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FORECASTING GROWTH CHARACTERISTICS AND YIELD OF COTTON FROM SPECTRAL REFLECTANCE DATA

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ABSTRACT

The present investigation was undertaken during 2001 and 2002 growing seasons to study the effect of two sowing dates on spectral reflectance during growth stages of cotton plants. The spectral reflectance was measured by radiometer instrument (Spectron SE 590) in four wavelength bands (TM1 = 0.45 to 0.52 µm, TM2 = 0.52 to 0.60 µm, TM3 = 0.63 to 0.69 µm and TM4 = 0.76 to 0.90 µm) and derived the Normalized Difference Vegetation Index (NDVI) from these band values as follows: NDVI = (TM4 - TM3) / (TM4 + TM3). The growth characteristics, i.e. chlorophyll concentration of leaves, fresh weight of biomass and leaf area index (LAI) were measured. TM1, TM2 and TM3 values showed a slight decrease, on the other hand TM4 and NDVI values increased considerably, with magnitude of the growth stages till S4 and S5 stages (90 – 106 days from planting). TM1, TM2 and TM3 of first sowing date were slightly higher than those of second sowing date. NDVI value at second sowing date was significantly higher than that in first date. NDVI may be considered as one of the most important spectral reflectance parameters. Chlorophyll concentration, biomass fresh weight and LAI were the most important characteristics that related with spectral reflectance of the plant canopy. The equation that estimated the LAI (LAI > 3.5) of cotton plants depending on NDVI values are: $LAI = 2.0294e^{1.7642NDVI}$. The equations that forecast the biological yield (B_y) and seed cotton yield (C_y) per Kg/faddan at harvest depending on NDVI values at S5 (106 days from planting) and S8 (156 days from planting), respectively are: $B_y = 3890.9\ NDVI_{S5} + 8220.77$ and $C_y = -453.08\ NDVI_{S8} + 1095$.

Key words: Remote Sensing, Thematic Mapper (TM), Normalized Difference Vegetation Index (NDVI), Cotton, Growth, Yield Forecasting

INTRODUCTION

Research and applied work undertaken in Egypt have shown that it is possible to identify and measure the area of the major crop species using remotely observed multispectral measurements, **Hamdi *et al* (1991)**. Nevertheless, the use of such technology was used to forcast the yield of winter crop as wheat,

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Abd **El-Gawad *et al* (2000)** and faba bean. **Zaki *et al* (2001)**.

Chlorophyll of green leaves absorbed 80 to 90 percent of light in the blue (about 0.45 µm) or red part (about 0.68 µm) of spectrum, **Kleshnin and Shulgin, (1959)**. There was an inversely proportional to the between 0.63 –0.69 µm radiance and amount of chlorophyll present in the plant canopy, and thus it is sensitive to green of photosynthetically active vegetation present, **Tucker (1979)**. The red radiance exhibits a non-linear inverse relationship between integrated spectral radiance and green biomass, **Tucker** (1979), while the near-infrared component exhibits a non-linear direct relationship, **Tucker, (1979)** and **Li *et al*** (2001 **a)**. The wavelength regions generally used for spectral biomass estimations are the red (0.63-0.70 µm) and near infrared (0.75-1.00 µm) wavelength, **Tucker** (1979). On the other hand, **Sellers (1985)** found that the ratio of near-infrared and visible reflectance is a poor predictor of leaf area index and biomass. **Colwell** (1983) and **Bausch and Duke, (1996)** declared that the near- infrared wavelength region is the best spectral band in which to distinguish plants and plant conditions. Reflectance in the 0,70 to 1,35 µm wavelength interval is caused by pigment and water absorption. Reflectance changes are associated primarily with changes in the size and shape of cells and intercellular spaces and with leaf structure. **Neale and Bausch (1983)** found that agronomic variable such as leaf area index and biomass were correlated with spectral information in thematic mapper bands TM3 and TM4.

Maas (1997) mentioned that the canopy reflectance of cotton in the near-infrared was independent of canopy density, while canopy reflectance at red wavelengths was only slightly affected by canopy density. Reflectance of cotton fields is affected more by percent ground cover than by plant canopy density. Reflectance appeared to involve primarily the top layer of leaves in the cotton canopy.

NDVI was positively correlated with soil available nitrogen **Buscaglia *et al*** **(1999) and Li *et al* (2001 a),** plant height, **Buscaglia *et al* (1999),** boll counts during midboll set development stage which converted to lint yield, **Wiegand *et al* (1994)** dry matter production and leaf area index **(Perumal *et al* 1999)** and seed cotton yield **Perumal *et al*** (1999) and **Buscaglia *et al* (1999)**. Spectral reflectance at 810 and 1665 nm was correlated with leaf relative water content and total water potential, **Bowman, (1989)**. Cotton lint yield was significantly correlated with red and near-infrared (NIR) reflectance and NDVI **Perumal *et al* (1999), Buscaglia *et al*** (1999) and **Li *et al* (2001 b)**, and temporal patterns of cotton reflectance were related to plant growth at different stages **Li *et al* (2001 b)**.

Growth-related crop factors were determined by using Landsat satellite imagery and predicted of lint yield by using commercially available multispectral satellite images, **Maas, (1996)**.

Li *et al* (2001 a) declared that there was a negative correlation of blue, green, red, and MIR reflectance with lint yield. Red and MIR reflectance was also negatively correlated with plant water content (PWC). Conversely, the NIR reflectance, NDVI. and NIR/red ratio were positively correlated with these parameters. The reflectance in the NIR band (797-829 nm) was exponentially related to fresh biomass of plant (PFB). The reflected NIR energy increased more quickly with an increase of PFB at early vegetation than late in the season. The NIR reflectance was near 50% of the total reflected radiance when the PFB ranged between 2500 and 2800 g m^{-2}. Differences in NIR reflectance can be attributed to differences in canopy density and PFB.

This work was raised to elucidate the spectral response of cotton at different growth stages under two sowing dates effect. Due consideration was given to develop an equation to describe the relations of spectral reflectance with cotton seed yield and biological yield.

MATERIAL AND METHODS

Two field trials were undertaken during 2001 in the Experimental Farm in Shalakan and 2002 in the campus area of the Faculty of Agriculture, Ain Shams University at Kalubia Governorate. Cotton [*Gossypium barbadense* (L.) cv. Giza 85] plants were grown at 20 cm on one ridge 60 cm width. Physical and chemical properties of the soils are presented in Table (1).

The two sowing dates were arranged in a complete randomized block design in six replications. The size of the plot was 19.8 m^2 consisting 6 rows 60 cm apart and 5.5m length. First sowing date was 21 March and the second was 21 April in both growing seasons.

The canopy characteristics and spectral reflectance data were estimated at 42 (S1), 58 (S2), 74 (S3), 90 (S4), 106 (S5), 122 (S6), 139 (S7), 156 (S8) and 173 (S9) days from planting in both growing seasons and also at 190 (S10) only in the first growing season. Six samples of four plants were taken at every sampling date. The characteristics of growth were recorded on a per plant basis and later calculated per unit area 1200cm^2 to equal the Target Area Unite (1200cm^2) by scanner of spectrometer instrument (Spectron SE590). These characteristics were leaves area/plant, chlorophyll concentration of leaves by SPAD unit, and leaf area index (LAI). All cultural practices as recommended were followed during growing seasons.

The spectral reflectance was measured using spectrometer instrument (Spectron SE590), the spectrometer equipped by scanner having 386 nm-1113 nm spectral range and 256 channels with band width of 2.8nm as well. Two field measurements were acquired for certain treatment. The third was for white lambertain-panel to normalize the former measurements and increase their accuracy (**Philipson *et al* 1989).** The scanner of the instrument was fixed using a wooden stand to keep a vertical distance between it and the plant at 1.5m. This vertical distance of scanner lead to measure a Target Area Unit (TAU) of 1200 cm^2.

Data were recorded into spectron memory using magnetic tape. Then the individual spectron data files (spectron measurements) were transferred from memory of Spectron Data Logger to PC via a RS2S2 cable. The Individual spectron files were compiled into single spreadsheet in Excel using a Macro (Maccomp.xls) to automate the process included in the commercial spreadsheet packages, Windows and Excel installed on PCIPC at Soil, Water and Environment Research Institute, A R C.

Bi-Directional Reflectance Factor (BDRF) was calculated, normalized and compiled for each replicate, in Excel using Macro where:

Table 1. Mechanical and Chemical analysis of experiment soil at two experimental sites, Khalubia Governorate

Components	Mechanical analysis				Chemical analysis						
	Sand (%)	Silt (%)	Clay (%)	Soil texture	pH	EC (mmohs /cm/25^0)	Organic matter (%)	Calcium carbonate %	Available (ppm) N	P	K
Shalakan	25.9	22.4	51.7	Clay	7.97	1.13	1.02	1.67	80.9	8.10	202
Shobra El-Khema	24.1	27.3	48.6	Clay	7.81	2.81	0.62	1.88	77.9	7.80	187

N.B. mechanical analysis was conducted as recommended by **Richards (1954)**. The chemical analysis was carried out according to methods of **Jackson (1967)**. Organic matter content was determined according to **Nelson and Sommers (1982)**. The electrical conductivity was cared out according to **Rhoades (1982)** and pH value was determined by **Mclean (1982)**.

BDRF = [cotton Radiance / integration time]/ [Panel Radiance / integration time].

Spectron BDRFs are processed to yield TM equivalent values for TM bands 1-4, (TM1 = 0.45 to 0.52 µm, TM2 = 0.52 to 0.60 µm, TM3 = 0.63 to 0.69 µm and TM4 = 0.76 to 0.90 µm). As mentioned by **Rouse *et al* (1973)** normalized difference vegetation index (NDVI) is defined by (IR-R / IR+R). Where: R = red spectral reflectance, IR = Infrared spectral reflectance. So, NDVI = (TM4 - TM3) / (TM4 + TM3) by Thematic Mapper in LANDSAT.

The analysis of variance, simple correlation and regression analyses were computed between different growth stages, canopy characteristics and spectral reflectance measurements. Correlation and regression were computed from data in first plus second growing seasons in nine stages; where the reading of the second stage in the first growing season was confined with reading of third stage, then the first growing season become in nine stages as it in the second growing season. Regression models to LAI estimating and yield forecasting were suggested depending on NDVI values.

RESULTS AND DISCUSSION

1- Spectral Reflectance as Affected by Cotton Properties

1-1- Effect of Different Growth Stages on Spectral Reflectance

The values of TMs and NDVI at different growth stages are elucidated in Table (2). The general trend of TM1 values showed a slight decrease with magnitude of the growth stages up to maximum of vegetative growth and then increased up to harvest stage. TM1 values at the early and late growing season were the highest and nonsignificant between them.

Results obtained in TM1 were similar to TM2 and TM3 over the growing stages. Data in Table (2) show an arrangement of spectral measurements as follows: TM2>TM3>TM1 at each growth stage.

The inverse relationship between plant age promotion and the reflectance in TM1, TM2 and TM3 could be understood on the light of increasing of land cover by cotton plant canopy till to maximum vegetative growth i.e. S4 and S5 (expressed as LAI and/or biomass) and also increase the absorptance 80 to 90% of light by chlorophyll of green leaves as reported by **Kleshnin & Shulgin (1959) and Tucker (1979).**

From previous discussions, one can detect that cotton stages can be significantly distinguished by TM1, TM2 or TM3 values.

TM4 values increased considerably with age up to top of vegetative growth and then decreased due to the reflectance of wavelength 680 nm correlated with water content, size and shape of cells and intercellular spaces **(Colwell, (1983)** and **Bausch and Duke, (1996)).** Also, data reveal that TM4 values differ significantly overall growth stages of plant. On the other hand, values of TM1, TM2 and TM3 at early and late stages did not differ significantly.

However the reflectance values of TM1, TM2, TM3 and TM4 in the early stages are influence by soil properties (Table, 1) more than plant canopy due to small of land cover in the reflectance scene.

Table 2. Spectral reflectance of cotton plants during different growth stages

STAGE	TM1	TM2	TM3	TM4	NDVI	TM1	TM2	TM3	TM4	NDVI
(days)	2001 season					2002 season				
S1 (42 d)	0.0448	0.0828	0.0636	0.3898	0.7115	0.0576	0.0978	0.0814	0.4408	0.6856
S2 (58 d)	0.0388	0.0720	0.0545	0.4176	0.7636	0.0406	0.0740	0.0557	0.5172	0.8094
S3 (74 d)	0.0335	0.0641	0.0472	0.4784	0.8152	0.0313	0.0617	0.0456	0.5334	0.8444
S4 (90 d)	0.0326	0.0598	0.0460	0.4752	0.8213	0.0473	0.0830	0.0653	0.5406	0.7886
S5 (106 d)	0.0241	0.0437	0.0338	0.4265	0.8519	0.0436	0.0771	0.0592	0.4619	0.7714
S6 (122 d)	0.0345	0.0625	0.0505	0.4893	0.8158	0.0416	0.0706	0.0603	0.3909	0.7364
S7 (139 d)	0.0371	0.0659	0.0535	0.4617	0.7936	0.0585	0.0860	0.0931	0.2880	0.5406
S8 (156 d)	0.0397	0.0676	0.0600	0.3917	0.7366	0.0611	0.0880	0.0973	0.3220	0.5386
S9 (173 d)	0.0512	0.0790	0.0822	0.3219	0.5901	0.0627	0.0834	0.0961	0.2761	0.4758
S10 (190 d)	0.0445	0.0662	0.0739	0.2632	0.5490					
LSD 5%	0.0065	0.0118	0.0105	0.0719	0.0369	0.0112	0.0157	0.0160	0.0551	0.0471

Values of NDVI increased considerably with aged plants up to a peak of vegetation growth, at S5 in the first and at S3 and S4 in the second growing season, and then declined to reach lowest value at the late stages of plant life. These could be explained as a composite reflectance was high in the red band (TM3) and low in NIR (TM4) which due to less plant ground cover at early and at late growth stages (**Li *et al* (2001 a)**), also to negative correlation of red reflectance with chlorophyll and positive correlation with plant water content and cell structure at maximum vegetative growth (**Tucker, (1979), Colwell, (1983)** and **Li *et al*** (2001 a)).

Nevertheless NDVI values can be distinguished significantly between cotton stages i.e. S5, S8 and S10 in the first growing season, and between S3, S7 and S9 in the second growing season. Similar results were found by **Quarmby *et al* (1993); Wiegand *et al* (1994); Buscaglia *et al* (1999) and Li *et al* (2001b)**.

The aforementioned results, generally, reveal that spectral reflectance characteristics vary considerably during different cotton growth stages and reach to critical values after 106 days from planting coinciding with S5 of cotton plant.

Accordingly, it may be suggested that reliable spectral reading to observe the vegetative growth must take place between (90-106) days from cotton planting.

1-2- Effect of Sowing Date on Spectral Reflectance

Data of spectral reflectance characteristics as affected by planting date are shown in Table (3). The results revealed that the spectral reflectance of first sowing date (D1) were slightly higher than those of second sowing date (D2) for TM1, TM2 and TM3. Such differences were significant in the second growing season. This may be due to that vegetative growth characteristics in the second sowing date surpassed those in the first one, also due to negative relationship between visible light and magnitude of the vegetative characteristics e.g. chlorophyll concentration.

TM4 in the first planting date was significantly lower to those in the second one in the first growing season, but the opposite trend was shown in the second growing season. This may be due to magnitude of growth characteristics in the first growing season.

NDVI values at second sowing date were significantly higher than those in first growing season. This may be due to the greater vegetative growth in the second than in the first sowing date, also to positive correlation between NDVI and vegetative characteristics (e.g. biomass, LAI and water content).

1-3- Effect of Sowing Date on Spectral Reflectance at Different Growth Stages

Data obtained on spectral reflectance at each growth stage in both sowing dates are shown in Table (4). The trend of spectral reflectance of TMs and NDVI in the second sowing date seems as they shifted from those in the first sowing date by temporal interval equal the period that between the two sowing dates with a little change.

TM1, TM2 and TM3 values near the end of growing season in the first sowing date were higher than those in the second sowing date, due mainly to longer reproductive phase with higher yield than

Table 3. Effect of sowing date on spectral reflectance of cotton plants

Sowing date	TM1	TM2	TM3	TM4	NDVI
(Date)			2001 season		
D1 (21-3)	0.0389	0.0677	0.0587	0.3827	0.7226
D2 (21-4)	0.0372	0.0650	0.0544	0.4403	0.7671
t test 5%	NS	NS	NS	0.0321	0.0165
			2002 season		
D1 (21-3)	0.0550	0.0896	0.0850	0.4325	0.6486
D2 (21-4)	0.0437	0.0708	0.0604	0.4055	0.7271
t test 5%	0.0053	0.0074	0.0076	0.0260	0.0222

those in the second sowing date. Higher yield of cotton lead to a view more reflectance in the visible light due to white color lint. The second sowing date produced lower yield than the first sowing date and more vegetative growth as reported in the agronomic studies (data were not included). This resulted to absorbing the visible light by photosynthesis. also decreased the reflectance at the same bands by decrease the lint cotton.

The reflectance of absorption spectral (TM1. TM2 and TM3) by green leaves decreased to minimum limits simultaneous with increase the vegetative growth, hence the red spectral interval corresponds to region of maximum chlorophyll absorption, **Tucker (1979)**.

TM1, TM2, and TM3 values at the early stages were higher due to the most reflectance in the scene done by soil and little vegetative growth of plant canopy. Also, TM1, TM2, and TM3 values near maturity stage reached maximum limits. However, maximum values of TM4 were realized at S6 in the second sowing date (D2) and at S3 in the first sowing date (D1), which coincided with peak of vegetative growth in the first and the second growing season, respectively. On the other hand, minimum values of TM4 were exhibit at S10 in the first sowing date and at S7 in the second sowing date, coinciding with maturity stage, in the first and the second growing seasons, respectively. TM4 values decrease significantly compared with those in the early stages. These results indicate that one could distinguish significantly between groups of stages and others i.e. between values in the vegetative growth and other in the maturity stage. NDVI values at initial stage in the first and the second sowing date were similar, whereas those at maturity stage exhibited lower values. However, in the second sowing date they were higher than those in the first sowing date. (Table, 4).

The aforementioned results reveal the superiority of NDVI and TM4 values at each stage in the second sowing date. This may be due to dominance the vegetative growth in the second sowing date than those in the first sowing date. and also the fact of NDVI and TM4 are correlated with all parts of plant, not only

Table 4. Effect of sowing date on spectral reflectance of cotton plants during growth stages

Sowing date (Date)	Stage (days)	TM1	TM2	TM3	TM4	NDVI	TM1	TM2	TM3	TM4	NDVI
		2001 season					2002 season				
D1 (21-3)	S1 (42 d)	0.0448	0.0828	0.0636	0.3898	0.7115	0.0639	0.1046	0.0924	0.4385	0.6480
	S2 (58 d)	0.0406	0.0762	0.0581	0.4074	0.7454	0.0438	0.0794	0.0612	0.5218	0.7929
	S3 (74 d)	0.0365	0.0696	0.0527	0.4250	0.7793	0.0358	0.0721	0.0547	0.5905	0.8299
	S4 (90 d)	0.0370	0.0672	0.0533	0.4406	0.7849	0.0576	0.0957	0.0808	0.5487	0.7441
	S5 (106 d)	0.0222	0.0414	0.0319	0.3651	0.8394	0.0418	0.0808	0.0589	0.4598	0.7703
	S6 (122 d)	0.0274	0.0497	0.0403	0.4074	0.8213	0.0465	0.0815	0.0699	0.4412	0.7318
	S7 (139 d)	0.0325	0.0579	0.0486	0.4496	0.8031	0.0799	0.1138	0.1324	0.3251	0.4232
	S8 (156 d)	0.0445	0.0756	0.0685	0.3944	0.7023	0.0642	0.0944	0.1119	0.3129	0.4750
	S9 (173 d)	0.0561	0.0869	0.0913	0.3282	0.5605	0.0615	0.0839	0.1023	0.2540	0.4223
	S10 (190 d)	0.0479	0.0690	0.0787	0.2199	0.4780					
D2 (21-4)	S1 (42 d)	0.0448	0.0828	0.0636	0.3898	0.7115	0.0512	0.0911	0.0703	0.4432	0.7232
	S2 (58 d)	0.0370	0.0677	0.0509	0.4278	0.7819	0.0373	0.0685	0.0502	0.5126	0.8259
	S3 (74 d)	0.0306	0.0585	0.0418	0.5318	0.8511	0.0269	0.0513	0.0364	0.4764	0.8588
	S4 (90 d)	0.0283	0.0523	0.0387	0.5098	0.8577	0.0370	0.0703	0.0497	0.5325	0.8330
	S5 (106 d)	0.0260	0.0461	0.0357	0.4878	0.8642	0.0454	0.0733	0.0594	0.4641	0.7725
	S6 (122 d)	0.0416	0.0753	0.0608	0.5713	0.8103	0.0367	0.0597	0.0508	0.3405	0.7411
	S7 (139 d)	0.0417	0.0738	0.0585	0.4739	0.7841	0.0372	0.0582	0.0539	0.2508	0.6579
	S8 (156 d)	0.0348	0.0595	0.0514	0.3890	0.7709	0.0579	0.0815	0.0826	0.3310	0.6022
	S9 (173 d)	0.0463	0.0711	0.0730	0.3157	0.6197	0.0638	0.0830	0.0900	0.2982	0.5293
	S10 (190 d)	0.0411	0.0633	0.0692	0.3065	0.6201					
LSD 5%		0.0093	0.0167	0.0149	0.1019	0.0523	0.0158	0.0222	0.0227	0.0779	0.0666

with the top layer of leaves as those in the visible light, and due to properties of TM4 in penetration the top layer of leaves and correlated with water content. Similar trend were reported by **Maas (1997)**. Generally, it can be differentiated between major specific growth stages and its statues depending on spectral reflectance values obtained on cotton plants.

2- Relationships between Spectral Reflectance and Growth Characteristics and Yield of Cotton

2-1- Relationships of Spectral Reflectance with Growth Stages

The correlation between spectral reflectance and growth characteristics at different growth stages are made to recognize the stage(s) that show high correlations between spectral reflectance and growth characteristics. The data were presented in Table (5) and Fig (1).

Generally, the results reveal that NDVI may be considered as one of the most important spectral reflectance parameters because it is correlated with most growth characteristics more than those with other TMs. Similar results had been reported by **Buscaglia *et al* (1999) Perumal *et al* (1999)** and **Li *et al* (2001a,b)**. In the same concept, it was found that the characteristics that achieved the most significantly correlations with spectral reflectance per TAU are leaves area, leaves fresh weight, chlorophyll content, biomass fresh weight, leaves water content, LAI and SLA. These results agree with findings of **Tucker, (1979), Colwell, (1983); Bowman (1989)** and **Li *et al* (2001a)**.

The aforementioned data in Fig (1) and Table (5) reveal that the most significant correlations with most important growth characteristics were achieved from S4 to S8. In more details, the NDVI was significantly correlated with growth characteristics at S5 till S9 and the high values from correlations recorded at S7. The reflected spectra (TM4) showed good correlation from S4 till S7, but at S8 correlations did not reach significant level. While the absorbed spectra (TM1, TM2 and TM3) were highly correlated from S4 up S8.

Fig (1) and Table (4) declare that the critical values in TM bands (i.e. the lower reflectance in absorbed spectra TM1,2,3 and the higher reflectance in reflected spectra (TM4)) which reflect the activated of photosynthesis and vigor of organ in plants had realized in cotton from S4 to S7, (90 – 139 days from planting) and the differences between values at these stages did not reach the significant level.

2-2- Relationships of Spectral Reflectance with Sowing Date

Table (6) shows the correlations between spectral reflectance and growth characteristics at each sowing date.

Generally, data shown in Table (6) detect that NDVI in both sowing dates in both growing seasons was most stable than other spectral reflectance parameters in correlation study between spectral reflectance parameters and growth characteristics. Also, data of the same Table reveal that the correlation values between spectral reflectance and growth characteristics in the second sowing date followed the same trend as those in the first sowing date, but the NDVI correlation with the leaves characteristics (LAI) were lower than those in the first sowing date and didn't reach significant level when

Table 5. Correlation between spectral reflectance and certain growth characteristics of cotton plants per TAU at different growth stages

Growth characteristics	TM1	TM2	TM3	TM4	NDVI
			S1		
Chlorophyll content (SPAD)	0.269	0.155	0.172	0.327	0.359
Biomass fresh weight (g)	0.074	0.083	-0.005	0.217	0.231
Leaf area index	0.265	0.215	0.207	0.254	0.063
			S2		
Chlorophyll content (SPAD)	-0.101	-0.160	-0.184	0.304	0.591 **
Biomass fresh weight (g)	-0.140	-0.173	-0.223	0.201	0.523 **
Leaf area index	-0.056	-0.096	-0.136	0.358	0.587 **
			S3		
Chlorophyll content (SPAD)	-0.452 *	-0.432 *	-0.430 *	0.404	0.791 **
Biomass fresh weight (g)	-0.260	-0.324	-0.332	0.507 *	0.066
Leaf area index	-0.348	-0.285	-0.367	0.001	0.429 *
			S4		
Chlorophyll content (SPAD)	-0.428 *	-0.319	-0.424 *	0.523 **	0.010
Biomass fresh weight (g)	-0.413 *	-0.331	-0.418 *	0.374	0.325
Leaf area index	-0.321	-0.395	-0.268	0.482 *	0.072
			S5		
Chlorophyll content (SPAD)	-0.666 **	-0.608 **	-0.583 **	0.387	0.464 *
Biomass fresh weight (g)	-0.262	-0.236	-0.167	0.442 *	0.615 **
Leaf area index	-0.604 **	-0.478 *	-0.530 **	0.538 **	0.247 *
			S6		
Chlorophyll content (SPAD)	-0.413 *	-0.415 *	-0.417 *	0.084	0.418 *
Biomass fresh weight (g)	-0.251	-0.239	-0.292	0.514 **	0.637 **
Leaf area index	-0.079	-0.104	-0.162	0.030	0.613 **
			S7		
Chlorophyll content (SPAD)	-0.706 **	-0.647 **	-0.693 **	0.300	0.807 **
Biomass fresh weight (g)	-0.841 **	-0.762 **	-0.850 **	0.188	0.912 **
Leaf area index	-0.749 **	-0.746 **	-0.762 **	0.128	0.710 **
			S8		
Chlorophyll content (SPAD)	-0.459 *	-0.432 *	-0.541 **	0.032	0.584 **
Biomass fresh weight (g)	-0.358	-0.390	-0.606 **	0.112	0.764 **
Leaf area index	-0.466 *	-0.473 *	-0.592 **	0.009	0.672 **
			S9		
Chlorophyll content (SPAD)	-0.343	-0.291	-0.400	0.302	0.640 **
Biomass fresh weight (g)	0.072	0.044	-0.123	0.442 *	0.526 **
Leaf area index	-0.122	-0.112	-0.200	0.412 *	0.545 **

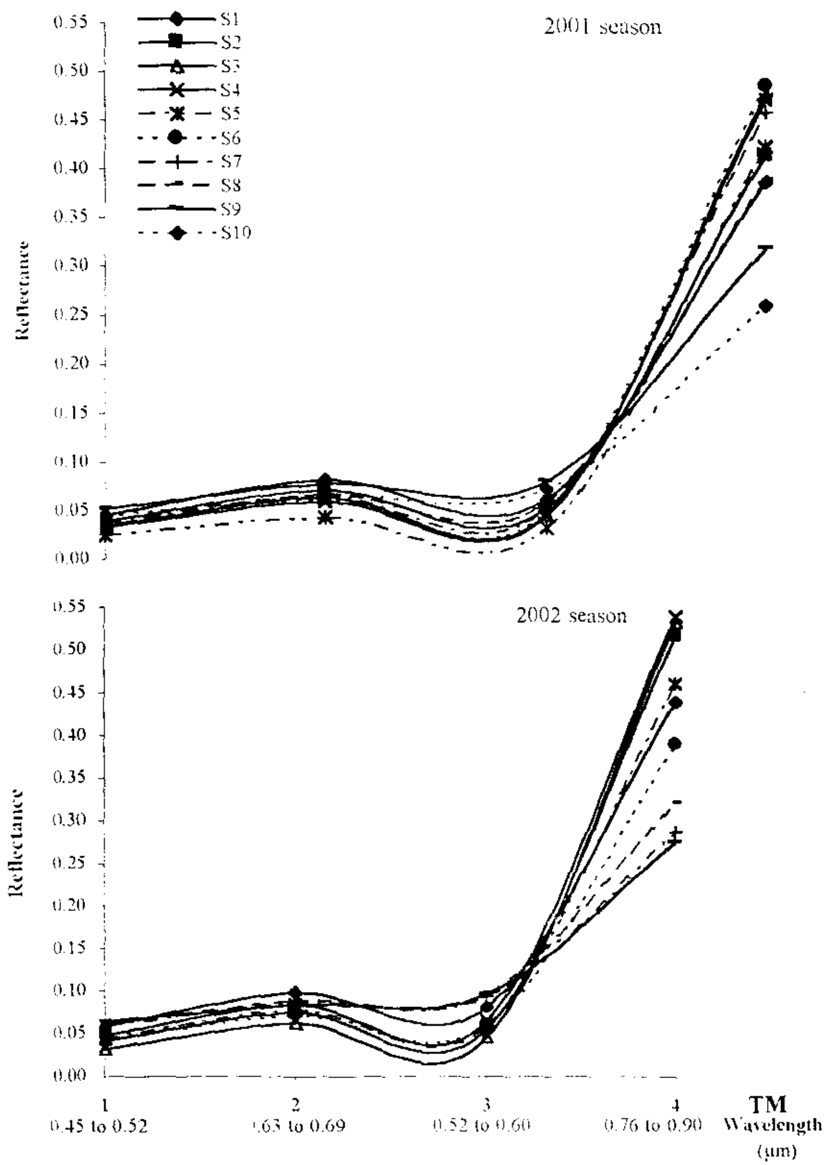

Fig. 1. Spectral reflectance of cotton plants during growth stages

Table 6. Correlation coefficient between spectral reflectance and growth characteristics of cotton plants for the studied sowing dates per TAU

Growth characteristics	2001 season					2002 season				
	TM1	TM2	TM3	TM4	NDVI	TM1	TM2	TM3	TM4	NDVI
	D1					D1				
Chlorophyll content	-0.574 **	-0.669 **	-0.489 **	0.025	0.395 **	-0.384 **	-0.145	-0.495 **	0.791 **	0.727 **
Biomass fresh weight	0.014	-0.251	0.108	-0.200	-0.388 **	0.183	0.020	0.290 *	-0.512 **	-0.457 **
Leaf area index	-0.400 **	-0.460 **	-0.339 **	0.277 *	0.422 **	-0.287 *	-0.172	-0.301 *	0.331 **	0.384 **
	D2					D2				
Chlorophyll content	-0.290 *	-0.334 **	-0.239	0.203	0.293 *	-0.528 **	-0.393 **	-0.592 **	0.502 **	0.766 **
Biomass fresh weight	0.184	0.017	0.283 *	-0.134	-0.295 *	0.125	-0.151	0.166	-0.527 **	-0.470 **
Leaf area index	0.053	-0.041	0.096	0.085	0.016	-0.302 *	-0.379 **	-0.322 *	0.109	0.197

the vegetative growth magnitude and continuing along growing season, like those in the second sowing date of first growing season.

2-3- Relationships of Spectral Reflectance in Estimating Growth Characteristics

A general pattern of the relationship of LAI to NDVI during plant ages was illustrated in Fig. (2). The equation that estimated the LAI of cotton plants depending on NDVI values are shown in Fig (3) and modeled by the form of:

$$\mathbf{LAI} = 2.0294e^{1.7642NDVI}$$

The accurate of this equation increased whenever, LAI exceed 3.5.

2-4- Relationships of Spectral Reflectance in Forecasting Yield and Biological Yield

Table (7) shows the values of correlation coefficient between spectral reflectance with yield and per faddan at different growth stages of cotton plants.

Biological yield per faddan at harvest was negatively correlated with TM1, TM2 and TM3 and reached the significant level at S5, S6 and S7 and positively correlated with NDVI and was significant at S5 and S6. These results agreed with those reported by **Colewell, (1983)** and **Neale and Buash, (1983)** when found that Red and NIR bands are superior for estimating biomass. Also, **Li *et al* (2001 a)** declared that NIR reflectance was positively correlated with biomass.

Cotton yield at harvest stage was negatively correlated with TM1,2,3 values in the early stage. But the correlation was positively at late stage and achieved a significant level at S8 and S7 only with TM3. Similar results in the early stage of growth were achieved by **Li *et al* (2001 a)** who found a negative correlation of blue, green and red reflectance with yield. However, these results are similar to results of **Wiegand *et al* (1994)** at midboll stage between NDVI and boll counts. On the other hand TM4 and NVDI were positively correlated with cotton yield at early stage, and inversed to negative relationship at late stages, where TM4 was significant at S9 and NDVI at S8 and S9.

Data analyses of Table (7) detect that:

- NDVI is most variable indicator than other spectral reflectance parameters with yield and biological yield. This result agreed with these reported by **Quarmby *et al* (1993); Wiegand *et al* (1994); Buscaglia *et al* (1999); Perumal *et al* (1999)** and **Li *et al* (2001a).**
- Biological and economic yield are more homogenous when correlated with spectral reflectance parameters than other yield or yield attributes.
- At S5 and S6 high positive correlation was achieved between biological yield and NVDI and in negative direction between biological yield and TM1, TM2 and TM3. Similar trend was noticed by **Perumal *et al* (1999).**
- While at S8 and S9, the high negative correlation was achieved between cotton yield and TM1, TM2, and TM3 only at S8. Similar results were reported by **Quarmby *et al* (1993);** who suggested that crop yield could be estimated from NDVI 50 – 100 days before harvest.

So, the data of NDVI at S5 and S6 are suggested to be used in model to forecast the biological yield per faddan at harvest.

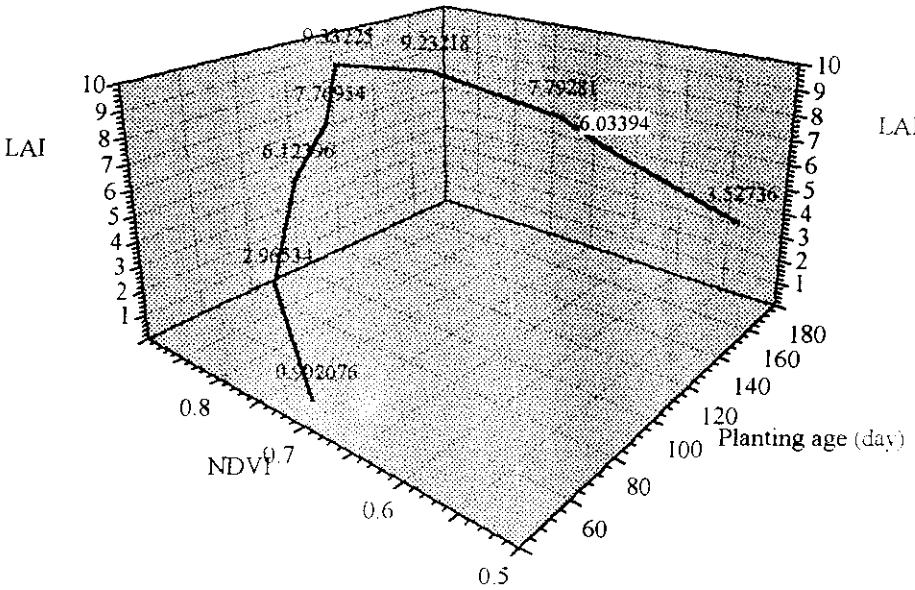

Fig. 2. Seasonal relationship of LAI and NDVI of cotton plant (average two growing seasons)

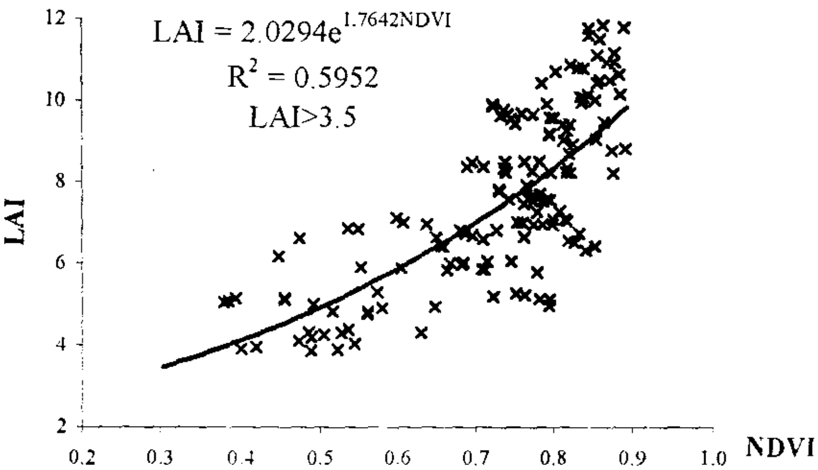

Fig. 3. NDVI and LAI relationship of cotton plants

Table 7. **Correlation coefficient of spectral reflectance at each growth stage with yield and biological yield**

Stage (day)	TM1	TM2	TM3	TM4	NDVI
	Biological yield				
S1 (42 d)	-0.197	-0.135	-0.236	0.212	0.278
S2 (58 d)	-0.135	-0.229	-0.239	0.107	0.288
S3 (74 d)	-0.482	-0.389	-0.377	0.353	0.055
S4 (90 d)	-0.197	-0.159	-0.213	0.040	0.303
S5 (106 d)	-0.525 **	-0.506 *	-0.579 **	0.045	0.995 **
S6 (122 d)	-0.424 *	-0.518 **	-0.744 **	0.268	0.894 **
S7 (139 d)	-0.003	-0.468 *	-0.503 *	0.307	0.126
S8 (156 d)	-0.289	-0.037	-0.010	0.344	0.081
S9 (173 d)	-0.143	-0.088	-0.080	0.111	0.221
	Cotton yield				
S1 (42 d)	-0.145	-0.095	-0.208	0.057	0.263
S2 (58 d)	-0.2	-0.233	-0.288	0.259	0.264
S3 (74 d)	-0.352	-0.165	-0.271	0.025	0.376
S4 (90 d)	-0.084	-0.014	-0.131	0.342	0.393
S5 (106 d)	-0.216	-0.334	-0.344	0.342	0.217
S6 (122 d)	0.006	0.063	0.082	-0.331	-0.125
S7 (139 d)	0.391	0.254	0.508 *	-0.342	-0.370
S8 (156 d)	0.520 **	0.533 **	0.439 *	-0.202	-0.525 **
S9 (173 d)	0.097	0.058	0.078	-0.412 *	-0.446 *

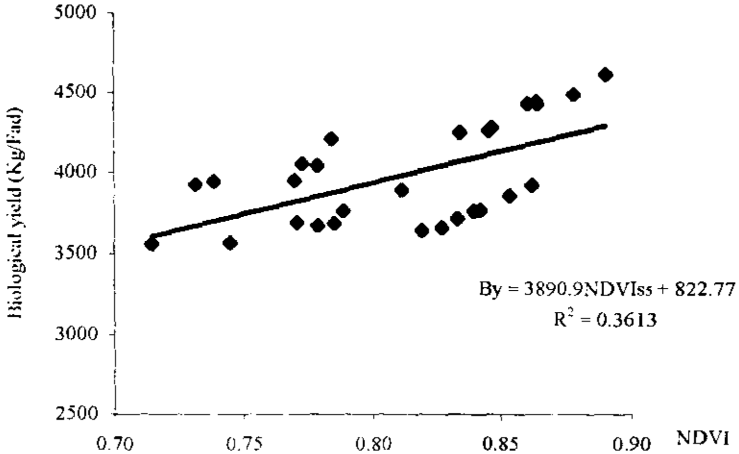

Fig. 4. Relationship of biological yield with NDVI values measured at stage S5 of cotton plants

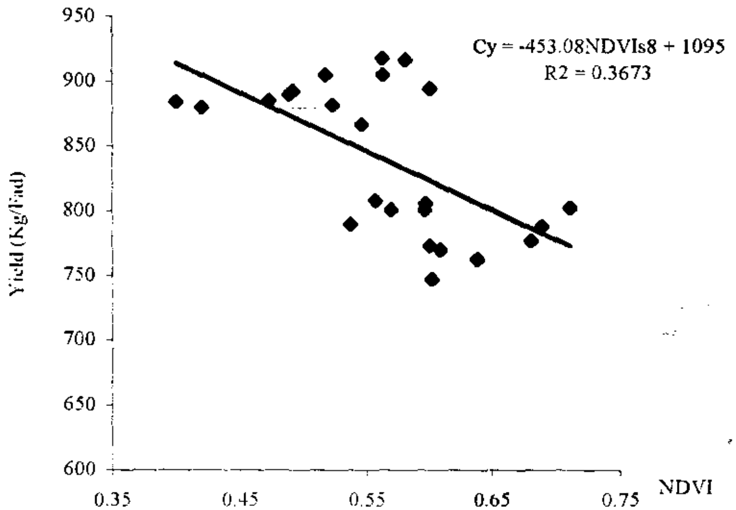

Fig. 5. Relationship of yield with NDVI values measured at stage S8 of cotton plants

while data of NDVI may be used at S8 and S9 be used to build model to forecast the cotton yield.

The equations that describe such models are presented here after and illustration in Figures (4 and 5):

$$B_y = 3890.9\ \mathbf{NDVI_{S5}} + 8220.77$$

$$C_y = -453.08\ \mathbf{NDVI_{S8}} + 1095$$

Where: B_y= biological yield (Kg/fad).

C_y = cotton yield (Kg/fad).

$NDVI_{S5}$ = NDVI values at S5 (110 days from planting).

$NDVI_{S8}$ = NDVI values at S8 (156 days from planting).

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مجلة حوليات العلوم الزراعية ، كلية الزراعة ، جامعة عين شمس ، القاهرة ، م٤٨ ، ع(٢)، ٥٨٥ - ٦٠٥ ، ٢٠٠٣

توقع صفات النمو وانتاجية محصول القطن من بيانات الانعكاس الطيفي

[٤١]

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أقيمت تجربتان حقليتان في كل من وحدة التجارب والبحوث الزراعية بشلقان عام ٢٠٠١ ومزرعة كلية الزراعة جامعة عين شمس بشبرا الخيمة عام ٢٠٠٢ بمحافظة القليوبية بهدف دراسة الانعكاس الطيفي لأطوال الموجات الطيفية التالية:

TM1 (0.45 to 0.52 μm)

TM2 (0.52 to 0.60 μm)

TM3 (0.63 to 0.69 μm)

TM4 (0.76 to 0.90 μm)

والدليل النباتي (NDVI) المشتق من هذه الانعكاسات بالصيغة: NDVI = (TM4-TM3)/(TM4+TM3) لنباتات القطن خلال مراحل النمو المختلفة : مرحلة النمو الخضري، بداية تكون البرعم الزهري، مرحلة تكوين البراعم الزهرية، بداية الإزهار، الإزهار، التلويز، تفتح اللوز، تفتح ٥٠ % من اللوز، تفتح معظم اللوز ثم اكتمال تفتح اللوز وسقوط الأوراق متزامنة مع ٤٢، ٥٨، ٧٤، ٩٠، ١٠٦، ١٢٢، ١٣٩، ١٥٦ و ١٧٣ يوم من الزراعة في الموسمين معاً وأيضا بعد ١٩٠ يوم من الزراعة في الموسم الأول فقط. درست الصفات التالية في كل مرحلة: مساحة الأوراق، تركيز الكلوروفيل في الأوراق، الكتلة الحيوية ودليل مساحة الأوراق وذلك تحت تأثير موعدي الزراعة تحت الدراسة: الأول ٢١ مارس والثاني ٢١ ابريل من كل عام في تجربة استخدم فيها تصميم القطاعات الكاملة العشوائية في ست مكررات لصنف جيزة ٨٥.

تضمنت أهم نتائج الدراسة انخفاض قيم TM1 ، TM2 و TM3 بينما زادت قيم TM4و NDVI بتقدم مراحل النمو حتى بداية الإزهار و الإزهار (٩٠ - ١٠٦ يوم من الزراعة). كانت قيم TM1 ، TM2 و

وTMD في الموعد الأول أعلى قليلاً منها في الموعد الثاني، بينما كانت قيم NDVI في الموعد الثاني أعلى منها في الأول. يعتبر NDVI من أهم المؤشرات الطيفية بينما يعتبر تركيز الكلوروفيل، الكتلة الحيوية ودليل مساحة الأوراق من أهم الصفات النباتية في العلاقة نبات-طيف. يمكن تقدير دليل مساحة الأوراق LAI (تزداد دقة التقدير بزيادة قيمة LAI عن ٣,٥) لنباتات القطن عن طريق NDVI بالمعادلة:

$$\mathbf{LAI} = 2.0294e^{1.7642\mathrm{NDVI}}$$

كما يمكن توقع الكتلة الحيوية النهائية ($\mathbf{B_y}$) (كيلوجرام/فدان) وانتاجية القطن الزهر ($\mathbf{C_y}$) (كيلوجرام/فدان) عند الحصاد (الجني) من خلال معرفة قيم NDVI في المرحلة الخامسة (S5) (بعد ١٠٦ يوم من الزراعة) والثامنة (S8) (بعد ١٥٦ يوم من الزراعة) على التوالي وفق المعادلتين:

$$\mathbf{B_y} = 3890.9\ \mathbf{NDVI_{S5}} + 8220.77$$

$$\mathbf{C_y} = 453.08\ \mathbf{NDVI_{S8}} + 1095$$

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