6. THE SPATIAL DATABASE

All the available information considered relevant to the study of the spatial variability of the crop for Pivots Major and Tweefontein has been acquired structured and then stored, so as to be analysed in a GIS environment. This whole process can be described as the pulling together of a 'spatial and temporal database'.

The data was attained from a range of sources such as the airborne images, the ground surveys and the data logger mounted on the harvester. From these, several other information layers were derived. These data can be described as belonging to two broad categories: static and dynamic data. Static data layers refer to those characteristics of the fields that do not change with time. The main static features are:

- The digital elevation model (DEM), made up of points representing the elevation above sea level (a.s.l.) and consequently the shape of the field surfaces. This was as derived from the measurements of the GPS mounted on the harvester data logger.
- The soil depth derived from a grid point augering campaign conducted by the University of Pretoria.
- The AWC map of the soil derived from the analysis on the soil samples collected in the course of the ground survey (see Section 4.2.2.). Three different maps were derived, one for the 0 to 20 cm depth soil layer, one for the 20 cm to spoil layer (or impermeable layer for Major) and one for the total AWC of the soil profile.

Further static data layers are derived from the above. For example:

- The elevation model of the spoil/impermeable layer, obtained by subtracting the depth to spoil map from the surface DEM.

- The depth of vadoze zone[18], obtained by manipulating the spoil DEM so as to represent the thickness of the layer of topsoil that is unlikely to ever be saturated.

The dynamic data represent those information layers, which represent the moment of acquisition and only that, such as the remote sensing images. This is data that can change with time. In detail:

- The Multi-Spectral images of the two pivots and the maps of the vegetation index (TVI) derived from these images.
- The map of the ground cover, of above ground dry matter and of LAI at the time of survey, extrapolated from the sample measurements done during the ground surveys.
- The above ground dry matter production of the crop derived from the analysis of vegetation samples collected in the course of those same ground surveys.
- The yield and moisture contents of the crop as derived from the data logger mounted on the harvester.

The data layers are listed in the following tables (Table 5 – 8).

Table 5: Static data layers for Major Pivot

Data layer topic	Unit	Source	Name of GIS layer
AWC 0-20	mm	Prof. A. Claassens	Maj-AWC-20
AWC 20 to spoil	mm		Maj-AWC-spoil
AWC Total	mm		Maj-AWC-total
Depth to spoil	mm	Auger measurements	Maj-d.t.s.
Depth of vadoze zone	mm	GIS processing	Maj-d.v.z.
Surface DEM	m (a.s.l.)		Maj-Sur-DEM
Spoil DEM	m (a.s.l.)		Maj-Spoil-DEM

[18] **Vadoze zone** The vadoze zone is the depth of soil from the surface down to the water table

Table 6: Dynamic data for Major Pivot

Data layer topic	Unit	Source	Name of GIS layer
Multi-Spectral image		08/99 Flight	Maj-MS-08/99
		10/99 Flight	Maj-MS-10/99
Vegetation Index		Image processing 08/99 flight	Maj-VI-08/99
		Image Processing 10/99 flight	Maj-VI-10/99
Second Principal Component		Image Processing 08/99 flight	Maj-PC1-08/99
		Image Processing 10/99 flight	Maj- PC1-10/99
Wheat yield	t ha^{-1}	Harvester data logger	Maj-yld
Wheat crop moisture	%		Maj-c.m.
Ground cover	%	Sampling and lab analysis	Maj-g.c.
Top dry matter	$g*m^{-2}$		Maj-t.d.m.
LAI	m^2*m^{-2}		Maj-LAI

Table 7: Static data for Tweefontein Pivot

Data layer topic	Unit	Source	Name of GIS layer
AWC 0-20	mm	Prof. A. Claassens	Twee-AWC-20
AWC 20 to spoil	mm		Twee-AWC-spoil
AWC Total	mm		Twee-AWC-total
Depth to spoil	mm	Auger measurements	Twee-d.t.s.
Depth of vadoze zone	mm	GIS processing	Twee-d.t.v.z.
Surface DEM	m (a.s.l.)		Twee-Sur-DEM
Spoil DEM	m (a.s.l.)		Twee-Spoil-DEM

Table 8: Dynamic data for Tweefontein Pivot

Data layer topic	Unit	Source	Name of GIS layer
Multi-Spectral image		10/99 Flight	Twee-MS-08/99
		08/99 Flight	Twee-MS-10/99
Vegetation Index		Image processing 08/99 flight	Twee-VI-08/99
		Image Processing 10/99 flight	Twee-VI-10/99
First Principal Component		Image processing 08/99 flight	Twee-PC1-08/99
		Image Processing 10/99 flight	Twee- PC1-10/99
Wheat yield	t ha^{-1}	Harvester data logger	Twee-yld
Wheat crop moisture	%		Twee-c.m.
Ground cover	%	Sampling and lab analysis	Twee-g.c.
Top dry matter	$g*m^{-2}$		Twee-t.d.m.
Leaf Area Index	m^2*m^{-2}		Twee-LAI

6.1. Point data interpolation procedure

The production of most of the maps utilised in the study required the interpolation of point data. These are characterised by a longitude and a latitude co-ordinate for each individual point.

This interpolation is done using the Inverse Weighted Interpolation (IWI) algorithm provided by the GIS Software, ERSI ArcView©[19] *(Watson, D. F. & Philip, G. M., 1985*). This interpolation determines cell values using a linearly weighted combination of points. The weight is a function of the inverse distance from point to point.

The surface being generated through the interpolation is usually that of a variable that is described by the sample points, but that in reality has a continuous spatial expression over the area of interest (e.g. LAI of the crop).

The IWI lets the user control the significance of the known sample points upon the interpolated values, based upon their distance from them. In other words, the nearer to a measured point, the higher the weight of that point in determining the interpolated value, but the user can, interactively, control this weight as a function of other ancillary variables.

The best results from IWI are obtained when the points representing the surface are sufficiently dense and when they effectively represent the local variation in the surface that is being simulated. If the sampling of input points is sparse or very uneven, the results may not sufficiently represent the desired surface (*Watson and Philip, 1985*). Since the influence of an input point on an interpolated value is distance related, IDW[20] is not ridge preserving (*Philip and Watson, 1982*), this means that the interpolation will create a continuous surface and not be able to represent an abrupt spatial variation (ridge) in the values that are mapped

[19] ERSI ArcView ©: The GIS application product used for the manipulation of the maps.
[20] IDW = Interpolated Distance Weight

6.1.1. Surface DEM

As a typical static map, the surface 'Digital Elevation Model' (DEM) was derived from the data logger linked to a GPS and mounted on the harvester deployed on the pivots. The original data source was a set of points, which were subsequently interpolated. The DEM map is in raster form with a resolution (maximum pixel size) of 2 m. The base and derived documents are illustrated in Figures 17 and 18.

Fig. 17: Point measurements of height a.s.l. from a GPS data-logger mounted on the harvester for Major (left) and Tweefontein (right).

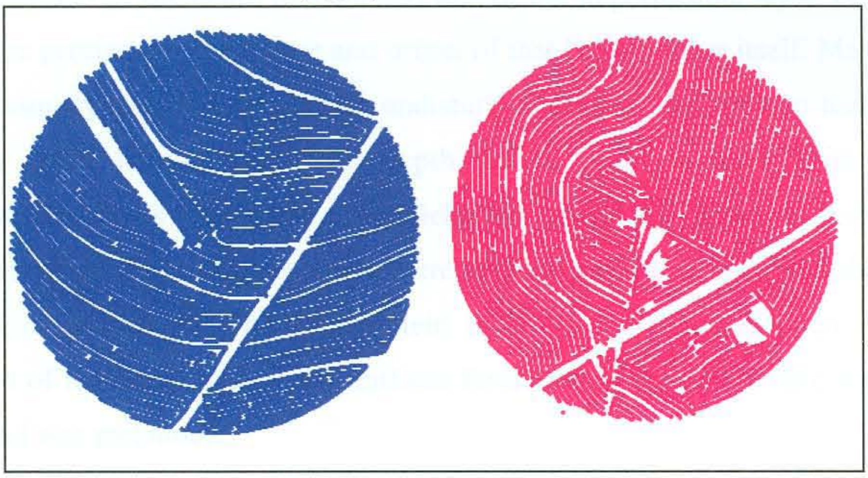
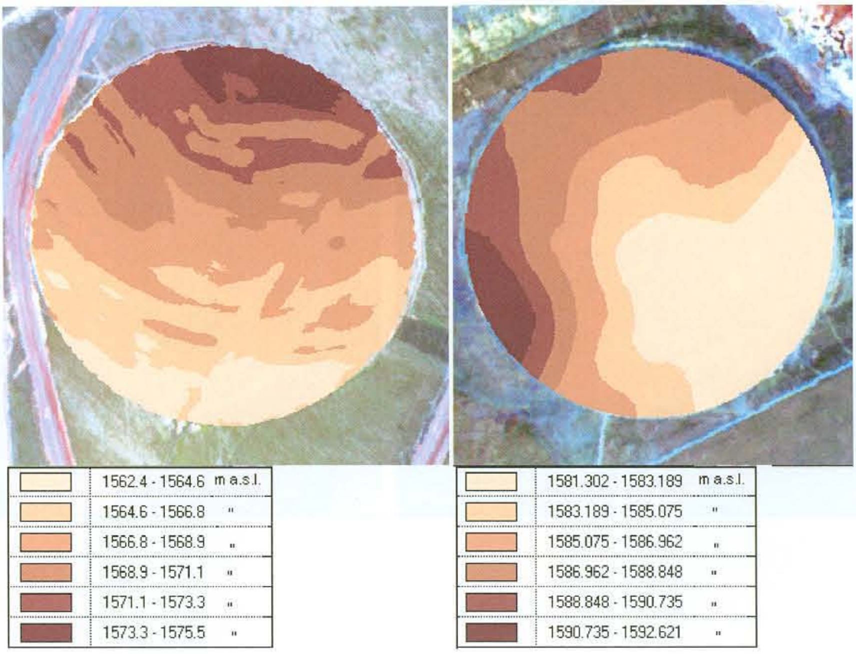


Fig. 18: DEM map of Major (left) and Tweefontein (right).



6.1.2. Depth to spoil or impermeable layer maps

Also a static data layer, the depth to spoil or impermeable layer map was derived from an auger sampling campaign conducted over the two pivots in a 40*40 m grid. Here too, the points where interpolated using the IWI procedure. As for the previous example, the map is also here in raster format with a pixel size of 2*2 m. The location of the auger samples and the derived map are shown in Figures 19 and 20.

Major and Tweefontein differ from one another essentially for the characteristic of the depth to spoil and that of the impermeable layer, or, to be more precise, for the nature and origin of that bottom layer itself. Major, as previously stated is set over an undisturbed tract of land. Due to this, it has a fairly homogeneous soil depth and a more uniform level of compaction across the surface of the field. Anomalies are present in certain sections of the field, such as where there is an impermeable layer, but these are of natural origin. The Tweefontein field is a rehabilitated open cast section of the mine, with a non-uniform formation of the soil profile when the land was reclaimed.

Fig. 19: Location of the auger sampling points for Major (left) and Tweefontein (right).

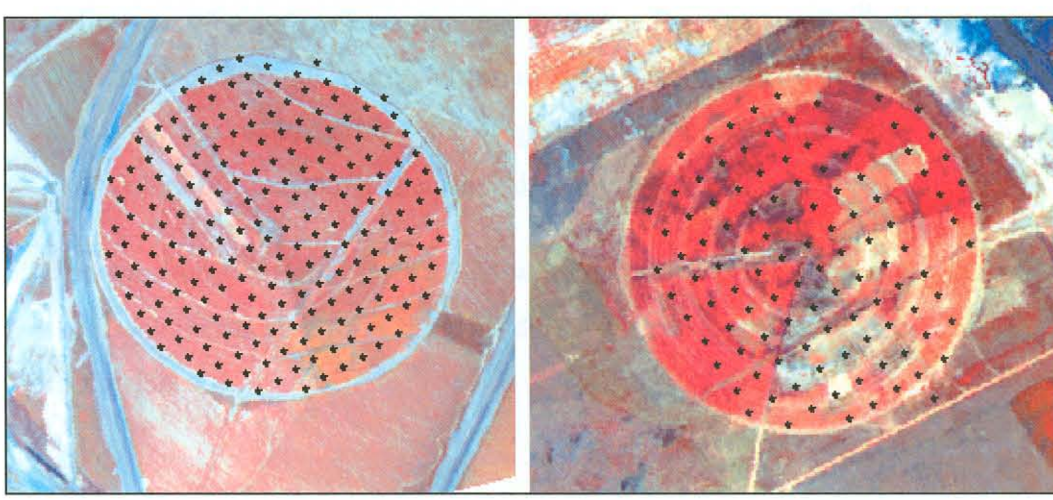
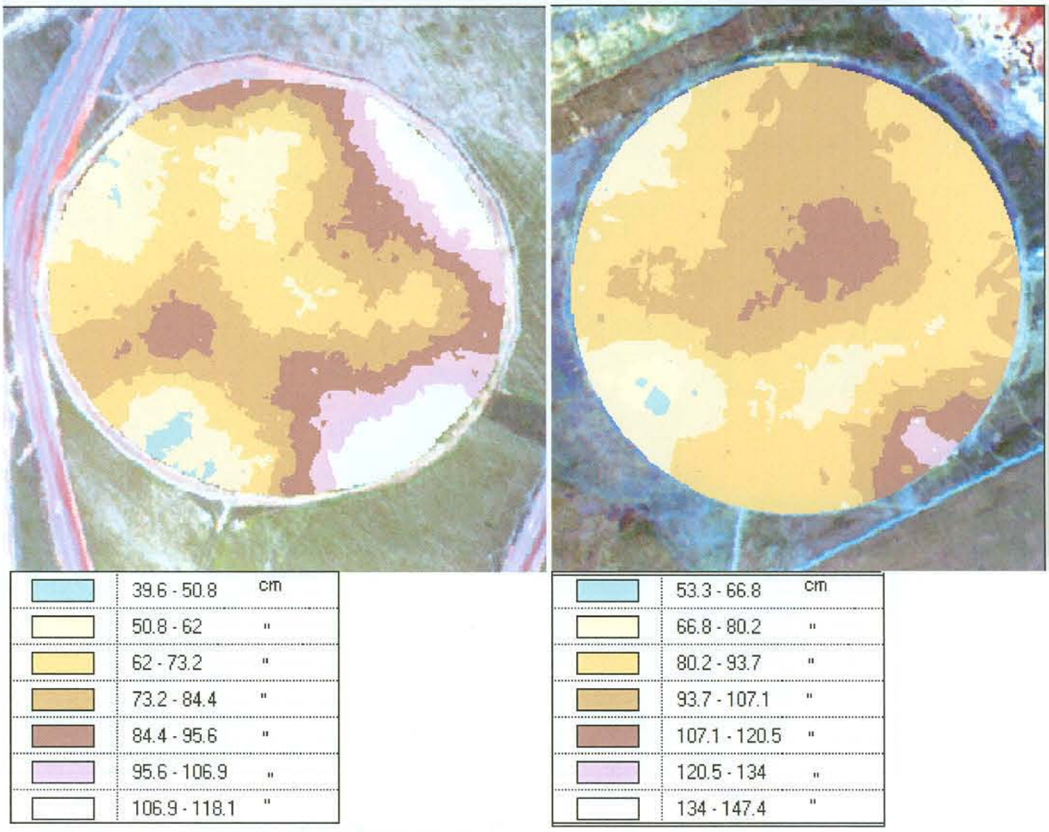


Fig. 20: Depth to the impermeable layer for Major (left) and Tweefontein (right).

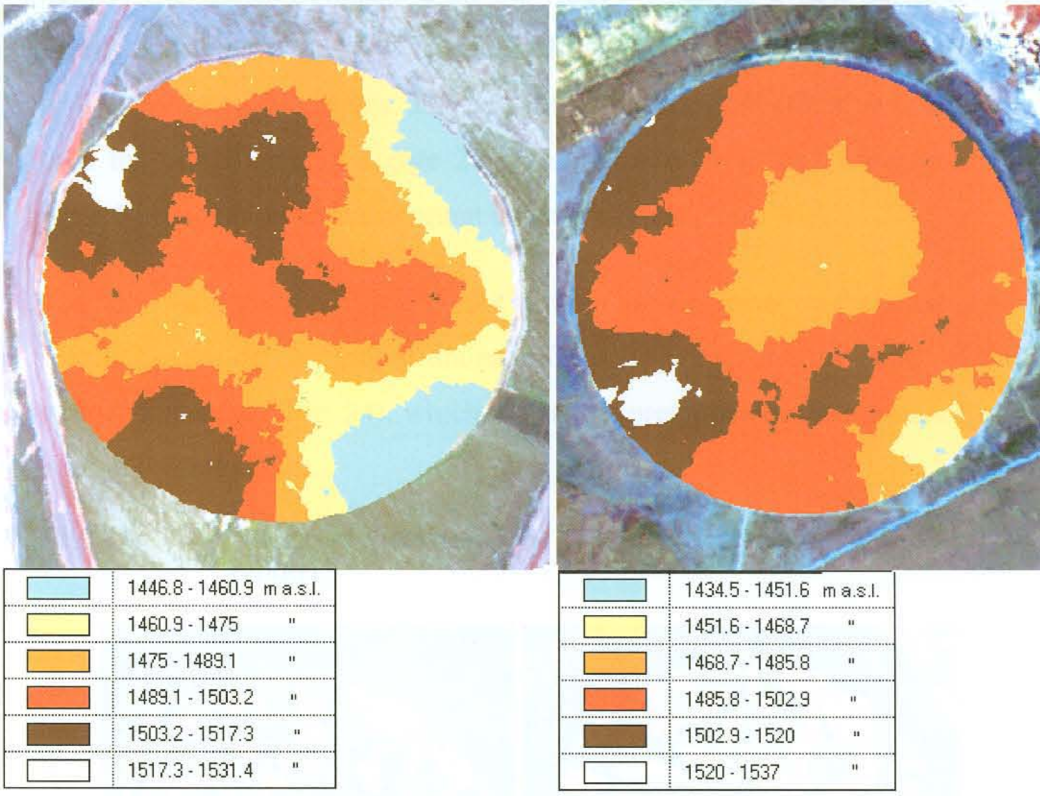


6.1.3. Spoil/impermeable layer DEM

The DEM of the spoil/impermeable layer was created in order to allow the definition of a subsurface drainage pattern. The shape of this layer can determine areas of water accumulation (underground ponding), thus affecting the condition of the vegetation in a way that may not be established by analysing the surface drainage pattern.

The spoil/impermeable layer DEM was derived by subtracting the depth of the soil/impermeable layer itself, as determined with the auger sample, from the surface DEM.

Fig. 21: Spoil/Impermeable layer DEM map of Major (left) and Tweefontein (right).



6.1.4. Depth of vadoze zone map

Also part of the 'static' data, the depth represented in this map refers to that portion of the soil layer where, in conditions of normal water supply, there is no water logging caused by underlying micro-topography. This map is derived from the spoil/impermeable layer DEM, by outlining the outer boundaries (the ridge) of the depression areas.

The delineation of the small and medium sized depressions on the spoil or the impermeable layer is performed by simulating the 'fill-up' of each depression until it 'spills over' to a neighbouring one. This simulation is a GIS process where the 'bottom' of the depression is first identified by means of a normal derivate analysis, and then the 'slopes' are identified by progressively 'pulling' the bottom upwards with the condition that the perimeter of the flat projection of the depression increases. The 'spill over' is identified when this surface is subject to a sudden increase, meaning that two or more depressions have come together. The point where this sudden change takes place is identified as the outer contour of the 'depression', namely the ridge. Connecting all the ridges generates a new surface that makes up the baseline of the portion of the soil profile where it is unlikely to find saturated conditions. This is a more 'meaningful' effective soil depth than the one shown in Figure 20, although soil depth and water holding capacity may not be that important under irrigation.

The following pictures illustrate the various 'depressions' on the spoil layer (Fig. 22.), the derived micro drainage lines (Fig. 23.) and the depth of the vadoze zone map (Fig. 24), which just as the previous ones is in raster form with pixel size of 2m.

Fig. 22: Micro depressions of Major (left) and Tweefontein (right).

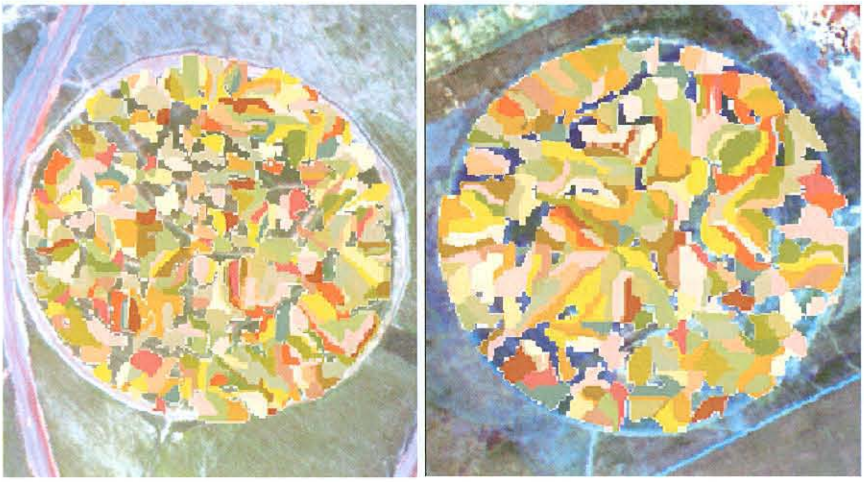


Fig. 23: The micro drainage lines for Major (left) and Tweefontein (right).

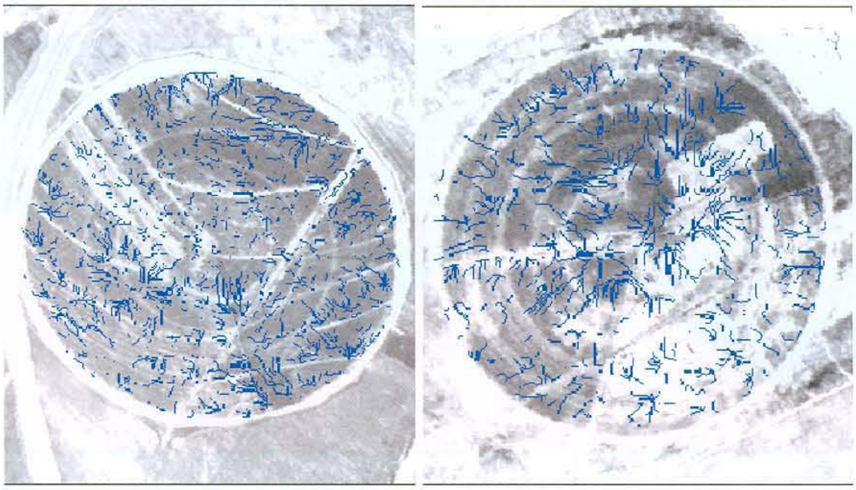
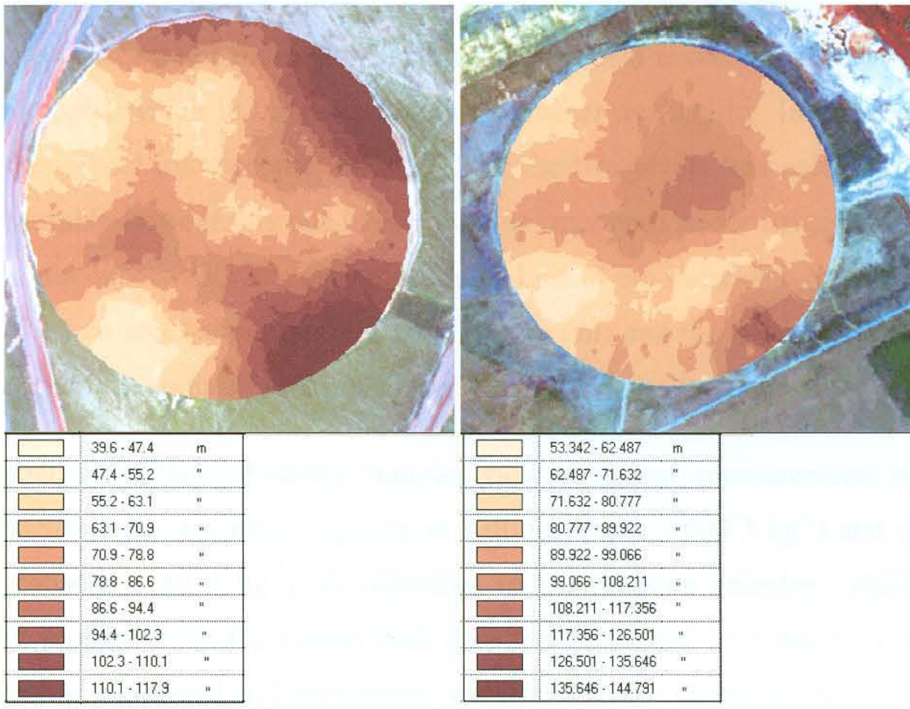
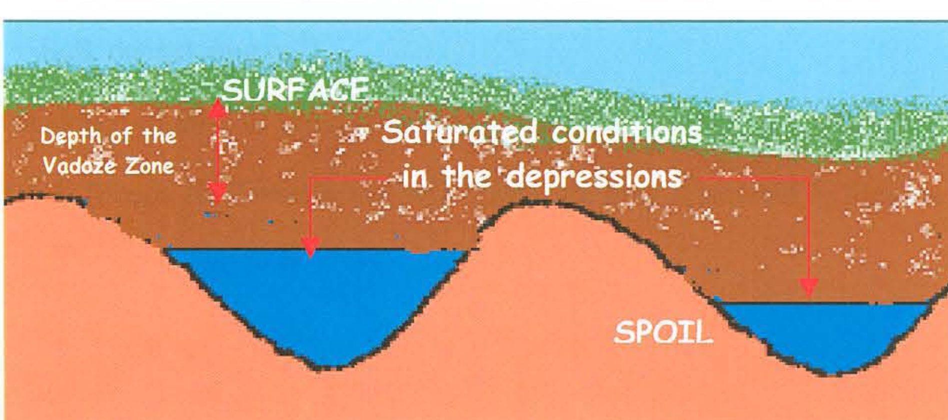


Fig. 24: The depth of the vadoze zone map for Major (left) and Tweefontein (right).



As this analysis is conducted with raster data, the actual size and shape of the micro and medium depressions may change as a function of the minimum number of cells that are considered to make up a 'depression'. The lower the number of cells, of course, the more 'depressions' can be identified. As a function of this, the drainage pattern was calculated over a variable number of cells contributing to the flow accumulation. These were, in order: 20, 50, 100, 200 and 500, thus generating alternative drainage pattern maps to be used in the analysis described above.

Fig. 25: Representation of the soil profile and the vadoze zone



6.1.5. Available water capacity maps

The appearance and condition of the crop on the field is conditioned by its water supply, which in turn is a function of water availability. In order to take this aspect into account, the AWC for the two pivots was calculated. This variable however, is not likely to be as important under irrigation as one would expect with dry land conditions. Last of the static data, this was done for two soil layers: the root zone (0 –20 cm) and the layer from the root zone to the spoil/impermeable layer.

The analysis of the soil survey samples yielded the two measurements of gravimetric water retention capacity at wilting point (–1500 J kg^{-1}) and at field capacity (–10 J kg^{-1}), as measured in the pressure chamber. These values, together with the known bulk densities (1.60 and 1.90 Mg m^{-3}) of the soils at Major and at Tweefontein, and the reference depths to the spoil, allowed the derivation of the AWC for the two soil layers and for the total profile on each pivot. The following equation was used for the calculation of the AWC:

$$AWC = .\ FC - PWP * BD.\ * Z$$

Where:

FC = Field capacity (g g^{-1})

PWP = Permanent wilting point (g g^{-1})

BD = Bulk density (mg m^{-3})

Z = thickness of the soil layer(s) (mm)

The AWC maps for Tweefontein and Mayor are here illustrated in Figures 26, 27 and 28.

Fig. 26: **Available water capacity map in the surface 20 cm layer for Major (left) and Tweefontein (right).**

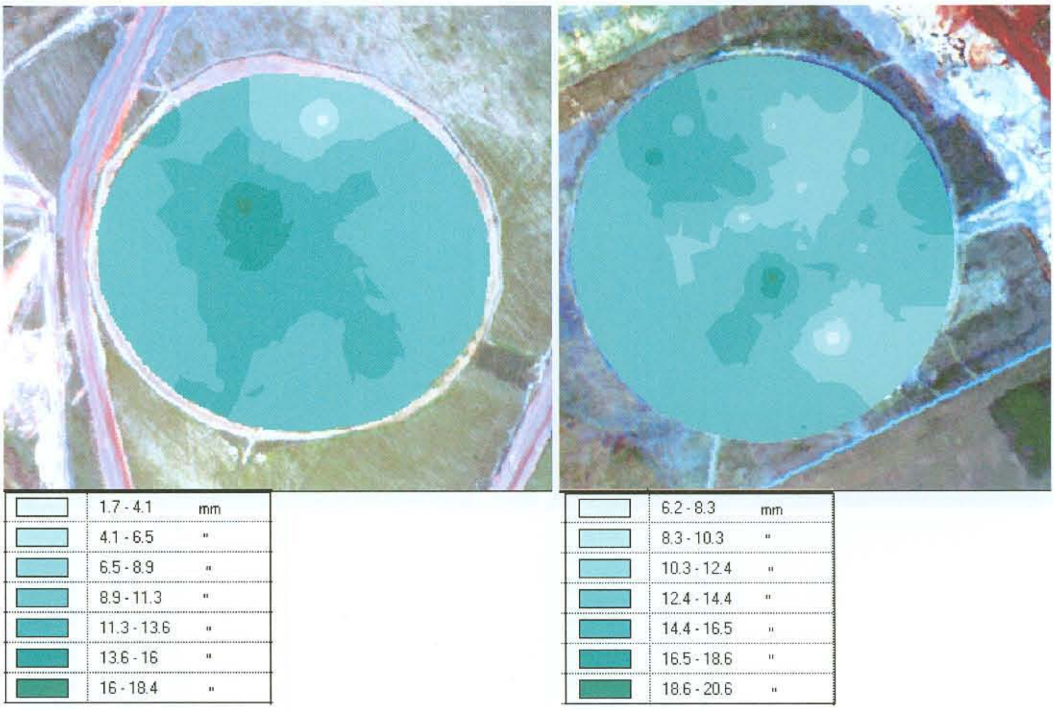


Fig. 27: **Available water capacity map in the 20 cm to spoil/impermeable layer for Major (left) and Tweefontein (right).**

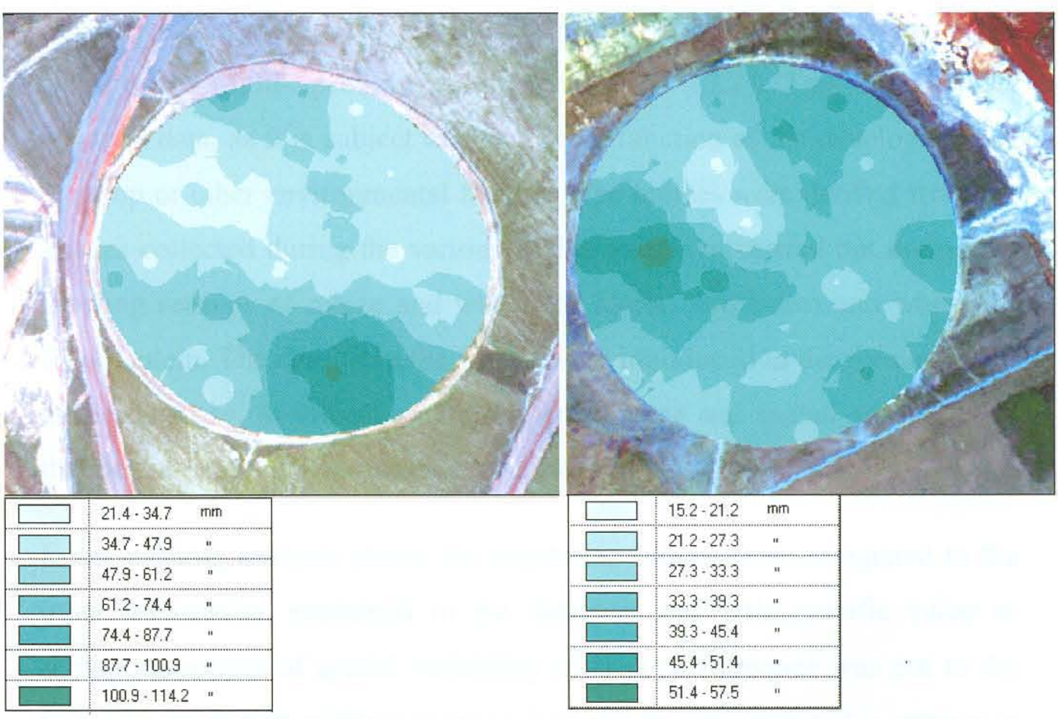
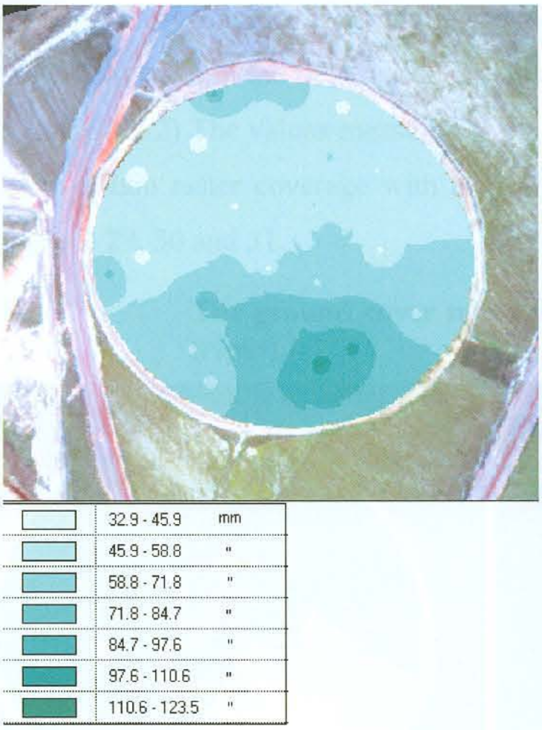
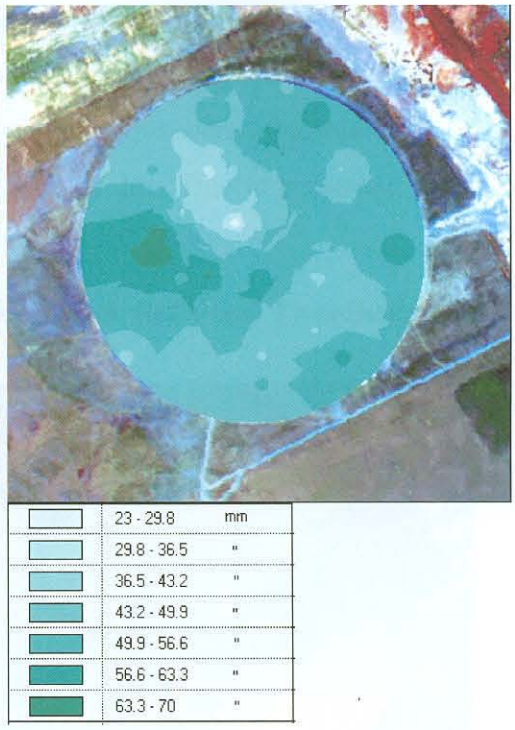


Fig. 28: **Total Available Water Capacity map for Major (left) and Tweefontein (right).**





6.1.6. Vegetation index maps

The vegetation index maps are the result of a specific combination of the bands of the Multi-Spectral images (See Section 5.2.2.). This is, of course, dynamic data, as it is subject to change as a function of the development of the crop or other environmental factors. The indices were derived from the images collected during the various flights that were carried out during the growing seasons of maize and wheat for Major, and beans and wheat for Tweefontein. The data from the flights were introduced in the form of maps in the database, as indicator of crop performance and spatial variability of that performance. These images are shown in Figure 15.

In the ensuing analysis phase, the vegetation indices were compared to the other information contained in the database and their specific value as remote indicators of spatial variability of crop performance was put to the test. The resolution of these maps is 2 m and the unit mapped is expressed in a generic scale ranging between 0 and 100.

6.1.7. Ground cover, top dry matter and leaf area index maps

The maps of ground cover, above ground dry matter production and LAI were derived from the field measurements conducted during the survey (See Section 4.2.2) The values measured at the single points were interpolated so as to obtain raster coverage with a pixel size of 2m. This is presented in Figures 29, 30 and 31.

Fig. 29: The ground cover maps for Major (left) and Tweefontein (right).

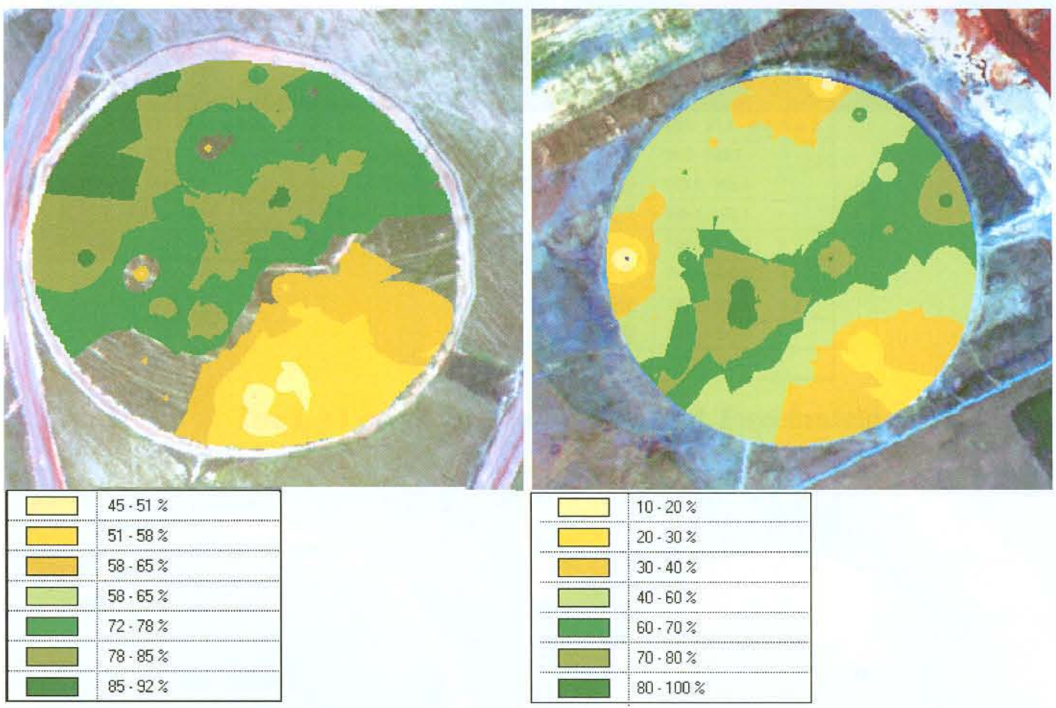


Fig. 30: **The above ground dry matter production maps for Major (left) and Tweefontein (right).**

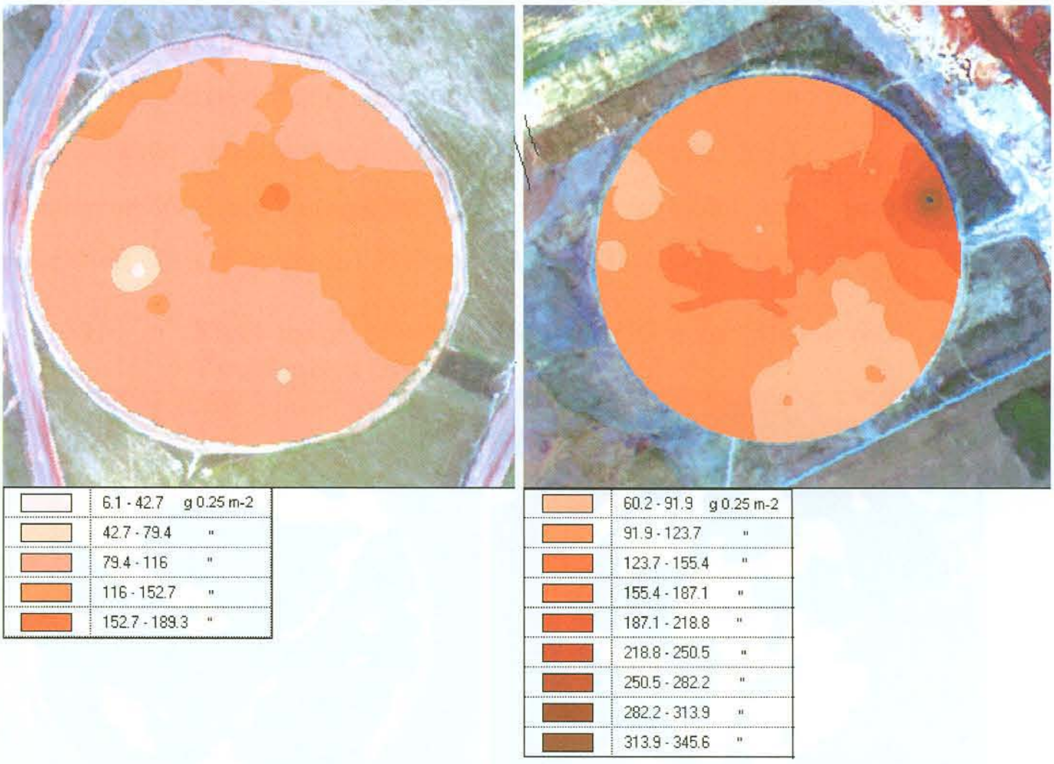
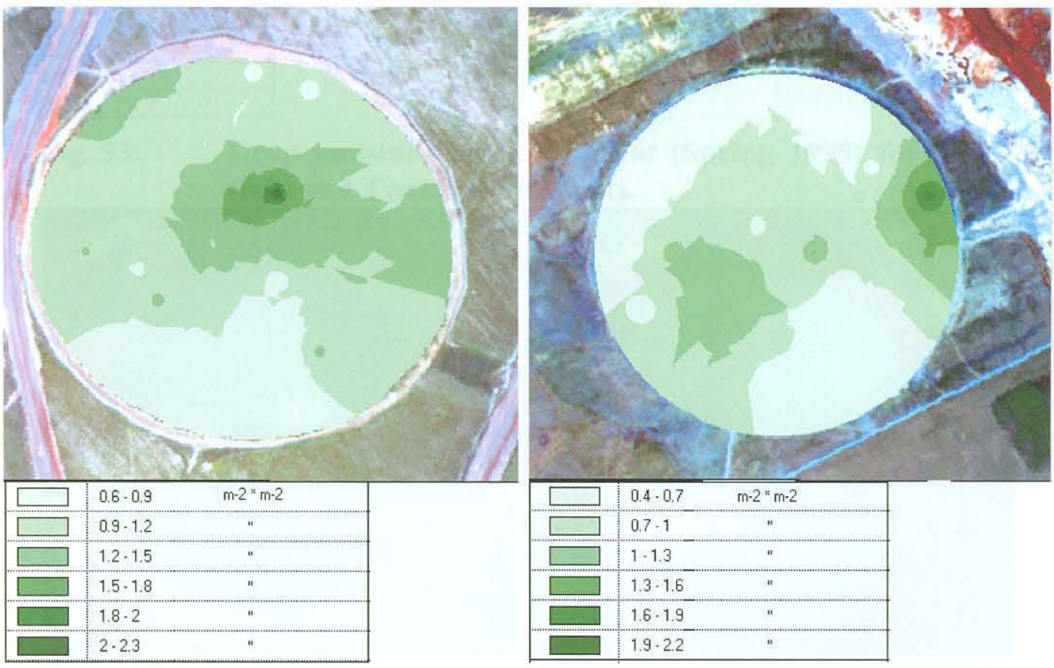


Fig. 31: **The LAI maps for Major (left) and Tweefontein (right).**



6.1.8. Yield and crop moisture at harvest map

The yield and crop moisture maps of the wheat harvest, as for the surface DEM, were derived from the data logger, linked to a GPS and mounted on the harvester deployed on the pivots (see section 4.2.3). The point measurements were interpolated to produce a raster map with 2 m resolution. This is presented in Figures 32 and 33.

Fig. 32: Yield maps of wheat (Spring 1999) for Major (left) and Tweefontein (right).

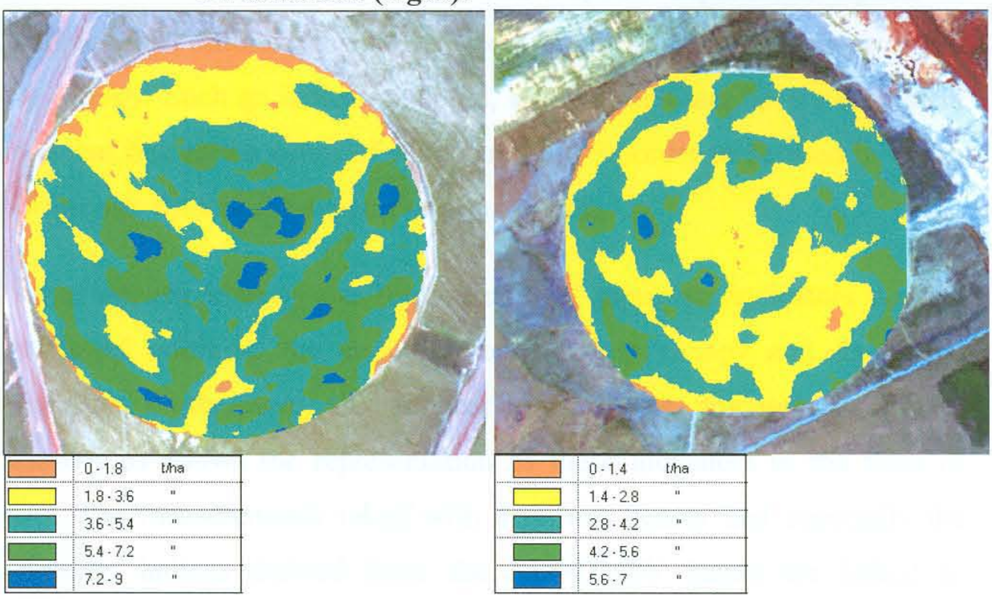


Fig. 33: Crop moisture maps of wheat (Spring 1999) for Major (left) and Tweefontein (right).