7. DATA ANALYSIS

Before engaging in the actual data analysis, it is necessary to devise ways to evaluate performance and variability over the surface of the pivots and the first step in this quest is to identify a spatial measure for these variables.

This spatial measure has to be generalised, repeatable and scientifically consistent and an effective indicator of spatial variability should, theoretically, be a numerical value, with a spatial expression, capable of identifying and outlining anomalies in development and performance over a crop canopy. Such an indicator should, at the same time, have a consistent functional link to the cause of such variability in order to be used in future applications without the support of ground truth.

Remote sensing imagery has the potential of supplying indicators that are capable of outlining the condition of the crop canopy and its spatial variability. Furthermore, the application of image processing and GIS technologies allows the representation of these indicators in the form of maps. The measurements taken with a remote sensor and especially the vegetation indices derived from the STS-DMSV bands are linked to physical variables such as photosynthetic activity and water contents in the leaves *(Wiengand et al. 1991, Steven et al 1990)*. Because of this, in some cases, they can contribute to resolving the causes and circumstances of such spatial variability in an objective and repeatable manner.

From the description of image enhancements in Section 5.2.2, the selection of possible candidate indicators has been restricted to the TVI (Transformed Vegetation Index) and the First Principal Component (PC1) of the four STS-DMSV (SpecTerra Systems-Digital Multi-Spectral Video) bands.

Major and Tweefontein were repeatedly flown for two consecutive seasons, images were acquired over different crops (beans, maize, and wheat) and, for the same crop, in different phenological phases. The two pivots, as described in Chapter 3, also represent two different cases, as Tweefontein was set up over a rehabilitated open cast section, while Major is over virgin land. Both performance and spatial homogeneity is expected to differ between the two due to the different nature of the substratum and the different levels of compaction resulting from the rehabilitation works at Tweefontein.

Since the pivots irrigate the crops, these can be considered as, more or less, indifferent to the major climatic contingency of water availability. The characteristics of the irrigation water though, rich in gypsum, could cause accumulation of this salt in the soil and thus influence anomalies over the crop canopy.

The correct labelling of such an occurrence is extremely difficult, as it may be masked or confused with other factors such as soil compaction or fertility. Another occurring problem, especially on the rehabilitated site (Tweefontein), is the possibility of water logging due to differing soil compaction over the field.

It is thus assumed that most of the spatial variability and anomalies in the crop development and productive outcome is due to the soil physical properties (e.g. drainage) but also soil characteristics or management practices (cultivation, fertilising, etc.).

Pests and weeds could also be considered cause for additional irregularities in the canopy of the crop. But, even though airborne remote sensing is a particularly suitable tool for detecting and managing these hazards, in the case of this project the frequency of over-flight was insufficient for the monitoring or even outlining of such events. The occurrence of pest infestations especially, is a rather sudden event, usually characterized by a rapid development. The early warning and identification of such hazards may require weekly and even more frequent monitoring in order to be effectively controlled.

The analysis was addressed at highlighting possible differences in the crop canopy over different periods within the same season and across the two pivots. Further scope of the analysis is to try to explain the causes of possible performance difference and variability between the 'virgin' Major and the rehabilitated Tweefontein.

7.1. Analysis procedures

In general, at the beginning of an analysis it is assumed that the cause–effect relation between events is unknown. In the specific case of this study however, the differing genesis of Major and Tweefontein and their soil characteristics provide strong enough clues for the spatial variability of the crop canopy. Scope of the analysis, in this case, is to prove the spatial connection between soil characteristics and vegetation performance using remote sensing. Also among the objectives of the study is to identify, among a number of variables, the one or ones, that are most significant in determining the spatial variability.

The method of analysis chosen to identify the variable or variables that can best explain spatial variability is a 'Pearson-r' correlation between the various maps described in the previous chapters. A correlation is a measure of the relation between two or more variables. 'Pearson-r' correlation determines the extent to which values of the variables are related to each other. The value of the correlation (i.e. correlation coefficient) does not depend on the specific measurement units used, thus making it particularly suited to the comparison of maps, with the same pixel number, but representing very different characteristics.

The correlation analyses between maps are carried out on a one to one basis and a straight line, sloped upward or downward can graphically represent this correlation. This line is called the regression line or least squares line, because it is determined such that the sum of the squared distances of all the data points from the line is the lowest possible.

Correlation coefficients can range from –1.00 to + 1.00. The value of –1.00

represents a perfect negative correlation, whilst a value of +1.00 represents a perfect positive correlation.

Three main analysis procedures were followed to verify the effectiveness of remotely sensed data as indicators of variability, and in order to identify causes of this variability:

- Overall correlation analysis: This first process has the scope of validating remotely sensed indicators for the explanation of canopy variability. It consists of running a statistical correlation analysis between the values of the indicators and the variables measured over the crop canopy (dynamic and static) on a one to one basis.

- Focal correlation analysis: The scope of this second analysis is to identify 'where', over the surface of the pivots, the indicators work best in explaining the physical variables statistically. This process was carried out in an attempt to represent the statistical correspondence between indicator and spatial variables, in the form of maps. It can be described as a 'local or focal analysis' and is also a regression, but performed on a much-reduced spatial scale. The correlation is conducted along a moving window that spans across the various pairs of maps being compared. The correlation coefficient obtained within each window is assigned to the window itself so that, at the end, the variability of the correlation coefficient itself can be mapped. The size of the windows of analysis is arbitrary and several were tested.

- Variability analysis: A third analysis had the aim of highlighting the differences in variability between the two pivots and within the same pivot, over two seasons and with different crops. This was done by extracting all the relevant information from the maps in the form of summary statistics and distribution graphs, and by comparing the various values.

7.1.1. Overall correlation analysis

The procedure was centred on the exploration of the statistical correlation between the TVI and the PC1, with all the other data layers describing the crop, the soil, and the hydraulic and structural characteristics of the fields (static data layers). The TVI and the PC1 were derived from the images of the flights carried out during the wheat season, in September and October 1999. These two dates roughly corresponded to the vegetative development and flowering stages of the crop on both pivots. The TVI and PC1 are used as independent variables, and so too are the values of yield and crop moisture contents at harvest. This second layer is probably of scarce value to the determination of crop performance, but it is considered because, being available spatially, it may say something on the moisture condition of the soil at harvest time. These four variables are also compared with each other so as to explore how interrelated they are.

The program script for the correlation procedure is made up by a protocol named 'Covariance'[21]. This procedure calculates a covariance matrix and a correlation matrix between the active grid themes (the maps being compared), sending output to a file.

Within the GIS ArcView© definitions, a map is defined as a 'grid' and the procedure requires the 'grid' themes to be active in a view[22]. It also requires that the grid themes that are to be compared be spatially the same in terms of geographical co-ordinates, projection, containing rectangle (extents) and resolution. Grid themes are the format in which the raster thematic data layers are stored in ArcView©, each pixel or 2*2 m cell of a map is characterised by a unique spatial location. All the pixels of a map can be structured as a list where the numeric value of the map has a unique position that can be characterised by a code or order number. Two maps can then be compared as two corresponding sequences of values in which these same

[21] **Covariance**: This program was obtained through an internet users/developers network working on the GIS, ArcView©

[22] A view is the user interface of the program ArcView Spatial Analyst.

values are considered as two characteristics of the same pixel.

In order to run the procedure, the script of the program was connected to a button in the user interface and the analysis was conducted within the program 'Spatial Analyst©' that is a subprogram of Arc View©.

The result of the program was a simple correlation coefficient between maps, and the results of the analyses that were performed are illustrated in Tables 9 and 10.

The black boxes in the table indicate correlations of the data layers with themselves (and thus equal to 1) and analyses already conducted and reported in the upper part of the table. The correlations between the TVI and the PC1 were also skipped as irrelevant to the scope of the study. Such is also considered the correlation between crop moisture contents at harvest, the TVI and PC1. The grey shaded boxes with the numbers in bold, represent the best correlations both positive and negative (inverse correlation), obtained in this analysis.

Table 9: Major Pivot: Correlation coefficients (*r*) between the various data layers

Data Layers	TVI		1st Principal Component		Ground Cover	Above ground Dry Matter	LAI	Yield	Crop Moisture Contents	AWC			Depth To Spoil	Depth Vadoze Zone
	8/99	10/99	8/99	10/99						0-20	20 to spoil	Tot		
Maj-VI-08/99					-0.07	0.13	0.12	0.40		0.17	-0.07	-0.02	-0.03	-0.08
Maj-VI-10/99					0.11	0.14	0.20	0.31		0.09	-0.15	-0.14	-0.07	-0.07
Maj-PC1-08/99					0.20	-0.06	-0.07	-0.41		-0.20	-0.14	0.17	-0.08	-0.08
Maj- PC1-10/99					-0.03	-0.12	-0.17	-0.24		-0.13	0.04	0.05	0.03	0.03
Maj-g.c.						0.32	0.55	-0.33	0.30	-0.05	-0.75	-0.81	-0.44	-0.40
Maj-t.d.m.							0.82	0.16	-0.18	-0.14	-0.43	-0.39	0.05	-0.02
Maj-LAI								0.07	-0.21	0.24	-0.55	-0.57	-0.02	-0.03
Maj-yld									-0.69	0.36	0.21	0.28	0.16	0.06
Maj-c.m.										-0.25	-0.19	-0.23	-0.23	-0.23

Table 10: Tweefontein Pivot: Correlation coefficients (*r*) between the various data layers

Data Layers	TVI	1st Principal Component	Ground Cover	Above ground Dry matter	LAI	Yield	Crop Moisture Contents	AWC			Depth To Spoil	Depth Vadoze Zone
								0-20	20 to spoil	Tot		
Twee-VI-08/99			0.15	0.20	0.19	0.29		0.11	0.10	0.12	-0.03	-0.03
Twee-VI-10/99			0.17	0.18	0.18	0.28		0.15	0.04	0.08	-0.07	-0.07
Twee-PC1-08/99			-0.19	-0.20	-0.20	-0.32		-0.12	-0.05	-0.08	-0.02	-0.02
Twee- PC1-10/99			-0.22	-0.17	-0.18	-0.27		0.15	0.04	-0.20	0.09	0.09
Twee-g.c.				0.59	0.80	0.18	-0.05	0.28	0.00	0.07	-0.12	-0.12
Twee-t.d.m.					0.84	0.30	-0.27	0.17	0.17	0.22	0.07	0.07
Twee-LAI						0.35	-0.07	0.26	0.18	0.25	-0.00	-0.00
Twee-yld							-0.23	0.04	0.30	0.32	-0.09	-0.09
Twee-c.m.								0.12	-0.27	-0.25	0.07	0.07

The correlation analysis yielded very poor results for both Major and Tweefontein. Most of the correlation coefficients (***r***) were below 0.36.

Better results had been expected for the correlation between the TVI and variables such as above ground dry matter production or yield, or between soil depth and above ground dry matter or yield. This expectation was based on the theory of vegetation indices, and on the expected link between soil depths, water availability and yield. For this second case, a possible explanation for the poor results could be attributed to the fact that wheat, with a limited root depth, is less sensitive to the structure of the subsoil, especially under conditions of irrigation. In other words, when irrigated, wheat is indifferent to the soil physical properties.

However, another explanation for these results, can be found in the interpolation procedure, and therefore in the creation of poorly representative maps. The soil depth, assuming the accuracy of measurement at the augering points, once interpolated and transformed into maps, possibly compared poorly with the data derived from the images, or with those interpolated from the ground surveys and the harvester data logger.

The interpolation process generates a raster map (GRID), which is made up of many more pixel values than the measurements. If the interpolation process generates maps that are scarcely representative of reality, the correlation of these maps will be compromised by the presence of an overwhelming number of 'wrong' values, masking the true correspondence of two phenomena. One could possibly look at the simple correlation between the measured values, but these derive from differing sampling campaigns and since they vary greatly in sample size, cannot be compared.

Some correlations, relative to the LAI, ground cover, and the above ground dry matter maps were an exception. For Major, the *r* between LAI and ground cover was 0.55, and between the LAI and above ground dry matter was 0.82. For Tweefontein, the *r* was 0.80 between LAI and ground cover and 0.84 between LAI and above ground dry matter. An *r* of 0.59 was also reported between above ground dry matter and ground cover. An explanation for these good correlation coefficients between LAI, ground cover and top dry matter probably lies in the fact that the maps that are being compared were generated from data collected on the same points. Consequently they had the same exact spatial origin and followed very similar interpolation procedures. On these points the data were already highly correlated and carried on this association throughout the interpolation process.

The Major pivot also recorded a significant negative correlation of –0.69 between the yield map and the crop moisture contents at harvest. These two values also have a common point origin and were subject to the same interpolation procedure, just as in the case of the ground survey measurements.

For pivot Major, good *r* values were reported between AWC, ground cover and LAI. These results are actually the most interesting as they derive from the comparison of totally independent data sources, with different source points and therefore also a different interpolation course. The *r* value between the AWC of the 20 cm to spoil layer and ground cover was –0.75, and the *r* between the total AWC and ground cover was –0.81. LAI reported an *r* of –0.55 with AWC (20 cm to spoil), and an *r* of –0.57 with the total AWC.

A positive and not a negative correlation between AWC and biomass proxies such as ground cover and LAI would have been expected. However, we are aware that the south most portion of Major actually has a plinthic layer around 110 cm depth. This layer can cause water logging on a large portion of the pivot.

The fact that 'Depth to spoil' and 'Depth to the vadoze zone layer' did not appear to affect the performance of the crop is most probably connected with the fact that it is an irrigated system and for the same reasons as for the AWC.

The crop did show a certain degree of variability both in the Vegetation Index and the Yield maps on both pivots. Other possible causes (fertility, texture, chemistry, management, etc.) should be explored, with this implying that the possible causes for spatial variability should also be transformed into maps and processed according to the procedure described above. Water logging, probably a major cause of variability, however, was not estimated as no spatialised water budget was calculated over the surface of the pivots.

7.1.2. Focal correlation analysis

The analysis of the "focal" correlation used the same statistical procedure as the previous overall analysis but with the additional objective of highlighting the local correlation between data layers and representing this statistical correspondence in the form of a map.

The difference between the two procedures lies in the fact that the correlation between the various data layers, instead of being investigated over the whole surface of the pivot, taking into account all the cells of the grid, was performed locally on a much-reduced focal area. This was done using a 'moving window' where the size of this 'window' is variable, as a function of the target resolution of the output map.

A user interface was implemented within ArcView© Spatial Analyst for this procedure, providing the option of running the analysis over any two selected maps (in GRID format) and for variable size windows, starting from a minimum of 3*3 pixels. Each window size is 'valid', as it represents a 'valid' correlation for the specific area analysed, however, a smaller window produces a 'salt and pepper' effect that makes it scarcely 'readable'.

Several options of sizes were consequently tested and the 20*20 pixel window was finally chosen for output, as it achieves the best visual effect over the pivots. This is illustrated in Figures 34 and 35.

The various comparison maps are illustrated in Appendix 2.

Some interesting local high correlation values did occur in the comparison between the yield values and the soil depth (to spoil/impermeable layer) map, thus suggesting a link between crop performance and the condition of the substratum, at least in specific areas of the field. This event was much more evident for the Tweefontein pivot which was actually the one on a rehabilitated site and thus prone to differential subsidence of spoil, while Major is not prone at all.

In addition to the graphical comparison, a set of statistics was extracted from the various maps. These statistics summarise the correlation values in ranges from –1 to + 1 in bins of 0.1 and, for each pair of maps being compared, the percentage of points within each correlation bin is reported (See Tables 11 and 12).

The results of the correlation experienced in the first analysis were confirmed in this second one. For Major, the correlations were significant for LAI and above ground dry matter, as well as for ground cover and depth of the vadoze zone, ground cover and LAI, and ground cover and above ground dry matter. For Tweefontein, the results were positive for LAI and ground cover as well as for above ground dry matter and ground cover.

The fact that positive correlation coefficients occurred locally suggests the presence of factors such as, for example, the presence of small depressions or local differences in soil texture.

Fig, 34: Correlation map between above ground matter production and LAI for Pivot Major with a moving window of 20*20 pixels

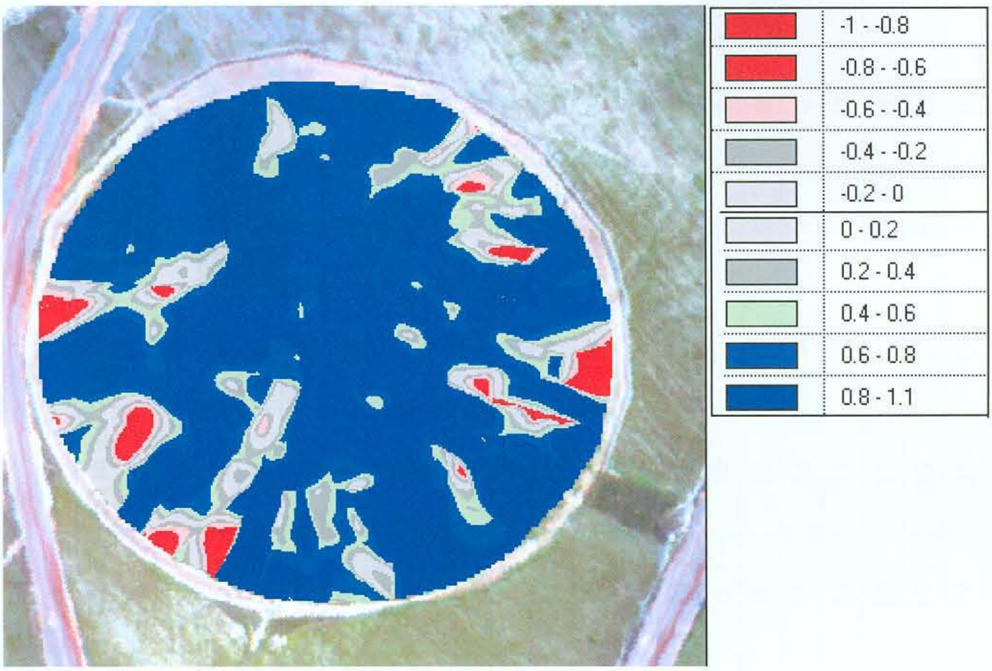


Fig. 35: Correlation map between above ground dry matter production and LAI for Pivot Tweefontein with a moving window of 20*20 pixels

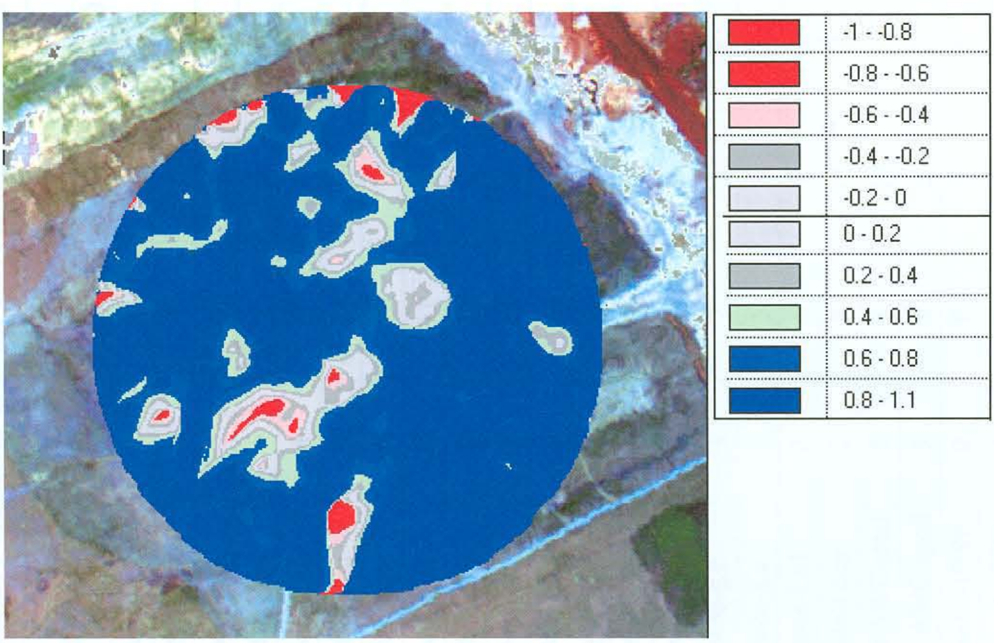


Table 11: Summary statistics of focal correlations for wheat, 1999 for Major and Tweefontein

GIS layers compared		r RANGE (%)											
		-1 to –0.8	-0.8 to –0.6	-0.6 to -0.4	-0.4 to -0.2	-0.2 to 0	0 to 0.2	0.2 to 0.4	0.4 to 0.6	0.6 to 0.8	0.8 to 1	0.6 to 1	-1 to -0.6
Maj-t.d.m.	Maj-LAI	2	1	1	2	3	3	4	6	11	66	77	3
Maj-g.c.	Maj-d.v.z.	1	9	13	14	13	14	13	12	9	2	11	11
Maj-g.c.	Maj-LAI	4	3	3	2	3	3	5	8	15	56	70	6
Maj-g.c.	Maj-t.d.m.	6	3	3	4	4	4	5	8	13	51	64	8
Maj-AWC-total	Maj-LAI	4	9	11	12	12	13	13	13	10	4	14	13
Maj-AWC-total	Maj-t.d.m.	18	15	10	8	8	8	8	8	8	10	19	32
Maj-AWC-total	Maj-g.c.	15	16	13	9	7	7	8	7	7	10	18	31
Maj -AWC-spoil	Maj-LAI	17	11	8	8	7	8	7	8	9	16	26	29
Maj -AWC-spoil	Maj-t.d.m.	20	12	9	8	8	8	7	7	7	13	20	32
Maj -AWC-spoil	Maj-g.c.	16	12	9	7	6	7	7	8	10	19	29	28
Maj-yld	Maj-g.c.	6	11	12	11	10	11	11	11	11	5	16	18
Maj-yld	Maj-AWC-20	2	9	10	10	11	12	11	13	15	8	23	11
Maj-VI-10/99	Maj-yld	0	0	1	5	15	25	28	19	5	1	6	0
Maj-VI-08/99	Maj-yld	0	0	2	6	12	20	26	21	12	1	13	0
Twee-LAI	Twee-g.c.	3	2	2	2	3	4	6	10	17	51	5	68
Twee-t.d.m.	Twee-g.c.	3	3	3	3	4	5	8	12	17	41	6	59
Twee-yld	Twee-LAI	2	6	9	10	12	14	13	14	14	5	9	19
Twee-yld	Twee-t.d.m.	2	8	10	11	11	13	13	13	13	5	11	18
Twee-yld	Twee-AWC-total	3	8	10	11	11	13	13	13	12	6	11	19
Twee-yld	Twee-AWC-spoil	3	8	9	11	12	12	12	13	13	6	11	18
Twee-yld	Twee-VI-10/99	0	0	2	4	8	16	23	31	15	1	0	16
Twee-yld	Twee-VI-08/99	0	0	2	5	9	18	23	28	14	1	0	15

7.1.3. Variability analysis

The analysis of variability within and between the pivots, and over two seasons, was performed through the comparison of the main statistics of the performance indicators, TVI and PC1, as well as that of the yield maps. The statistics were drawn from the maps of the TVI and the PC1 for the flights of the 1998 and 1999 seasons and from the yield map relative to the 1999 season

From the various maps, the main statistics were extracted for each growing season, and from the two flights. These are: minimum (Min), maximum (Max), Mean, Median, Mode and Standard Deviation (SD). These values have been compared to derive a percentage variation within the season (flight 1 and flight 2), across seasons and between the two pivots (Tweefontein over Major).

The TVI variation over Pivot Tweefontein, (See Table 12) for the summer crop (beans) and within the season, shows a marked decrease of minimum values, a moderate increase in maximum and median and a significant increase in the values of the standard deviation, considered as a measure of variability. This variation takes place from the vegetative development phase to the pod-filling phase.

The interpretation of this can be that, with the progression of the season, there are portions of the field where the crop failed, consequently lowering the minimum as well as increasing the variability, as measured by the SD.

This level of crop failures and the increase in variability under an irrigation regimen may signify that, all other things being equal (fertilizer, pesticides, etc), for Pivot Tweefontein, the problems rest with the soil, its profile, its fertility or its physical characteristics.

These same variations were not experienced for wheat (the winter crop), and this may be interpreted as a higher adaptability of the crop to the particular conditions of Tweefontein.

For the Pivot Major, a comparison was not possible within the summer season because only data for the flowering stage was available. For the winter season the values of minimum, maximum and mean of the vegetation index, show a marked decay from vegetative development to grain filling. The standard deviation, as a measure of within field variability, also decreases.

This could all be due to the particular subsoil set-up of Major where, the presence of a fairly shallow impermeable layer in the bottom (South) portion of the pivot affects the growth of maize in the later stages, thus affecting the overall statistics of crop performance.

Table 12: Analysis of the Vegetation Index variability: Statistics

Pivot		Tweefontein (rehabilitated) -				Major (virgin)			
Season		SUMMER		WINTER		SUMMER		WINTER	
Crop		Beans	Beans	Wheat	Wheat	NO DATA	Maize	Wheat	Wheat
Phenological Phase		Veg. Dev.[23]	Pod filling	Veg. Dev.	Maturity		Flowering	Veg. Dev.	Maturity
Average per survey	Min	14	4	27	28		5	15	5
	Max	247	255	249	250		255	255	213
	Mean	167	170	194	199		186	175	161
	Median	169	179	200	208		196	181	167
	Mode	167	186	209	218		209	195	175
	SD	23	40	29	26		39	32	24
Variation within the season (Flight 1 over flight 2)	Min	-71 %		+4 %		NO DATA		-67 %	
	Max	+3 %		+0.4 %				-16 %	
	Mean	+2 %		+3 %				-8 %	
	Median	+6 %		+4 %				-8 %	
	Mode	+11 %		+4 %				-10 %	
	SD	+77 %		-11 %				-26 %	
Seasonal Average	Min	9		27		5		10	
	Max	251		249		255		234	
	Mean	169		196		186		168	
	Median	174		204		196		174	
	Mode	176		213		209		185	
	SD	32		27		39		28	
Variation across seasons (Winter over summer)	Min	+206 %				+100 %			
	Max	-0.6 %				-8 %			
	Mean	+16 %				-9 %			
	Median	+17 %				-11 %			
	Mode	+21 %				-11 %			
	SD	-14 %				-29 %			

The overall comparison of the two pivots within the same season (see Tables 13), although referring to two very different crops, such as beans and maize, shows that Tweefontein has higher minimum values in summer and in winter, lower maximum and mean values in summer and higher in winter. Both in summer and winter Pivot Major shows a lower variability as indicated by the standard

[23] Veg. Dev: vegetative development

deviation. This is possibly a consistent demonstration of the higher uniformity over the virgin site, as compared to the rehabilitated one.

Table 13: Analysis of the Vegetation Index variability: Variations across the pivots

SEASON		SUMMER	WINTER
Variations in Major over Tweefontein	Min	+44 %	+64 %
	Max	-2 %	+6 %
	Mean	-10 %	+14 %
	Median	-13 %	+15 %
	Mode	-18 %	+13 %
	SD	-23 %	-2 %

The analysis of the PC1 (Table 14) provides results and variations that are inverted and highly enhanced, with respect to the TVI. The variation within season for summer crops, on Tweefontein and Major, shows the expected behaviour of an overall increase in values from vegetative development to grain filling. The opposite happens for the winter crop (wheat).

As for the variation from season to season and within the same pivot, (Table 15) Tweefontein shows an increase of all main statistics and variability from summer to winter crops, while Major has an almost completely opposite behaviour.

What this data show is that Major has an overall better performing canopy for summer and winter crops. The variability of the canopy is higher for summer crops (again due to the influence of impermeable layers on deep root systems) but lower for winter crops when there is more control of the water balance due to irrigation and absence of rainfall.

A consideration deriving from this analysis is that PC1 could be used alternatively to TVI in virtue of its enhancement of the variations.

Table 14: Analysis of the First Principal component: Statistics

	Pivot	Tweefontein (rehabilitated) -					Major (virgin)		
	Season	SUMMER		WINTER			SUMMER	WINTER	
	Crop	Beans	Beans	Wheat	Wheat		Maize	Wheat	Wheat
Phenological Phase		Veg. Dev.	Pod Filling	Veg. Dev.	Maturity	NO DATA	Flowering	Veg. Dev.	Maturity
Average per survey	Min	16	36	3	15		50	2	28
	Max	255	255	253	251		255	255	248
	Mean	51	106	61	52		100	64	57
	Median	46	100	53	42		91	57	50
	Mode	43	91	47	30		77	42	41
	SD	22	34	34	30		33	34	25
Variation within the season (Flight 1 over flight 2)	Min	+125 %		+400 %			NO DATA	+1300 %	
	Max	0 %		-0.8%				-3 %	
	Mean	+108 %		-13 %				-11 %	
	Median	+117 %		-21 %				-12 %	
	Mode	+112 %		-36 %				-2 %	
	SD	+60 %		-13 %				-24 %	
Seasonal Average	Min	26		9			50	15	
	Max	255		252			255	251	
	Mean	78		56			100	60	
	Median	73		47			91	53	
	Mode	67		38			77	41	
	SD	28		32			33	29	
Variation within the season (Flight 1 over flight 2)	Min	+125 %					+400 %		
	Max	0 %					-0.8%		
	Mean	+108 %					-13 %		
	Median	+118 %					-21 %		
	Mode	+112 %					-36 %		
	SD	+60 %					-13 %		

Table 15: Analysis of the PC1: Variations across the pivots

SEASON		SUMMER	WINTER
Variations in Major over Tweefontein	Min	92 %	66 %
	Max	0 %	-0.2 %
	Mean	27 %	7 %
	Median	25 %	13 %
	Mode	15 %	8 %
	SD	19 %	-7 %

The comparison between the yield maps (See Table 16), shows that there is a common maximum value between the two pivots (11 t ha^{-1}) but a higher mean yield on Major (24 %).

The variability, as measured by the standard deviation, is also higher for Major.

These results confirm what resulted from the analysis of the TVI and PC1, and that is that wheat, though producing less over Pivot Tweefontein, has a higher homogeneity. This again could be due to the plinthic layer in the lower portion of Major that affected the outcome of the crop in the later stages of development causing water logging.

Table 16: Analysis of Yield: Statistics

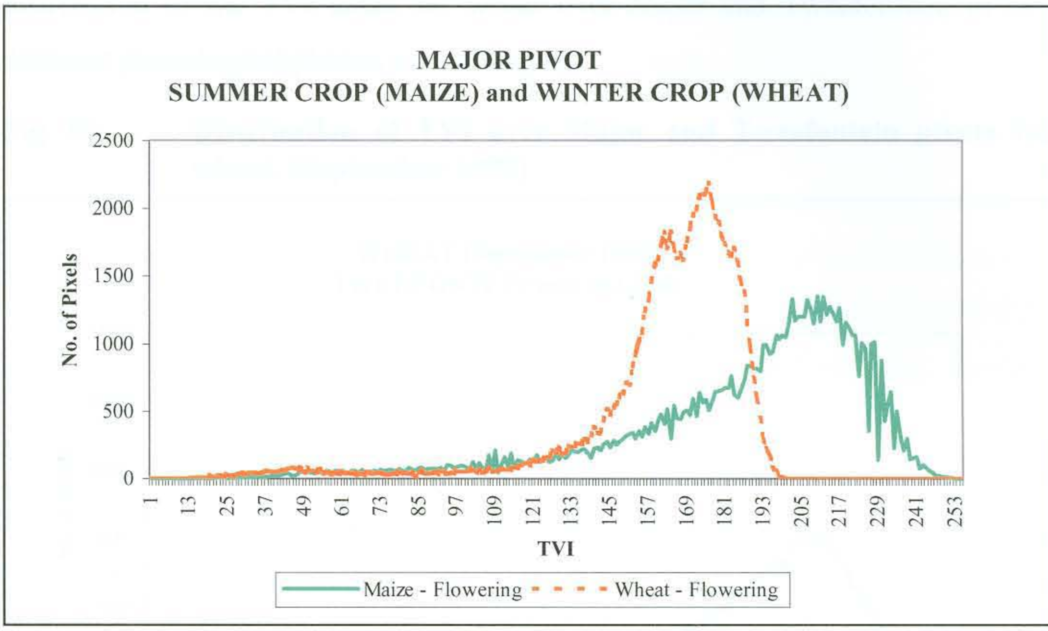
Pivot		Tweefontein (rehabilitated)	Major (virgin)
Season		WINTER	WINTER
Crop		Wheat (t/ha)	Wheat (t/ha)
Average over the Pivot	Min	0	0.0
	Max	11	11.0
	Mean	1.5	1.8
	Median	1	1.0
	Mode	0	0.0
	SD	1.4	2.0
Variations in Major over Tweefontein	Min	0%	
	Max	0%	
	Mean	+24%	
	Median	0%	
	Mode	0%	
	SD	+ 41%	

7.1.4. Analysis of the indicator's distributions

In addition to the variability analysis and the statistical comparison of indicators, a set of diagrams were produced to highlight differences in behaviour between the rehabilitated site (Tweefontein) and the virgin pivot (Major) as well as the difference of behaviour of the summer and winter crops over the same pivot. These diagrams are relative to the distribution of the pixel values over the pivots (See Figures 36 to 43). The first diagram (Fig. 36) compares the level and distribution of the pixel values for maize (second flight, flowering phase, February 2, 1999) and wheat (fourth flight, also flowering phase, October 1999) over Pivot Major. Both the distributions show a shift towards the high values of the TVI as they tend towards the maximum values of the indicator in the phenological cycle, as well as the maximum for green biomass for both crops.

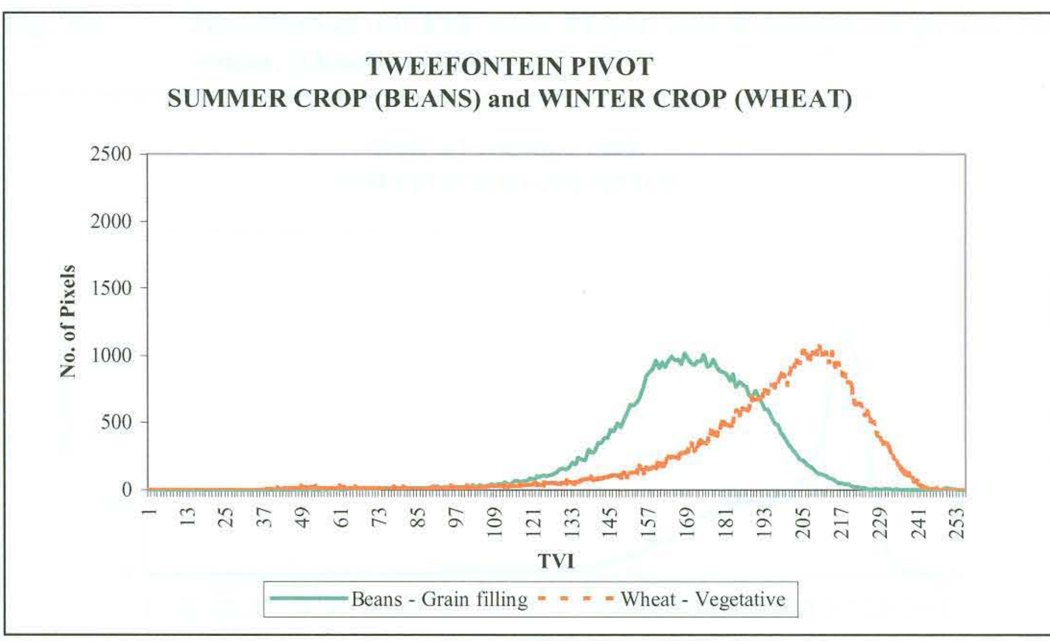
Maize has higher values due to the higher level of biomass with respect to wheat. The crop, however, is also less homogeneous as can be deduced by the wider spread of the curve, this means a higher variability of physiological condition across the field. The curve for wheat peaks at a lower level of TVI but is also less spread out. An interpretation of this is that wheat seems to be better adapted (more homogeneous) to the cultivation conditions.

Fig. 36: Major pivot: Distribution of TVI for maize and wheat.



The same analysis has been conducted for the Tweefontein pivot (Fig. 37). The comparison here is between beans and wheat at the same time of survey.

Fig. 37: Tweefontein pivot: Distribution of TVI for beans and wheat.



Wheat shows a higher overall maximum of the indicator (TVI), while the high spread of the index for both crops is roughly comparable. The reason for such a distribution could, in this case, be attributed to the characteristics of the pivots. What is shown in the two following diagrams (Figures 38 and 39) is the distribution of the TVI index for wheat over Major and Tweefontein, in two different phenological phases, a month apart.

Fig. 38: Distribution of TVI over Major and Tweefontein pivots for wheat. (September 1999)

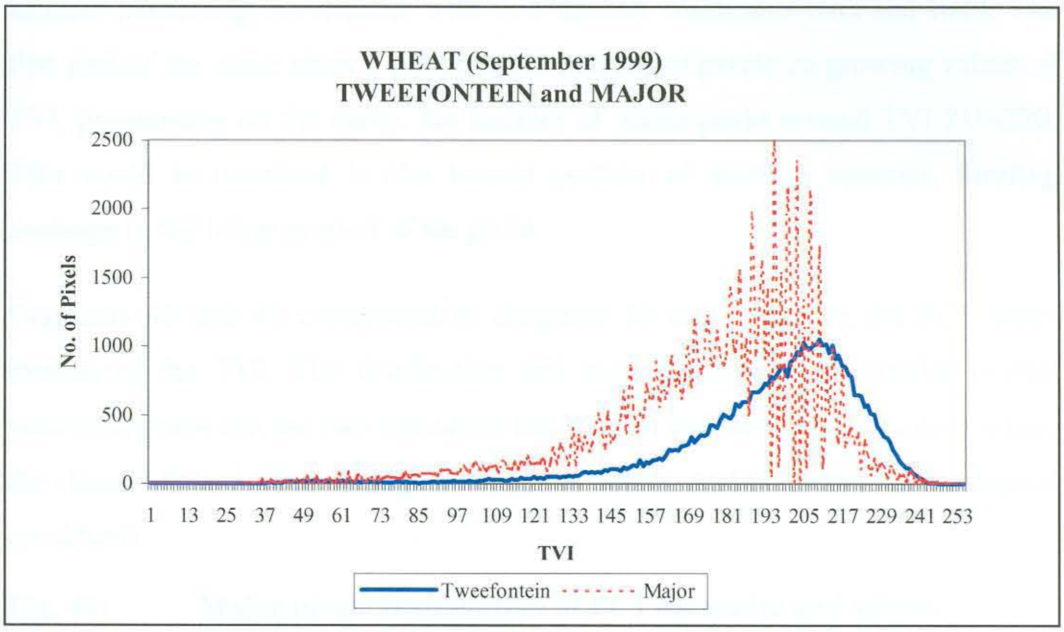
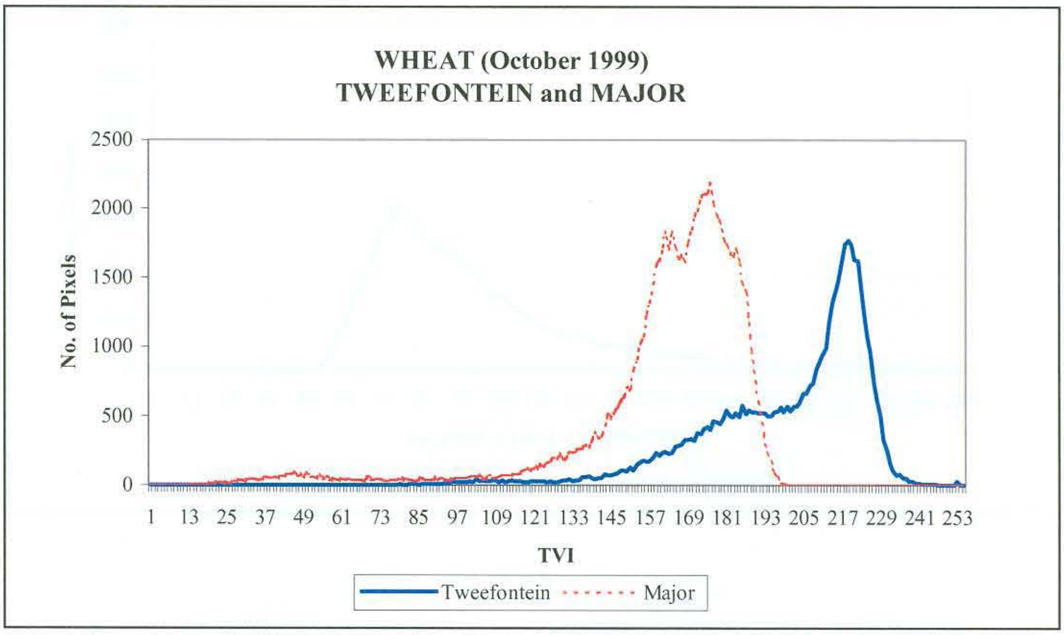


Fig. 39: Distribution of TVI over Major and Tweefontein pivots for wheat. (October 1999)



As was clear from Figure 37, Tweefontein seems to have higher values of the TVI index while the spread is roughly comparable. The variability of the index, however, was much higher over Major in the September survey and then it stabilized in October. There are not enough elements of analysis to explain such an event, it could however be attributed to a very recent irrigation event which resulted in peaks of high IR absorption to the wet crop.

The shape of the curve for Major in the October flight (See Fig. 39) shows another interesting occurrence, with two distinct conditions over the field. The first part of the curve show a rather stable number of pixels on growing values of TVI, progressing on the curve, the number of pixels peaks around TVI 210-220. This could be ascribed to the known portion of plinthic material, limiting drainage in the lower portion of the pivot.

Diagrams 40 and 41 correspond to diagrams 36 and 37, using the PC1 index instead of the TVI. The distribution and overall trends show similar overall behaviours between the two indicators but with an inverted scale of values where the lower PC1 indicates higher biomass levels and/or better physiological conditions.

Fig. 40: Major pivot: Distribution of PC1 for maize and wheat.

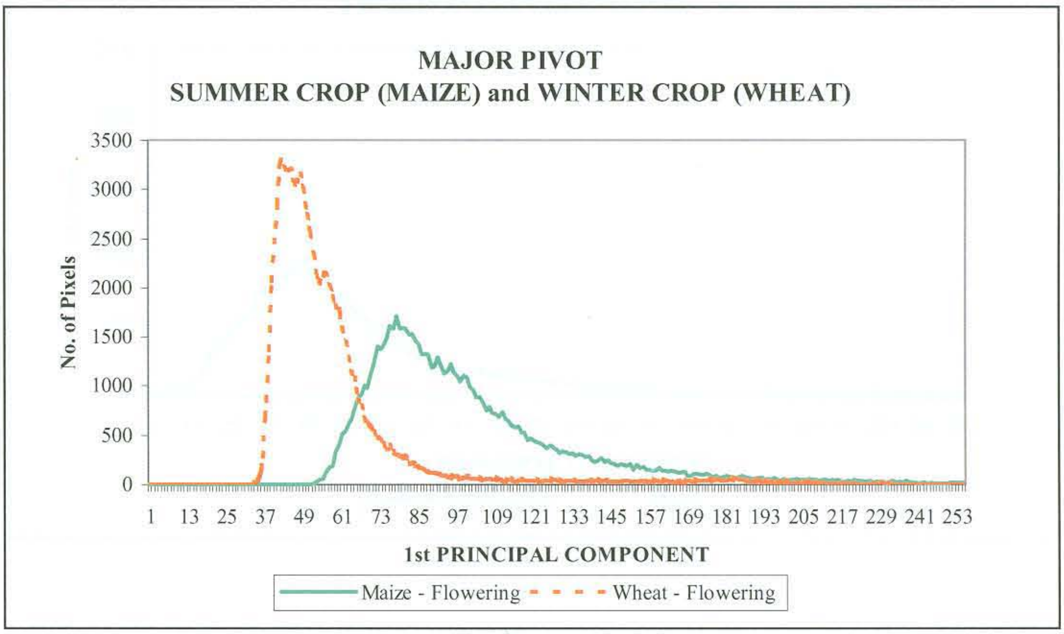
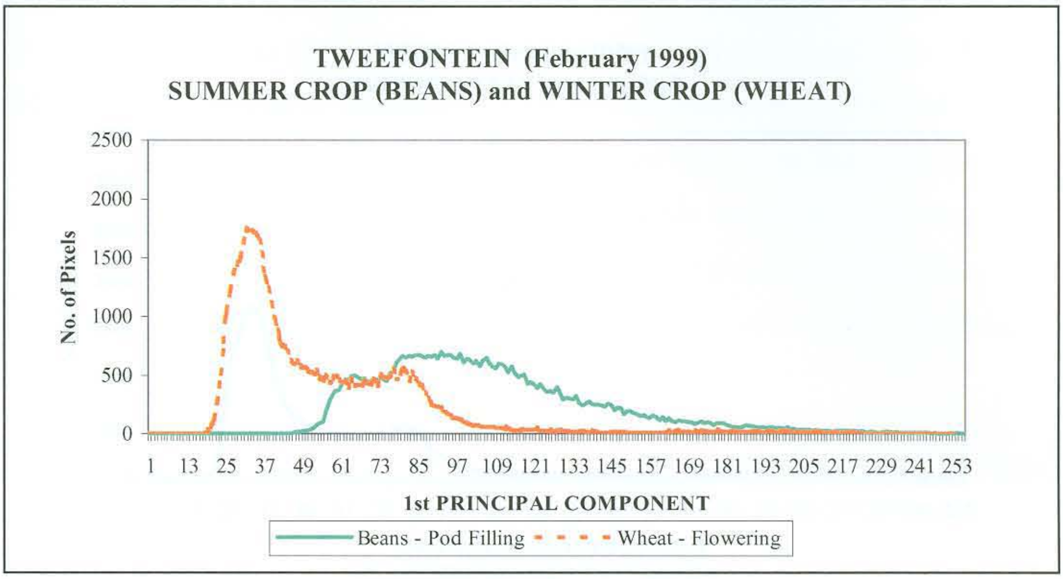


Fig. 41: Tweefontein pivot: Distribution of PC1 for the beans and wheat



The same trend is apparent in Fig. 42 and 43, which are comparable to Fig. 38 and 39. A slight difference appears for the high variability of wheat over Tweefontein in September; the PC1 reflects it as an overall lower value.

Fig. 42: Distribution of PC1 over Major and Tweefontein pivots for wheat. (September 1999)

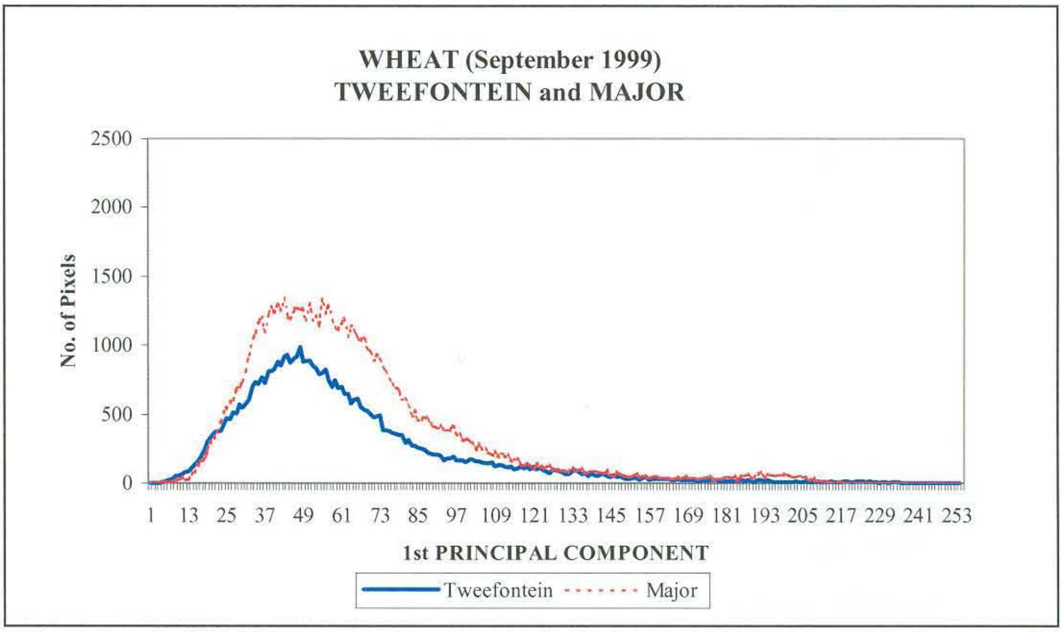


Fig. 43: Distribution of PC1 over Major and Tweefontein pivots for wheat. (October 1999)