

THE EFFECT OF FERTILIZER APPLICATION ON SOLAR REFLECTANCE FROM A WHEAT CROP

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Solar reflectivity of wheat crops subject to a wide range of different fertilizer treatments was measured radiometrically from the ground in two broad spectral bands (280-690 nm and 690-2800 nm) and photographically from the air in two narrower bands (500-700 nm and 700-900 nm). Visible and infrared reflectivity were considerably but differently affected by fertilizer treatment; the effects were attributed to the amount of plant material rather than its optical properties. The effect of radiation balance differences on growth and water loss was calculated to be small. Possible applications of the relationships for yield prediction are discussed briefly.

INTRODUCTION

The effect of fertilizers on the reflective properties of crop canopies is of interest from both the theoretical and practical points of view: theoretically as an aid to understanding the way in which fertilizer applications increase the efficiency of solar radiation fixation, and practically as a possible remote-sensing method of diagnosing nutrient deficiencies and predicting crop yields.

Solar reflectivity measurements of wheat plots receiving a wide range of fertilizer treatments are presented in this paper and analyzed from the theoretical and practical points of view outlined above.

MATERIALS AND METHODS

The investigation was carried out in the permanent plots of a long-term fertilizer experiment conducted on a 7-ha area at the Bet Dagan Experiment Farm in the central coastal plain of Israel. The soil of the farm is a deep clay loam classified as an alluvial

Publication of the Agricultural Research Organization. No. 2168-E. Received June 1971; accepted Jan. 1972.

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brown grumusol. A full description of the experiment has been published elsewhere (4). Briefly, the experiment consists of 450 plots, each 4 m X 27 m: there are two replicates of 225 combinations of five levels of N (0, 150, 300, 600 and 1,200 kg ha⁻¹) applied in equal base and top dressings of 21% NH₄SO₄ and NH₄NO₃-CaCO₃, respectively, in 72-m-wide strips; five levels of P (0, 90, 180, 360 and 720 kg ha⁻¹) applied as a base dressing of 21% P₂O₅ superphosphate in 12-m-wide strips; three levels of K (0, 300 and 600 kg ha⁻¹) applied as a base dressing of K₂SO₄ (50% K₂O) in 4-m-wide strips; and the residual effects of three levels of organic manure applied three years previously (0, a leguminous crop plowed in as green manure, and 40 m³ ha⁻¹ farmyard manure), in 24-m-wide strips.

The semi-dwarf local variety of wheat grown was Miriam 1, a recently introduced cross. It was sown on November 24, emerged on December 7, 1969 and was harvested on May 25, 1970. Two irrigations, totaling 110 mm, supplemented the 302 mm of rain which fell during the growing season.

Direct radiometric measurements of solar reflectivity were made from the ground on March 27, 1970, during a cloudless noon-time period when the incident global radiation varied between 1.33 and 1.14 cal cm⁻² min⁻¹ and the solar elevation varied from 61° to 51°. The radiometers were held approximately 1.25 m above the crop canopy in the center of 30 plots. A long probe was used with a bubble level at the handle end. Two of the radiometers were Kipp solarimeters mounted back to back; the outer glass hemisphere of one of the solarimeters was replaced by a RG8 hemispherical filter of the same size which restricted its spectral sensitivity to radiation in the 690-2800 nm wavelength band. A polyethylene-shielded Funk net radiometer projected from the end of the probe. The outputs from the three radiometers were read in succession from a portable, battery-operated millivoltmeter, allowing one minute for a stable reading to be achieved.

Solar reflectivity was measured photographically from the air on two occasions in the middle of winter 1970. On January 28, black and white photographs were taken from a height of 1000 m with an aerial exposure index of 80. Kodak Plus X Aerographic film 2402 was used with a Pan 2.0 X filter restricting sensitivity to wavelengths greater than 500 nm. Three days later, infrared photographs were taken from a height of 1600 m. Kodak Infrared Aerographic film 2424 was used with an infrared filter restricting sensitivity to wavelengths greater than 700 nm. Details of the spectral sensitivity of the two film and filter combinations are given in Fig. 1, together with the spectral radiance of a green maturing wheat crop reported in the literature (3).

The optical density of the film image of each plot was measured with a Baldwin radiological densitometer (Mk. 3) on an enlarged negative transparency. A single reading within the borders of the film image of each plot was deemed sufficient, as replicate readings within a single plot did not differ by more than 5%.

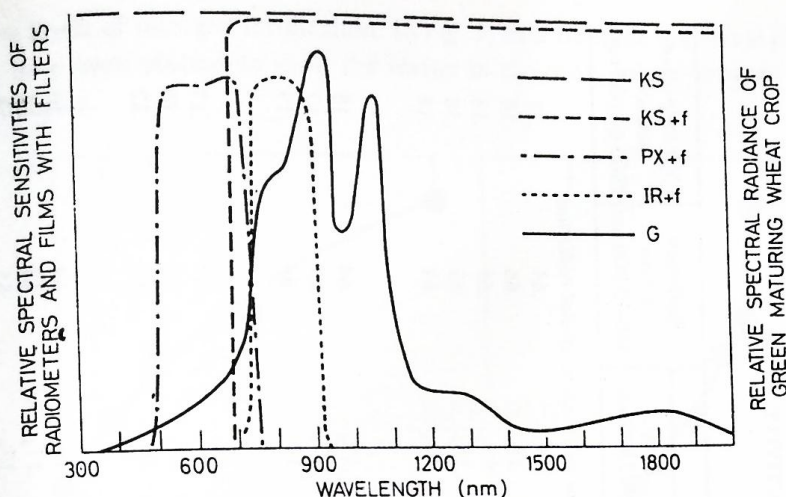


Fig. 1. Relative spectral sensitivities of radiometric and photographic systems used for solar reflectivity measurements and radiance from a green, maturing wheat crop. KS = Kipp solarimeter; KS + f = Kipp solarimeter with RG8 filter; PX + f = Kodak Plus X Aerographic film 2402 (black and white) with Pan 2.0 X filter; IR + f = Kodak Infrared Aerographic film 2424 with infrared filter; and G = green maturing wheat crop (3).

RESULTS

Radiometric measurements were restricted to 30 plots and as earlier results had shown the nitrogen treatments to have the greatest effect, the plots were selected to represent equally the five rates of N application. The reflectivity values in the visible (280-690 nm), infrared (690-2800 nm) and total (280-2800 nm) solar spectra are presented as fertilizer treatment means in Table 1 together with the net radiation balance of solar plus terrestrial radiation and net long-wave balance of terrestrial radiation. All fluxes are expressed as fractions of the appropriate incident global radiation.

The relationships between solar reflectivity and rates of N application and mean crop height at the time of measurement are shown in Fig. 2. The points of zero crop height represent the measurements over an adjacent plot of bare soil.

The relationship between solar reflectivity in different spectral bands and final yield of the 30 plots measured, is shown in Fig. 3 with details of the linear relationships which were fitted to the data statistically.

The optical density values of both the black and white and infrared film images of each of the 450 plots, are presented as fertilizer treatment means in Table 2, together with the variance of these results.

In Fig. 4 the mean transmission or transparency, *i.e.*, the antilog reciprocal of optical density of the two film types, has been plotted against the rate of N application for each

TABLE 1
RADIOMETRIC MEASUREMENTS OF WHEAT CROP REFLECTIVITY
(Bet Dagan, 27.III.1970; treatment means)

Treatments	Number of plots measured	Crop height, 27.III.1970 (cm)	Final yield, 25.V.1970 (ton ha ⁻¹)	Solar reflectivity			Radiation balance 300-60,000 nm	Net long-wave balance 2800-60,000 nm
				Visible, 280-690 nm	Infrared, 690-2800 nm	Total, 280-2800 nm		
All values are fractions of incident global radiation								
Nitrogen (kg N ha ⁻¹) 0 30 60 120 240	6	64	1.44	.03 ₄	.26 ₂	.14 ₉	.64	.21
	6	92	2.41	.02 ₉	.29 ₀	.16 ₀	.66	.18
	6	104	3.49	.02 ₃	.31 ₈	.17 ₀	.65	.18
	6	117	4.55	.01 ₀	.33 ₃	.18 ₈	.63	.18
	6	118	3.71	.01 ₀	.38 ₂	.19 ₉	.64	.16
Phosphorus (kg P ha ⁻¹) 10 20 80	10	99	3.14	.01 ₇	.33 ₀	.17 ₃	.64	.18
	5	97	3.44	.01 ₈	.32 ₈	.17 ₄	.65	.17
	15	100	3.00	.02 ₆	.31 ₈	.17 ₃	.64	.19
Potassium (kg K ha ⁻¹) 0 150 300	10	100	3.28	.01 ₈	.33 ₈	.17 ₉	.65	.17
	15	98	3.02	.02 ₂	.31 ₈	.17 ₁	.64	.18
	5	98	3.11	.02 ₅	.30 ₉	.16 ₈	.62	.22
Residual organic matter 0 Green manure Farmyard manure	15	97	2.93	.02 ₆	.31 ₂	.16 ₉	.64	.20
	5	97	3.44	.01 ₇	.32 ₈	.17 ₄	.65	.17
	10	102	3.24	.02 ₀	.33 ₉	.17 ₉	.65	.18

of the five levels of nitrogen fertilization. In Fig. 5, data from the individual plots shown in Fig. 3 have been plotted to show the scatter in the relationships between final yield and transmission.

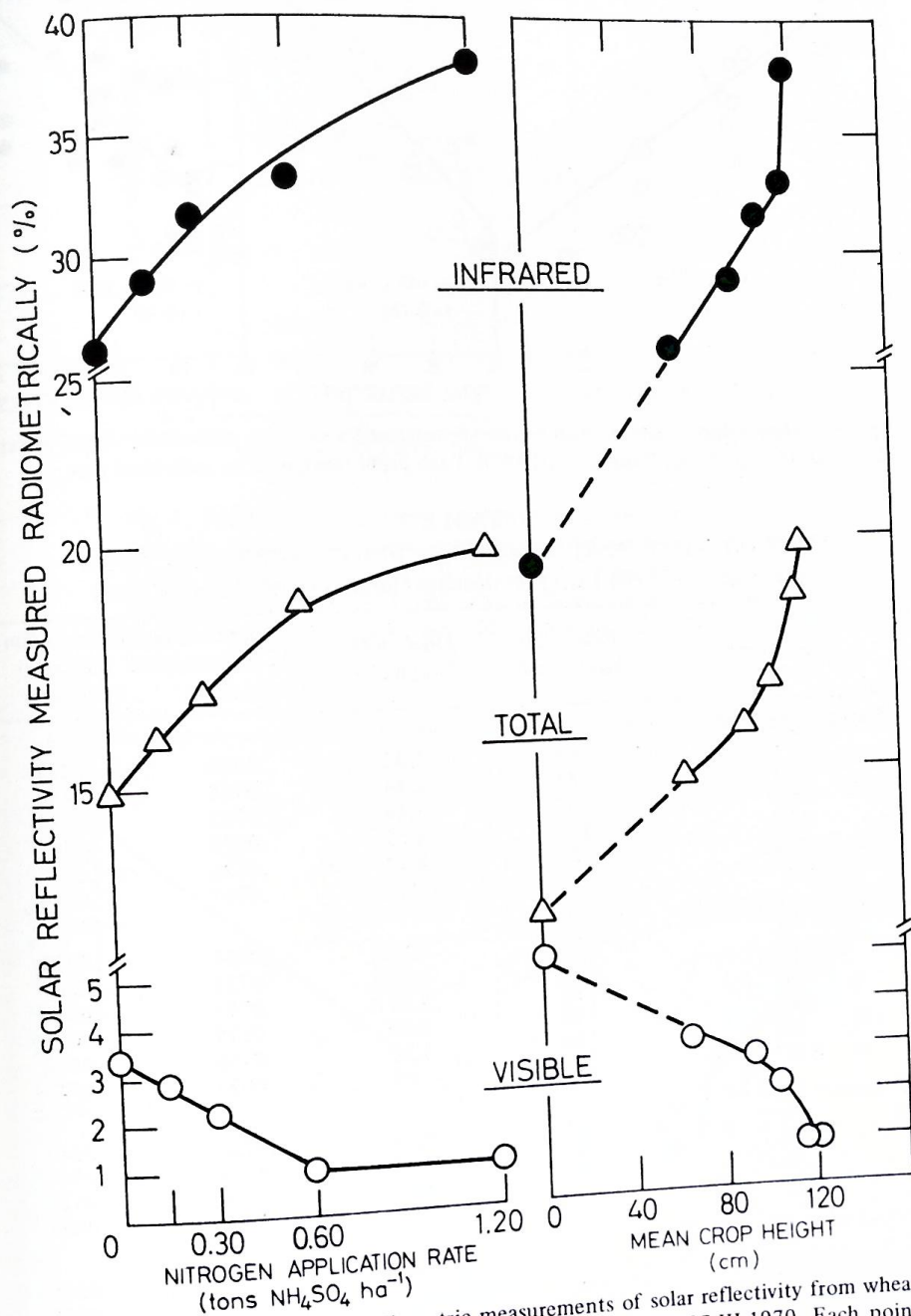


Fig. 2. Relationship between radiometric measurements of solar reflectivity from wheat plots, nitrogen application rate and crop height; Bet Dagan, 27.III.1970. Each point represents the mean of six plots.

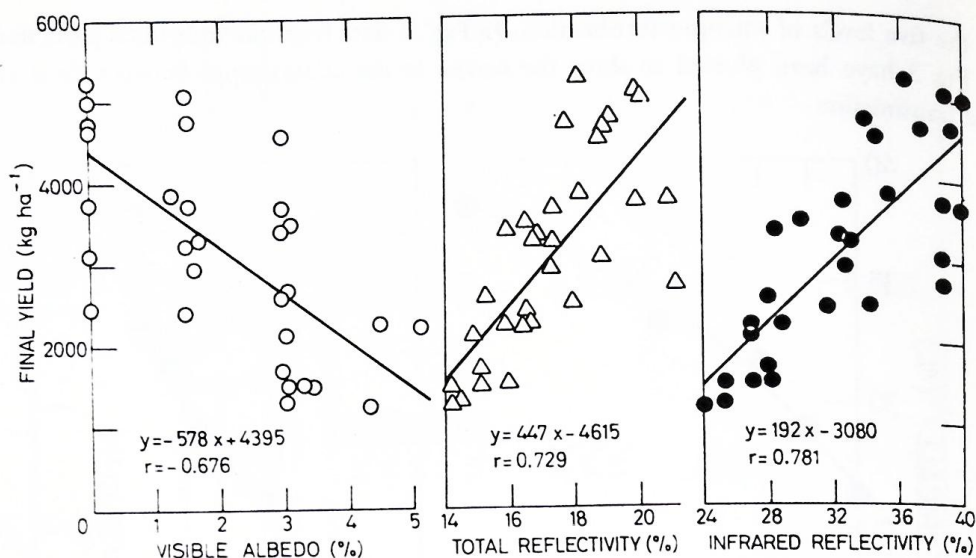


Fig. 3. Relationship between radiometric measurements of solar reflectivity from wheat plots and final yield; Bet Dagan, 27.III.1970. Each point represents an individual plot.

TABLE 2
PHOTOGRAPHIC MEASUREMENTS OF WHEAT CROP REFLECTIVITY
(Bet Dagan, 28.I and 1.II.1970; treatment means in optical density units)

Treatments	Final crop height (cm)	Final yield (ton ha ⁻¹)	Black and white film (negative) and filter	Infrared film (negative) and filter
<i>Nitrogen (kg N ha⁻¹)</i>				
0	64	1.42	.1014	.0223
30	88	2.44	.0768	.0450
60	97	3.44	.0702	.0626
120	105	4.52	.0610	.0667
240	104	4.12	.0626	.0725
S.E.*	1.3	.08	.0037	.0024
<i>Phosphorus (kg P ha⁻¹)</i>				
0	83	2.54	.0834	.0352
10	93	3.35	.0721	.0565
20	93	3.32	.0751	.0549
40	95	3.40	.0679	.0614
80	96	3.32	.0736	.0612
S.E.*	1.3	.09	.0023	.0029
<i>Potassium (kg K ha⁻¹)</i>				
0	91	3.24	.0738	.0540
150	92	3.17	.0739	.0547
300	92	3.15	.0756	.0528
S.E.*	.45	.03	.0006	.0004
<i>Residual organic matter</i>				
0	89	2.98	.0789	.0505
Green manure	94	3.37	.0714	.0563
Farmyard manure	92	3.20	.0730	.0547
S.E.*	.42	.08	.0019	.0021

* From analysis of variance.

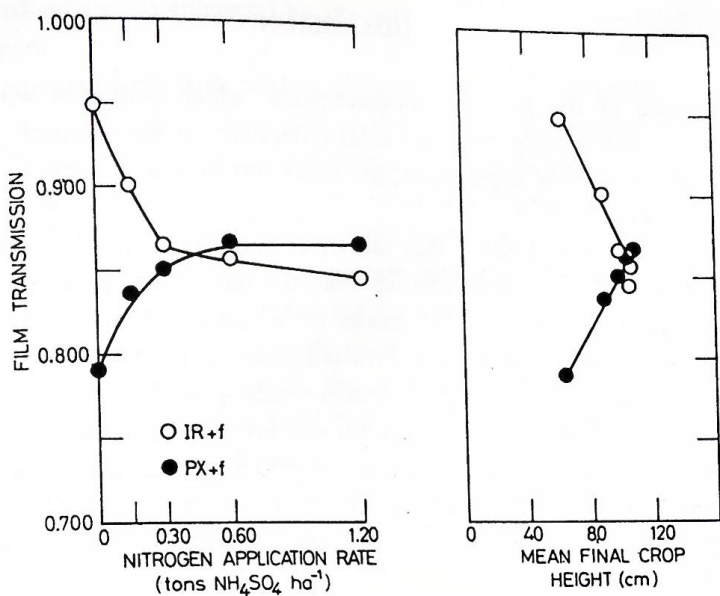


Fig. 4. Relationship between photographic measurements of solar reflectivity from wheat plots, nitrogen application rates and final crop height, Bet Dagan, 28.I and 1.II.1970. IR + f = negative of Kodak Infra-red Aerographic film 2424 with infrared filter; and PX + f = negative of Kodak Plus X Aerographic film 2402 (black and white) with Pan 2.0 X filter.

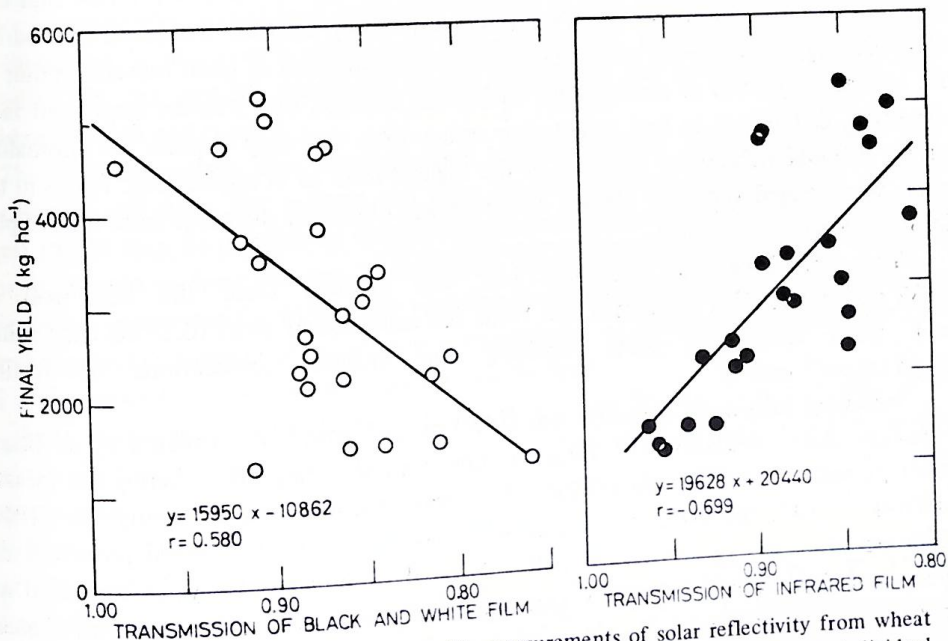


Fig. 5. Relationship between photographic measurements of solar reflectivity from wheat plots and final yield; Bet Dagan, 28.I and 1.II.1970. Each point represents an individual plot.

DISCUSSION

At the time of the radiation measurements, which coincided with the stage of maximum vegetative development, the solar reflectivity of the wheat plots was markedly affected by the rate of N application; the other fertilizer treatments had much smaller and less consistent effects.

It can be seen from Table 1 that plots receiving the heaviest rate of N application reflected one third more global radiation than the unfertilized plots; there were similar but slightly larger proportional differences in infrared reflectivity. The reflection of visible radiation from the most heavily fertilized plots was proportionately much less than that of the unfertilized plots, with differences reaching 340%. The relationship between visible reflectivity and rates of N application was inverse and linear up to 120 kg N ha⁻¹.

Differences in net long-wave radiation (>2800 nm) were similar in magnitude but opposite in sign to those for global solar reflectivity, canceling each other's effect so that there were virtually no differences in the net radiation balance of plots receiving different levels of nitrogen application.

Nitrogen fertilization could affect the solar reflectivity of the wheat plots in three ways, by altering (a) the optical properties of the plant material, (b) the amount of plant material and hence the proportion of plant to soil cover, and (c) the posture and structure of the plant material within the canopy – thus affecting radiation reflection and absorption within the crop stand.

The close relationship between crop height and reflectivity and the fact that extrapolation to zero crop height gives values corresponding to those measured over bare soil (Fig. 2), suggest that in the case examined it was the amount of plant material rather than its optical properties or arrangement within the canopy, that was the important factor. However, differences in leaf orientation rather than size may explain the anomalously higher infrared reflectivity observed at the highest level of N application. Plants in these plots were lodged and their canopy structure was obviously different from that of plants in other plots.

The net long-wave radiation loss was greatest from the bare soil area (0.37 cal cm⁻² min⁻¹), somewhat less from the unfertilized plots (0.27 cal cm⁻² min⁻¹), and least from the plots receiving the heaviest applications of fertilizer (0.23 cal cm⁻² min⁻¹).

Incoming long-wave radiation was 0.469 cal cm⁻² min⁻¹ as estimated by an Elsasser radiation chart calculation (1), from the upper air sounding taken during the measurement period at a radiosonde station 2 km away. Assuming an emissivity for all three surfaces of 0.95, the surface temperature of the bare soil, unfertilized plots and most fertilized plots was calculated to be 40°, 31° and 27°C, respectively, as compared with the screen air temperature of 29°C measured at the same time. The advection of energy to the heavily fertilized plots implied by their lower-than-air temperature is not unreasonable considering the taller height of the plants in those plots and the oasis effect of the

patchwork of small-area plots enhanced by the very low (10%) relative humidity at the time of measurement.

Despite the comparatively large relative differences in solar reflectivity and net long-wave radiation loss, the effect of these differences on rates of potential photosynthesis and potential transpiration is likely to have been small. This is because the difference in the absolute amount of photosynthetically active radiation reflected from the different plots was small ($<5\%$ of the incident photosynthetically active flux) and because differences in the short- and long-wave characteristics cancel each other out, leaving very similar amounts ($\pm 2\%$) of net radiation available for transpiration.

Although no measurements were made of solar radiation absorption by the plant material growing on the different plots, the large differences in the amount of leaf material and degree of ground cover suggest that crop absorptivity must have differed to a marked degree. If this is so, it would support Watson's conclusion from growth analysis studies (6) that differences in dry matter production caused by fertilizer application are caused mainly by the effect that such applications have on the area of photosynthetic tissue produced.

The conclusion that fertilizer application rates are related to wheat crop reflectivity via their effects on the amount of leaf material produced rather than through changes brought about in the optical properties of the leaf material, suggests that reflectivity measurements, at least in the broad spectral bands examined, are unlikely to provide a useful remote-sensing method for detecting specific nutrient deficiencies. Presumably, the existence of any other growth-limiting factor, such as soil water shortage or damagingly low air temperatures, would lead to similar changes in crop reflectivity. Another important limitation is that, for a given crop and sun height, reflectivity is also strongly dependent on the optical properties of the underlying soil surface (2), which vary considerably with soil type.

The soil limitation also suggests that yield-reflectivity relationships will vary according to soil type. For a given soil type the relationships shown in Figs. 3 and 5 suggest that it may be possible to develop remote-sensing methods to predict yields or to estimate drought or frost damage. Variations in the best radiometric measure – infrared reflectivity – accounted for 61% of the variation in yield harvested two months later. The best photographic measure of reflectivity – transmission of infrared film – accounted for 49% of the variation in yield measured four months later.

These values are comparable with those reported by Thomas *et al.* (5), who correlated the photographically measured reflectance of 16 sites of varying soil salinity within a large cotton field in Texas with the final yields, using the optical density of Kodak Ektachrome Infrared Aerofilm viewed through various filters. The most successful single filter was green (525-575 nm), accounting for 62% of the variation in lint yield measured one month later. Variation in the combined transmission value derived from three filter readings accounted for 78% of the yield variation.

ACKNOWLEDGMENTS

We wish to acknowledge the financial support of the United States Department of Agriculture and the technical assistance of Mr. Y. Cohen. Mr. Z. Raz of the Survey and Mapping Division of the Ministry of Agriculture was responsible for the aerial photography.

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