve the blocking efficiency. This indication was confirmed by simulations. The generalized results of the present study will be used in the future in planning field trials on this field.

5. REFERENCES

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