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<p>This paper describes the correlations between two crop parameters (green leaf area index and percent soil cover) and eighteen TM/LANDSAT-5 parameters (six bands and twelve band ratios). The TM/LANDSAT-5 data used were the digital numbers extracted from CCT's and corrected for minimizing atmospheric effects. It was used three overpasses during wheat and bean vegetative cycles. The percent soil cover was estimated using 35mm photographs taken perpendicular to the ground. The results showed that the correlation between remote sensing data and crop parameters is dependent on the level of expression of the crop parameter (crop stages). When the crop vegetative parameters are at their maximum expression there are poor correlations with remote sensing data. So, the more significant values of correlations were obtained in the pre-flowering stage. The most useful TM bands were TM4 and TM3, but their usefulness varied in function of the date of overpass, the crop family, and the crop parameter. Ratios were useful in cases where the single bands showed poor correlations, but no single ratio could be identified with good correlation in all situations. Finally, it was concluded that the knowledge of general development condition of crops is necessary in the selection of the most appropriate remote sensing parameter for correlation to the crop parameters considered in this study.</p>				
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TM/LANDSAT-5 DATA TO EVALUATE WHEAT AND BEAN PERCENT SOIL
COVER AND LEAF AREA INDEX

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ABSTRACT

This paper describes the correlations between two crop parameters (green leaf area index and percent soil cover) and eighteen TM/LANDSAT-5 parameters (six bands and twelve band ratios). The TM/LANDSAT-5 data used were the digital numbers extracted from CCT's and corrected for minimizing atmospheric effects. It was used three overpasses during wheat and bean vegetative cycles. The percent soil cover was estimated using 35mm photographs taken perpendicular to the ground. The results showed that the correlation between remote sensing data and crop parameters is dependent on the level of expression of the crop parameter (crop stages). When the crop vegetative parameters are at their maximum expression there are poor correlations with remote sensing data. So, the more significant values of correlations were obtained in the pre-flowering stage. The most useful TM bands were TM4 and TM3, but their usefulness varied in function of the date of overpass, the crop family, and the crop parameter. Ratios were useful in cases where the single bands showed poor correlations, but no single ratio could be identified with good correlation in all situations. Finally, it was concluded that the knowledge of general development condition of crops is necessary in the selection of the most appropriate remote sensing parameter for correlation to the crop parameters considered in this study.

1. INTRODUCTION

The application of remote sensing to agricultural related studies is affected by large variations that occur within of agricultural target areas, such as crop species, tillage, development conditions. Crop development monitoring by remote sensing can allow inferences about crop species and conditions at a specific time. Among various parameters of crop development evaluation, percent soil cover and green leaf area index (LAI) are very important from the point of view of crop evaluation via remote sensing.

The difference between plant and soil reflective spectral behavior is very strong. This can be seen during the crop growing cycle where, at the early stage the spectral response comes mainly from the soil and, with time, the vegetation becomes the main part of the upwelling scene radiance.

However, the evolution from typical soil radiometric response to a fully vegetation response varies in function of crop parameters such as row spacing, crop height, and the intrinsic characteristics of the crop, e.g. foliar emission pattern, and

foliar distribution and disposition in relation to a plane. The interaction of these parameters will determine the percent soil cover and the green leaf area index which can, through evolutive monitoring, provide information of agricultural interest.

Utilization of remote sensing data to study crop development has been carried out by many authors. Well established correlations between green leaf area index and field measured reflectance have been obtained by Ahlrichs and Bauer (1983), Kamat et al. (1983), Daughtry et al. (1985) and Gardner and Blad (1986), among others. Another crop parameter that has been analysed is the percent soil cover. Richardson and Wiegand (1977) working with sorghum obtained significative correlations between percent soil cover and digital values for multispectral scanner (MSS) bands, MSS4 (0.5-0.6 μ m) and MSS5 (0.6-0.7 μ m); and poor correlations when MSS6 (0.7-0.8 μ m) and MSS7 (0.8-1.1 μ m) were utilized. The inverse was obtained when the crop parameter was the LAI. Daughtry et al. (1980) working with wheat and making field radiometry observed that higher correlations between reflectance and soil cover occurred between emergence and flowering in the visible region of the electromagnetic spectrum. When the vegetative cycle goes on senescence there is a decrease in the correlation between crop parameters and reflectance because there is a decrease of photosynthetically active radiation, which has high correlation with reflectance (Leamer et al., 1978; Aase and Siddoway, 1980). Huete et al. (1985) and Huete (1987) observed good correlations between field reflectance and cotton percent soil cover. Further, they showed that this relation was different in each of the four soils studied and that the higher influence of the soil/crop target occurred when crop covers varies between 20 and 75%.

The utilization of indices obtained by combining two or more TM/LANDSAT bands that produce new values for each pixel has been realized by various authors for many purposes. The more simple indices are the ones obtained by the ratio between two single bands. Since LANDSATs 1-3 carried MSS sensors with only four bands (0.5-1.1 μ m) the literature related to indices largely covers only this portion of the electromagnetic spectrum.

Perry et al. (1984) made an study showing the relationships between various indices constructions. Richardson and Wiegand (1977) point out that, although isolated bands can be well correlated with crop parameters, the utilization of indices allows better consistency for multitemporal comparisons between crop development conditions.

Among the simplest and more utilized indices are the infrared to red ratio (TM4/TM3), and the normalized difference between these two bands (TM4-TM3)/(TM4+TM3), (Huete et al., 1985). Many authors found good correlations between these indices and percent soil cover and green leaf area index (Gardner and Blad, 1986; Holben et al., 1983; Daughtry et al., 1984). Daughtry et al. (1984) found that the correlation coefficients between vegetation index and crop parameters were higher for percent soil cover than that for green leaf area index.

The objective of this work is to explore the potential correlative of each single TM/LANDSAT-5 band with green leaf area index and percent soil cover; and between these crop parameters and empiric band ratio indices. Furthermore it is analysed the influence of general growing stages of crops on that potential.

2. EXPERIMENTAL PROCEDURES

In this work 30 irrigated fields of wheat (15 fields) and beans (15 fields) were selected in northern São Paulo State (Brazil). The crop development at each area was accompanied since the early stages. The planting dates were not coincident, and therefore there was a considerable range of percent soil cover, mainly in the early growing season.

Percent soil cover was estimated according to Heilman et al. (1981) and Cihlar et al. (1987), in which a vertical 35 mm photograph is obtained at 2 meters height. Over this photograph, usually in slide format, it is superimposed a millimetric grid and it is evaluated the soil and vegetation contribution on that area. Green leaf area index was measured by junction of leaf planimetry of plants and mean row and plant spacing data. LAI expresses one side leaf area to unit soil area.

TM/LANDSAT-5 data were acquired on three dates, namely P1, P2 and P3 (06/17/86, 07/19/86, and 08/04/86, respectively), where P2 is 32 days after P1 and P3 16 days after P2. The WRS reference to overpasses is 221/74. These data were recorded on CCT's in which an atmospheric minimization was accomplished using deep water bodies to extract minimum digital values for each TM band (Schowengerdt, 1983).

From these magnetic tapes were extracted four samples of 12 pixels each of digital values over each wheat and bean field. This was repeated for the three overpasses and for TM1, TM2, TM3, TM4, TM5 and TM7/LANDSAT-5 spectral bands. The percent soil cover and green leaf area index were acquired during field works carried out nearly satellite overpasses. Due to the large fields extension, magnetic tapes samples are in greater number and might not match with field samples.

Correlations were attempted with the following ratios: $I1=TM2/TM1$, $I2=TM3/TM2$, $I3=TM4/TM2$, $I4=TM5/TM2$, $I5=TM7/TM2$, $I6=TM4/TM3$, $I7=TM5/TM3$, $I8=TM7/TM3$, $I9=TM4/TM5$, $I10=TM4/TM7$, $I11=TM5/TM7$, $I12=(TM4-TM3)/(TM4+TM3)$. From these, there are some largely tested and some proposed to test now, as $TM5/TM7$.

With percent soil cover, green leaf area index, mean digital value for single bands and empiric simple ratio data it was established the correlations between these variables.

3. RESULTS AND DISCUSSION

Crop parameters for three overpasses are shown on Table 1. In P1 the percent soil cover presents low values, particularly the fields of beans. In P2, 32 days after P1, percent soil cover was high, and none wheat field showed less than 90% soil cover,

but five bean fields showed less than 60% soil cover. In P3, the situation of crop development was characterized by the presence of areas with very different biologic stage, and signals of maturity in some areas were present, making bean leaves to be yellowish and green wheat leaves decreased.

TABLE 1
MEAN (\bar{x}), STANDARD DEVIATION (σ) AND NUMBER OF OBSERVATIONS (n)
FOR PERCENT SOIL COVER AND GREEN LEAF AREA INDEX (LAI) FOR BEAN
AND WHEAT FIELDS MEASURED SIMULTANEOUSLY TO THREE
LANDSAT OVERPASSES

		<u>% SOIL COVER</u>		<u>GREEN LAI</u>	
		WHEAT	BEAN	WHEAT	BEAN
P1	\bar{x}	75.2	36.6	3.1	1.7
	σ	28.6	25.7	2.2	1.8
	n	12	11	14	12
P2	\bar{x}	97.3	75.5	3.8	3.6
	σ	2.2	22.5	1.6	2.8
	n	13	15	15	15
P3	\bar{x}	97.3	84.5	3.1	4.1
	σ	2.1	18.1	1.5	2.2
	n	15	15	15	14

Correlations between percent soil cover and green leaf areas with single bands and band ratios for three overpasses are shown on Table 2. At first glance it can be observed that better correlations between crop parameters and remote sensing parameters were obtained for overpass P1 than for P2 and P3, and also for P3 than for P2. This sequence is similar to the general growing development of the areas, that is, at the time of the P1 passage there was more heterogeneity between the various fields in terms of vegetative development, varying from minimum vegetation cover to maximum cover registered by the large standard deviation (Table 1); during the P2 passage there was more homogeneity in the vegetative stage; and in P3 it was common the occurrence of reproductive organs differentiation and senescence signals. So, these results show that early crop stages are more suitable for the establishment of correlations between remote sensing parameters related to soil/plant area. Daughtry et al. (1980) found similar results.

TABLE 2

CORRELATIONS BETWEEN PERCENT SOIL COVER AND GREEN LEAF AREA INDEX, SINGLE TM BANDS
AND BAND RATIOS FOR WHEAT AND BEAN IN THREE OVERPASSES

		TM1	TM2	TM3	TM4	TM5	TM6	TM7	TM8	TM9	TM10	TM11	TM12	TM13	TM14	TM15	TM16	TM17	TM18	TM19	TM20	TM21	TM22	TM23	TM24	TM25	TM26	TM27	TM28	TM29	TM30	TM31	TM32	TM33	TM34	TM35	TM36	TM37	TM38	TM39	TM40	TM41	TM42	TM43	TM44	TM45	TM46	TM47	TM48	TM49	TM50	TM51	TM52	TM53	TM54	TM55	TM56	TM57	TM58	TM59	TM60	TM61	TM62	TM63	TM64	TM65	TM66	TM67	TM68	TM69	TM70	TM71	TM72	TM73	TM74	TM75	TM76	TM77	TM78	TM79	TM80	TM81	TM82	TM83	TM84	TM85	TM86	TM87	TM88	TM89	TM90	TM91	TM92	TM93	TM94	TM95	TM96	TM97	TM98	TM99	TM100	TM101	TM102	TM103	TM104	TM105	TM106	TM107	TM108	TM109	TM110	TM111	TM112	TM113	TM114	TM115	TM116	TM117	TM118	TM119	TM120	TM121	TM122	TM123	TM124	TM125	TM126	TM127	TM128	TM129	TM130	TM131	TM132	TM133	TM134	TM135	TM136	TM137	TM138	TM139	TM140	TM141	TM142	TM143	TM144	TM145	TM146	TM147	TM148	TM149	TM150	TM151	TM152	TM153	TM154	TM155	TM156	TM157	TM158	TM159	TM160	TM161	TM162	TM163	TM164	TM165	TM166	TM167	TM168	TM169	TM170	TM171	TM172	TM173	TM174	TM175	TM176	TM177	TM178	TM179	TM180	TM181	TM182	TM183	TM184	TM185	TM186	TM187	TM188	TM189	TM190	TM191	TM192	TM193	TM194	TM195	TM196	TM197	TM198	TM199	TM200	TM201	TM202	TM203	TM204	TM205	TM206	TM207	TM208	TM209	TM210	TM211	TM212	TM213	TM214	TM215	TM216	TM217	TM218	TM219	TM220	TM221	TM222	TM223	TM224	TM225	TM226	TM227	TM228	TM229	TM230	TM231	TM232	TM233	TM234	TM235	TM236	TM237	TM238	TM239	TM240	TM241	TM242	TM243	TM244	TM245	TM246	TM247	TM248	TM249	TM250	TM251	TM252	TM253	TM254	TM255	TM256	TM257	TM258	TM259	TM260	TM261	TM262	TM263	TM264	TM265	TM266	TM267	TM268	TM269	TM270	TM271	TM272	TM273	TM274	TM275	TM276	TM277	TM278	TM279	TM280	TM281	TM282	TM283	TM284	TM285	TM286	TM287	TM288	TM289	TM290	TM291	TM292	TM293	TM294	TM295	TM296	TM297	TM298	TM299	TM300	TM301	TM302	TM303	TM304	TM305	TM306	TM307	TM308	TM309	TM310	TM311	TM312	TM313	TM314	TM315	TM316	TM317	TM318	TM319	TM320	TM321	TM322	TM323	TM324	TM325	TM326	TM327	TM328	TM329	TM330	TM331	TM332	TM333	TM334	TM335	TM336	TM337	TM338	TM339	TM340	TM341	TM342	TM343	TM344	TM345	TM346	TM347	TM348	TM349	TM350	TM351	TM352	TM353	TM354	TM355	TM356	TM357	TM358	TM359	TM360	TM361	TM362	TM363	TM364	TM365	TM366	TM367	TM368	TM369	TM370	TM371	TM372	TM373	TM374	TM375	TM376	TM377	TM378	TM379	TM380	TM381	TM382	TM383	TM384	TM385	TM386	TM387	TM388	TM389	TM390	TM391	TM392	TM393	TM394	TM395	TM396	TM397	TM398	TM399	TM400	TM401	TM402	TM403	TM404	TM405	TM406	TM407	TM408	TM409	TM410	TM411	TM412	TM413	TM414	TM415	TM416	TM417	TM418	TM419	TM420	TM421	TM422	TM423	TM424	TM425	TM426	TM427	TM428	TM429	TM430	TM431	TM432	TM433	TM434	TM435	TM436	TM437	TM438	TM439	TM440	TM441	TM442	TM443	TM444	TM445	TM446	TM447	TM448	TM449	TM450	TM451	TM452	TM453	TM454	TM455	TM456	TM457	TM458	TM459	TM460	TM461	TM462	TM463	TM464	TM465	TM466	TM467	TM468	TM469	TM470	TM471	TM472	TM473	TM474	TM475	TM476	TM477	TM478	TM479	TM480	TM481	TM482	TM483	TM484	TM485	TM486	TM487	TM488	TM489	TM490	TM491	TM492	TM493	TM494	TM495	TM496	TM497	TM498	TM499	TM500	TM501	TM502	TM503	TM504	TM505	TM506	TM507	TM508	TM509	TM510	TM511	TM512	TM513	TM514	TM515	TM516	TM517	TM518	TM519	TM520	TM521	TM522	TM523	TM524	TM525	TM526	TM527	TM528	TM529	TM530	TM531	TM532	TM533	TM534	TM535	TM536	TM537	TM538	TM539	TM540	TM541	TM542	TM543	TM544	TM545	TM546	TM547	TM548	TM549	TM550	TM551	TM552	TM553	TM554	TM555	TM556	TM557	TM558	TM559	TM560	TM561	TM562	TM563	TM564	TM565	TM566	TM567	TM568	TM569	TM570	TM571	TM572	TM573	TM574	TM575	TM576	TM577	TM578	TM579	TM580	TM581	TM582	TM583	TM584	TM585	TM586	TM587	TM588	TM589	TM590	TM591	TM592	TM593	TM594	TM595	TM596	TM597	TM598	TM599	TM600	TM601	TM602	TM603	TM604	TM605	TM606	TM607	TM608	TM609	TM610	TM611	TM612	TM613	TM614	TM615	TM616	TM617	TM618	TM619	TM620	TM621	TM622	TM623	TM624	TM625	TM626	TM627	TM628	TM629	TM630	TM631	TM632	TM633	TM634	TM635	TM636	TM637	TM638	TM639	TM640	TM641	TM642	TM643	TM644	TM645	TM646	TM647	TM648	TM649	TM650	TM651	TM652	TM653	TM654	TM655	TM656	TM657	TM658	TM659	TM660	TM661	TM662	TM663	TM664	TM665	TM666	TM667	TM668	TM669	TM670	TM671	TM672	TM673	TM674	TM675	TM676	TM677	TM678	TM679	TM680	TM681	TM682	TM683	TM684	TM685	TM686	TM687	TM688	TM689	TM690	TM691	TM692	TM693	TM694	TM695	TM696	TM697	TM698	TM699	TM700	TM701	TM702	TM703	TM704	TM705	TM706	TM707	TM708	TM709	TM710	TM711	TM712	TM713	TM714	TM715	TM716	TM717	TM718	TM719	TM720	TM721	TM722	TM723	TM724	TM725	TM726	TM727	TM728	TM729	TM730	TM731	TM732	TM733	TM734	TM735	TM736	TM737	TM738	TM739	TM740	TM741	TM742	TM743	TM744	TM745	TM746	TM747	TM748	TM749	TM750	TM751	TM752	TM753	TM754	TM755	TM756	TM757	TM758	TM759	TM760	TM761	TM762	TM763	TM764	TM765	TM766	TM767	TM768	TM769	TM770	TM771	TM772	TM773	TM774	TM775	TM776	TM777	TM778	TM779	TM780	TM781	TM782	TM783	TM784	TM785	TM786	TM787	TM788	TM789	TM790	TM791	TM792	TM793	TM794	TM795	TM796	TM797	TM798	TM799	TM800	TM801	TM802	TM803	TM804	TM805	TM806	TM807	TM808	TM809	TM810	TM811	TM812	TM813	TM814	TM815	TM816	TM817	TM818	TM819	TM820	TM821	TM822	TM823	TM824	TM825	TM826	TM827	TM828	TM829	TM830	TM831	TM832	TM833	TM834	TM835	TM836	TM837	TM838	TM839	TM840	TM841	TM842	TM843	TM844	TM845	TM846	TM847	TM848	TM849	TM850	TM851	TM852	TM853	TM854	TM855	TM856	TM857	TM858	TM859	TM860	TM861	TM862	TM863	TM864	TM865	TM866	TM867	TM868	TM869	TM870	TM871	TM872	TM873	TM874	TM875	TM876	TM877	TM878	TM879	TM880	TM881	TM882	TM883	TM884	TM885	TM886	TM887	TM888	TM889	TM890	TM891	TM892	TM893	TM894	TM895	TM896	TM897	TM898	TM899	TM900	TM901	TM902	TM903	TM904	TM905	TM906	TM907	TM908	TM909	TM910	TM911	TM912	TM913	TM914	TM915	TM916	TM917	TM918	TM919	TM920	TM921	TM922	TM923	TM924	TM925	TM926	TM927	TM928	TM929	TM930	TM931	TM932	TM933	TM934	TM935	TM936	TM937	TM938	TM939	TM940	TM941	TM942	TM943	TM944	TM945	TM946	TM947	TM948	TM949	TM950	TM951	TM952	TM953	TM954	TM955	TM956	TM957	TM958	TM959	TM960	TM961	TM962	TM963	TM964	TM965	TM966	TM967	TM968	TM969	TM970	TM971	TM972	TM973	TM974	TM975	TM976	TM977	TM978	TM979	TM980	TM981	TM982	TM983	TM984	TM985	TM986	TM987	TM988	TM989	TM990	TM991	TM992	TM993	TM994	TM995	TM996	TM997	TM998	TM999	TM1000	TM1001	TM1002	TM1003	TM1004	TM1005	TM1006	TM1007	TM1008	TM1009	TM1010	TM1011	TM1012	TM1013	TM1014	TM1015	TM1016	TM1017	TM1018	TM1019	TM1020	TM1021	TM1022	TM1023	TM1024	TM1025	TM1026	TM1027	TM1028	TM1029	TM1030	TM1031	TM1032	TM1033	TM1034	TM1035	TM1036	TM1037	TM1038	TM1039	TM1040	TM1041	TM1042	TM1043	TM1044	TM1045	TM1046	TM1047	TM1048	TM1049	TM1050	TM1051	TM1052	TM1053	TM1054	TM1055	TM1056	TM1057	TM1058	TM1059	TM1060	TM1061	TM1062	TM1063	TM1064	TM1065	TM1066	TM1067	TM1068	TM1069	TM1070	TM1071	TM1072	TM1073	TM1074	TM1075	TM1076	TM1077	TM1078	TM1079	TM1080	TM1081	TM1082	TM1083	TM1084	TM1085	TM1086	TM1087	TM1088	TM1089	TM1090	TM1091	TM1092	TM1093	TM1094	TM1095	TM1096	TM1097	TM1098	TM1099	TM1100	TM1101	TM1102	TM1103	TM1104	TM1105	TM1106	TM1107	TM1108	TM1109	TM1110	TM1111	TM1112	TM1113	TM1114	TM1115	TM1116	TM1117	TM1118	TM1119	TM1120	TM1121	TM1122	TM1123	TM1124	TM1125	TM1126	TM1127	TM1128	TM1129	TM1130	TM1131	TM1132	TM1133	TM1134	TM1135	TM1136	TM1137	TM1138	TM1139	TM1140	TM1141	TM1142	TM1143	TM1144	TM1145	TM1146	TM1147	TM1148	TM1149	TM1150	TM1151	TM1152	TM1153	TM1154	TM1155	TM1156	TM1157	TM1158	TM1159	TM1160	TM1161	TM1162	TM1163	TM1164	TM1165	TM1166	TM1167	TM1168	TM1169	TM1170	TM1171	TM1172	TM1173	TM1174	TM1175	TM1176	TM1177	TM1178	TM1179	TM1180	TM1181	TM1182	TM1183	TM1184	TM1185	TM1186	TM1187	TM1188	TM1189	TM1190	TM1191	TM1192	TM1193	TM1194	TM1195	TM1196	TM1197	TM1198	TM1199	TM1200	TM1201	TM1202	TM1203	TM1204	TM1205	TM1206	TM1207	TM1208	TM1209	TM1210	TM1211	TM1212	TM1213	TM1214	TM1215	TM1216	TM1217	TM1218	TM1219	TM1220	TM1221	TM1222	TM1223	TM1224	TM1225	TM1226	TM1227	TM1228	TM1229	TM1230	TM1231	TM1232	TM1233	TM1234	TM1235	TM1236	TM1237	TM1238	TM1239	TM1240	TM1241	TM1242	TM1243	TM1244	TM1245	TM1246	TM1247	TM1248	TM1249	TM1250	TM1251	TM1252	TM1253	TM1254	TM1255	TM1256	TM1257	TM1258	TM1259	TM1260	TM1261	TM1262	TM1263	TM1264	TM1265	TM1266	TM1267	TM1268	TM1269	TM1270	TM1271	TM1272	TM1273	TM1274	TM1275	TM1276	TM1277	TM1278	TM1279	TM1280	TM1281	TM1282	TM1283	TM1284	TM1285	TM1286	TM1287	TM1288	TM1289	TM1290	TM1291	TM1292	TM1293	TM1294	TM1295	TM1296	TM1297	TM1298	TM1299	TM1300	TM1301	TM1302	TM1303	TM1304	TM1305	TM1306	TM1307	TM1308	TM1309	TM1310	TM1311	TM1312	TM1313	TM1314	TM1315	TM1316	TM1317	TM1318	TM1319	TM1320	TM1321	TM1322	TM1323	TM1324	TM1325	TM1326	TM1327	TM1328	TM1329	TM1330	TM1331	TM1332	TM1333	TM133
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When each family (gramineae and leguminosae) is analysed individually, there is a diverse behavior with respect to overpass dates and to analysed crop parameter. It is shown that for bean fields in all overpasses the percent soil cover had significant correlations with many remote sensing parameters. On the other hand, wheat fields showed poor correlations with remote sensing parameters in P2 and in P3 passages. This is due to the fact that wheat presents high soil cover percentages and small variation coefficients at these overpasses (Table 1). This makes that gray level variations in various areas don't have percent soil cover variations correspondence, contrarily to the bean.

In the case of green leaf area index, the precise analysis of results is more complex, not only due to greater difficulty to its real field evaluation as well as the evaluation of the impact of its variation on reflectance when percent soil cover is invariable. To analyse the green leaf area index it is necessary to observe its relationship with percent soil cover. When the correlation between percent soil cover and LAI is high there are various remote sensing parameters that present good correlations with both crop parameters, as occurred with bean and wheat in P1 and bean in P3. When the correlation between crop parameters are not significant two situations are possible. First, various remote sensing parameters correlate with only one crop parameter (percent soil cover for bean in P2 and LAI wheat in P3). Second, few remote sensing parameters correlate with both crop parameters (wheat in P2). What determines the occurrence of one case or another is the general condition of the areas with respect to both crop parameters. When there are high percentage of soil cover and LAI few remote sensing parameters correlates with both crop parameters (wheat in P2). When one of the crop parameters is not at its maximum expression in many areas, it can occur that various remote sensing parameters correlate with only one crop parameter.

This interrelationship between LAI and percent soil cover is very important once their behavior during growing season are different and not necessarily simultaneous. In the early season, after germination, it is a parallelism between them. However, when the vegetation covers completely the soil there is a percent soil cover stabilization (Figure 1). At the end of season, with the senescence process there is again a tendency to a similarity between both crop parameters. The timing of these relations are typical for each crop species and surely affect their evaluations via remote sensing.

The discussion of the remote sensing parameters that show better correlations with the two crop parameters includes not only single bands, but also the band ratios.

The analysis of single bands showed that there is great variations with respect to their correlative potential with crop parameters. From Table2, the following general decreasing classification is obtained with respect to the number of correlations: TM4>TM3>TM5>TM7>TM2>TM1. This sequence can be understood through the knowledge of vegetation and soil

spectral behavior. In TM1 and TM2 bands these targets are spectrally similar, which produces a low sensibility in terms of cover differences; the same applies to the green leaf area index. In the infrared region, where is located the TM4, the difference between soil and vegetation reflectance is stronger, and is just where that are more correlations between digital values and the crop parameters. In an intermediate position are the TM3, TM5 and TM7 bands with intermediate correlative potentials.

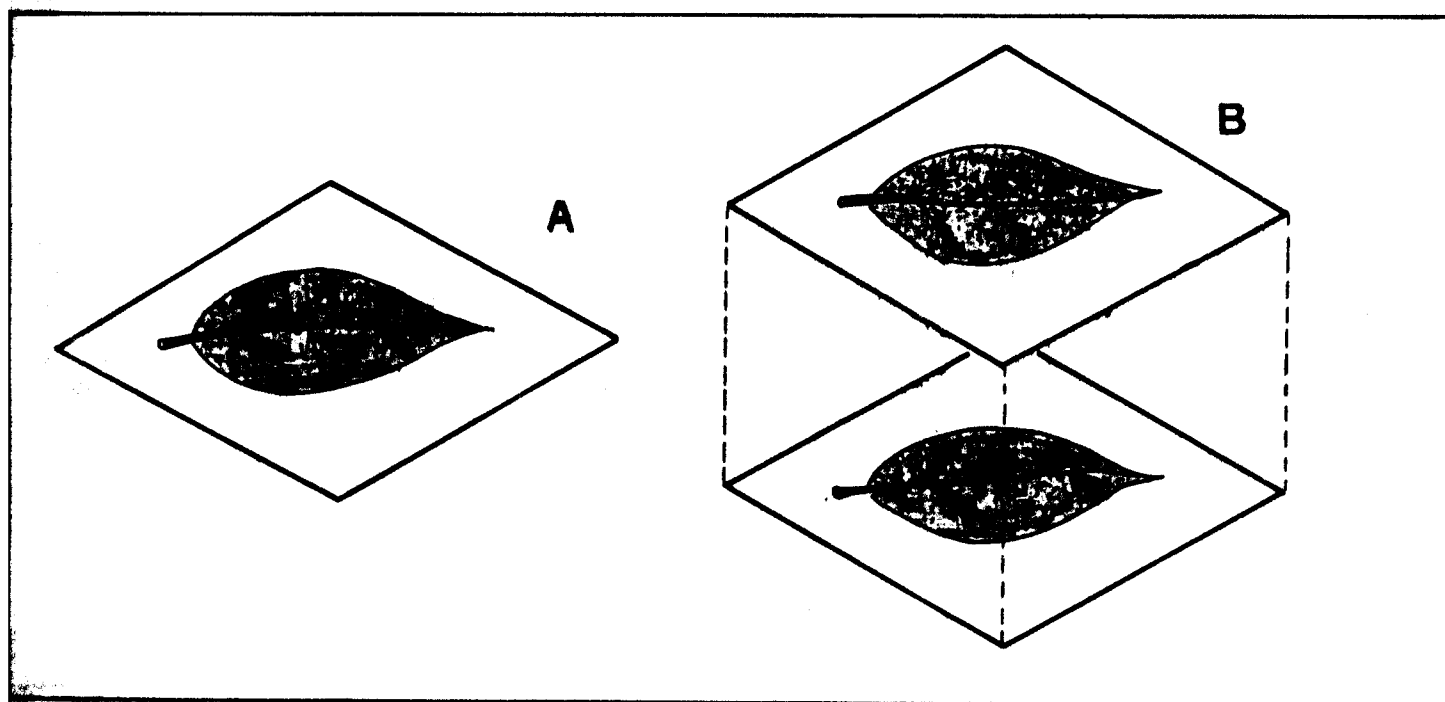


Fig. 1 - In (A) soil cover has perfect correspondence to LAI and in (B) the same percent soil cover corresponds to two LAI units.

An analysis of band ratios showed that the indices with TM4 as a component are those that present greater correlative potentials with crop parameters. These are the cases of I3, I6, I9, I10 and I12. In addition these, it should be noticed the index I11 (TM5/TM7) that presented together with I10 (TM4/TM7) a large number of correlations with crop parameters in the three overpasses. In the more distant spectral bands occur spectral response inversion between vegetation and soil, that is, the soil develops a greater reflectance values than the vegetation. These results indicate the importance of TM5 and TM7 spectral bands to agronomic studies.

Although none of the indices utilized presented better results than TM4, some show similar performance to the TM4 and can be considered satisfactory. In order of decreasing number of correlated ratios are: $I_{10}=I_{11}>I_{12}>I_6=I_9>I_7$. On the other hand there are ratio indices that have shown low utility in the establishment of correlations with crop parameters utilized here. These are: $I_1<I_5<I_4=I_8=I_2$. These results show the high potential of TM4 spectral band to establish correlations with crop parameter related to crop vigor or general crop conditions. Furthermore, one observes that band associations in the ratio indices produce better results than isolated bands, mainly if one of which is the TM4.

4. SUMMARY

Nevertheless only three satellite overpasses were available, this work showed the importance of the species and the general growing stage of the fields in studies related to green leaf area index and percent soil cover. It was confirmed the higher performance of the TM4 in relation to other TM single bands and to the tested band ratios also. Finally it should be necessary to achieve additional studies that relate TM5 and TM7 to another agronomic parameters.

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