VINEYARD CANOPY DENSITY MAPPING
WITH IKONOS SATELLITE IMAGERY[*]

Lee F. Johnson
Calif. State Univ. Monterey Bay
NASA Ames Research Center
Moffett Field, CA 94035 U.S.A.

Dean Roczen and Shlemon Youkhana
VESTRA Resources, Inc.
Redding, CA 96002 U.S.A.

ABSTRACT

Satellite-based IKONOS imagery is being evaluated for precision viticultural management. Multispectral imagery was collected over California's Napa Valley, a premium winegrowing region, in late season 2000. Image data were geo-registered and converted to normalized difference vegetation index (NDVI) on a per-pixel basis. Spatial resolution was sufficient to detect within-field variations in canopy density, a key variable for operational vineyard management. Field measurements of leaf area index (LAI=m^2 leaf area m^{-2} ground area) and post-season pruning weight were made at several calibration sites, and registered to the imagery using GPS. A linear relationship (r^2=.74) between NDVI and LAI was used to generate LAI imagery. A GIS data layer containing information on row and vine spacing, or area allocation per vine, was applied to the LAI imagery to derive leaf area per vine and leaf area per meter of row. Validation results are presented for all image products. These types of image products are potentially useful for canopy and irrigation management.

1.0 INTRODUCTION

Vineyard leaf area is related to fruit ripening rate (Winkler, 1958), disease incidence (English *et al.*, 1989), and fruit and wine quality (Smart, 1985; Iland *et al.*, 1994). Despite its importance, growers have no efficient way of monitoring and mapping leaf area during the growing season. Canopy density is perhaps most commonly assessed on the basis of pruning weights (prior season woody production) collected on sample vines during dormancy. Decisions are then made concerning viticultural management practices to be applied during the remainder of the dormant period and following growing season.

---

[*] Presented at the Third International Conference on Geospatial Information in Agriculture and Forestry, Denver, Colorado, 5-7 November 2001.

Use of airborne multispectral imagery, converted to NDVI, has been previously demonstrated for mapping differences in canopy density within individual vineyard blocks (Johnson *et al.*, 1998, 2001). Today, an expanding clientele uses commercial NDVI based imagery for various purposes such as harvest preparation, vineyard re-development, and identification of problems related to irrigation, nutrient status, disease and pest infestation (Penn, 1999; Carothers, 2000). However, NDVI measures the way in which a canopy reflects sunlight as a function of wavelength, a variable generally not of direct relevance to growers. Therefore its use is primarily as a *relative* indicator of canopy density. The purpose of this study was to explore the use of NDVI for obtaining *absolute* estimates of leaf area, a variable of direct relevance to viticultural management. Calibration and validation sites were established to test robustness with respect to several potential confusion factors encountered in the vineyard.

2.0 METHODS

2.1 STUDY AREAS

Study areas were the Tokalon and Huchica Hills vineyard properties (ranches) of the Robert Mondavi Winery (Oakville, CA). The ~500 ha Tokalon ranch is located in California's Napa Valley at ~38°25'N/122°25'W, growing mainly red grape varieties on sandy clay loam soils. The ~300 ha Huchica Hills ranch is located in the cooler Carneros region just south of Napa Valley (~38°14'N/122°22'W), growing red and white varieties on clay soils and with varying topography. Both ranches are subdivided into individual fields (blocks) of planting density, age and trellis structure. In both areas, full canopy expansion (maximum LAI) is generally attained by late July and persists through harvest.

2.2 LEAF AREA CALIBRATION

Direct measurements of LAI were made at 16 sites: seven at Tokalon and nine at Huchica Hills. Three to six sample vine replicates were measured per site, distributed over an area of ~10 m x 10 m. All leaves were removed from each sample vine, placed in separate plastic bags and sealed. Total leaf weight was recorded per sample vine. A subsample was extracted and weighed for each vine. Within 24 hours, subsample area was measured with a leaf area meter. Total area per sample vine was calculated as $LA_v = LA_s * (w_t/w_s)$, where LA_v is leaf area per sample vine, LA_s is leaf area per subsample, w_t = total weight, and w_s is subsample weight. Sample vine LAI was then $LAI_v = LA_v/vine\_area$, where vine_area is vine_spacing * row_spacing (alternatively, block_size/vines_per_block). Site LAI was mean LAI_v. Measurements were made 22-SEP to 6-OCT, 2000, shortly after harvest.

Indirect measurements of LAI were made at six additional sites based on shoot length observation. For each sample vine, the total number of shoots was recorded and mean length was calculated as the mean of five randomly selected shoots. Mean shoot length was then converted to shoot leaf area (based on an observed relationship shoot_leaf_area=-355+30.1*shoot_length, r^2=0.64), and subsequently to LA_v and site LAI.

The location of each calibration site was mapped to sub-meter accuracy with differential GPS.

2.3 IMAGE PROCESSING

Two IKONOS 4-meter multispectral satellite images were collected during the period of full canopy expansion: 21-AUG-2000 for Huchica Hills and 4-OCT-2000 for Tokalon. Digital counts were converted to at-sensor radiance units by applying radiometric calibration coefficients (Peterson, 2001). The atmosphere was assumed uniform throughout each scene and no correction was applied. The images were projected to the State Plane Coordinate system by image-to-image registration with an orthorectified base map. The images were then converted on a per pixel basis to NDVI. A relationship was established between NDVI and ground based LAI using a nearest neighbor approach (Fig. 1). The resulting calibration equation was then applied per-pixel to generate an LAI image. Raster GIS layers containing per-block row and vine spacing were used to convert the LAI image per-pixel to LA_v as LAI*vine_area, and to leaf area per meter of row (LA_{m_row}) as LAI*row_spacing (Plates 1, 2).

2.4 VALIDATION

Pruning weights were recorded on all sample vines used for direct LAI measurement. Year 2000 shoots were removed, weighed, and a relationship between shoot mass and leaf area per vine was established (Fig. 2). These measurements were taken during dormancy 17-NOV-2000.

Pruning weights and DGPS measurements were collected at 29 additional sites (15 in Huchica, 14 in Tokalon) during 15-20 NOV, 2000 for use in image validation. The weights were converted to vine leaf area, and subsequently to LAI and leaf area per meter of row, according to the above relationship. These ground measurements were compared with image-based estimates to evaluate prediction accuracy.

3.0 RESULTS and DISCUSSION

The NDVI-LAI calibration relationship (Fig. 1) was found to be linear at these study areas due to the relatively low LAIs involved (~0.5-3.0). This LAI range is fairly typical of Napa Valley vineyards, although greater values might be encountered in warmer winegrape and table grape climates such as found in California's Central Valley. In these cases, a curvilinear relationship between NDVI-LAI might result due to saturation of canopy reflectance with increasing canopy density.

The validation results (Table 1) indicate the following root-mean-square (rms) errors for image products: 0.45 m^2 leaf area m^{-2} ground area, 1.3 m^2 leaf area m^{-1} row, and 2.4 m^2 leaf area vine^{-1}. There is some indication that the procedure fails for the highest leaf area vines (validation sites 27-29), where substantial underestimation is observed (Table X). Foliage at these sites is highly clumped, with high leaf area, widely spaced rows, and hence a high

proportion of bare soil. In such cases it may be more appropriate to express NDVI as the mean of several pixels rather than extracting single pixels as here. In any case, the issue is perhaps not of major concern as these blocks are well established (sometimes decades old) with generally lower maintenance requirements. Also, the widely spaced, discontinuous planting arrangement is now somewhat obsolete, at least in the Napa Valley. When sites 27-29 are excluded from consideration, rms errors decline to 0.37 m^2 m^{-2} ground area (r^2=0.67), 0.9 m^2 m^{-1} row (r^2=0.74), and 1.6 m^2 $vine^{-1}$ (r^2=0.78) (Fig. 3).

4.0 CONCLUSIONS

These results suggest that NDVI provides a fairly robust basis for calculation of vineyard leaf area with respect to such potential confusion factors as trellis type (canopy architecture), planting density, variety, age, soil type, topography and image acquisition date. Leaf area is relevant to canopy and irrigation management. Remote mapping of LA_v and LA_{m_row} relates to canopy management, which is used to influence microclimate and assure adequate supply of photosynthate to fruit (Iland *et al*., 1994). Remotely sensed LAI can serve to parameterize irrigation management models (*e.g*., Nemani and Johnson, 2001) for maintenance of vines at target levels of water stress. Both of these aspects are under evaluation.

5.0 ACKNOWLEDGMENT

6.0 REFERENCES

J. Carothers, "Imagery technology meets vineyard management." *Practical Winery and Vineyard*, May/June 2000.

J. English, C. Thomas, J. Marois and W. Gubler, "Microclimates of grapevine canopies associated with leaf removal and control of Botrytis bunch rot." *Phytopathology* 79:395-401, 1989.

P. Iland, D. Botting, P. Dry, J. Giddings and R. Gawel, "Grapevine Canopy Performance." In *Proceedings of Canopy Management Viticulture Seminar*, Australian Soc. Viticulture and Oenology, Mildura, Victoria, Australia, pp. 18-22, August 1994.

L. Johnson, D. Bosch, D. Williams and B. Lobitz, "Remote Sensing of Vineyard Management Zones: Implications For Wine Quality." *Appl. Engin. Agric.,* 17/4, 2001 (in press)

L. Johnson, B. Lobitz, D. Bosch, D. Williams, S. Wiechers, and P. Skinner, "Of Pixels and Palates: Can Geospatial Technology Help Produce a Better Wine?"

In *Proceedings, First Int'l. Conference Geospatial Information in Agriculture & Forestry*, Lake Buena Vista FL, 2:469-476, June 1998.

R. Nemani and L. Johnson, "Adding Science to Intuition: Application of Remote Sensing and Ecosystem Modeling to Vineyard Management." Australian Grapegrower and Winemaker, Annual Technical Issue, June 2001.

C. Penn, "Grape Growers Gravitating Toward Space Age Technologies." Wine Business Monthly, pp. 53-56, February 1999.

B. Peterson, "IKONOS Relative Spectral Response and Radiometric Calibration Coefficients." SE-REF-016, Rev. A, Space Imaging, Inc., April 2001.

R. Smart, "Principles of Grapevine Canopy Microclimate Manipulation with Implications for Yield and Quality." *Amer. J. Enol. & Vitic.*, 36:230-239, 1985.

A. Winkler, "The Relation of Leaf Area and Climate to Vine Performance and Grape Quality." *Amer. J. Enol. & Vitic.*, 9:10-23, 1958.
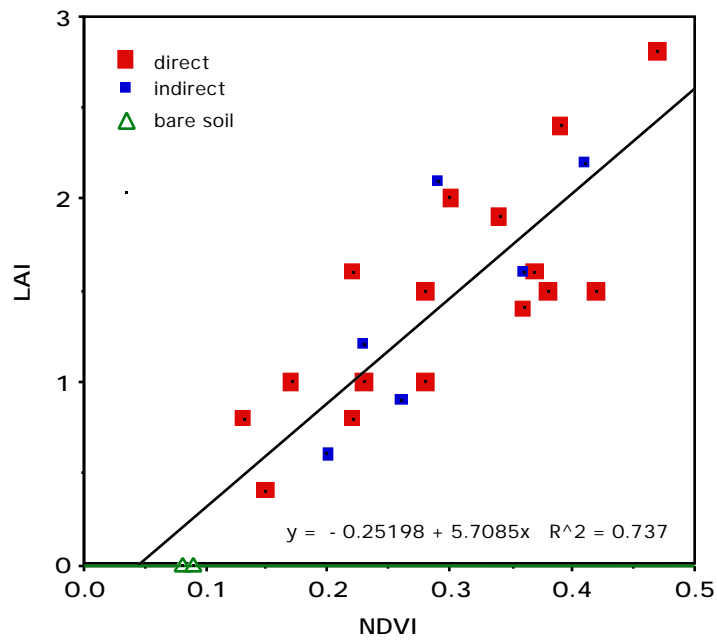
Figure 1. Image NDVI vs. *in-situ* LAI. LAI measurement approach (direct, indirect) as indicated. Bare soil at study areas at included for reference.
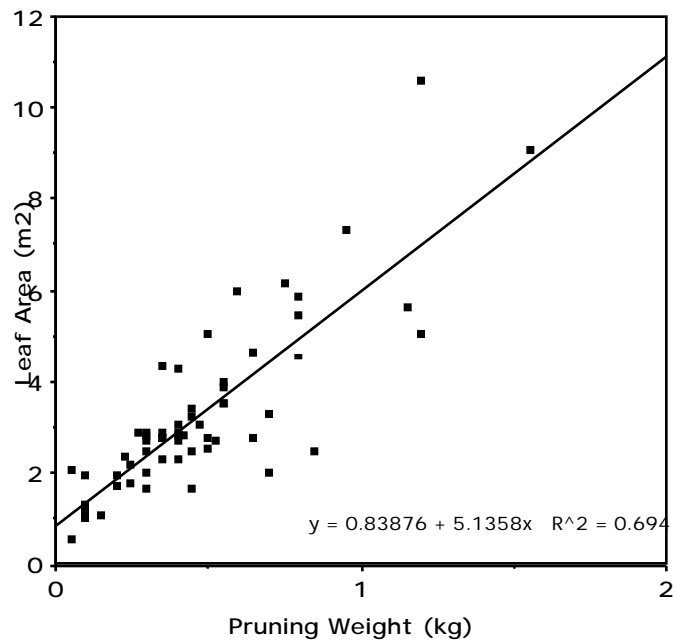

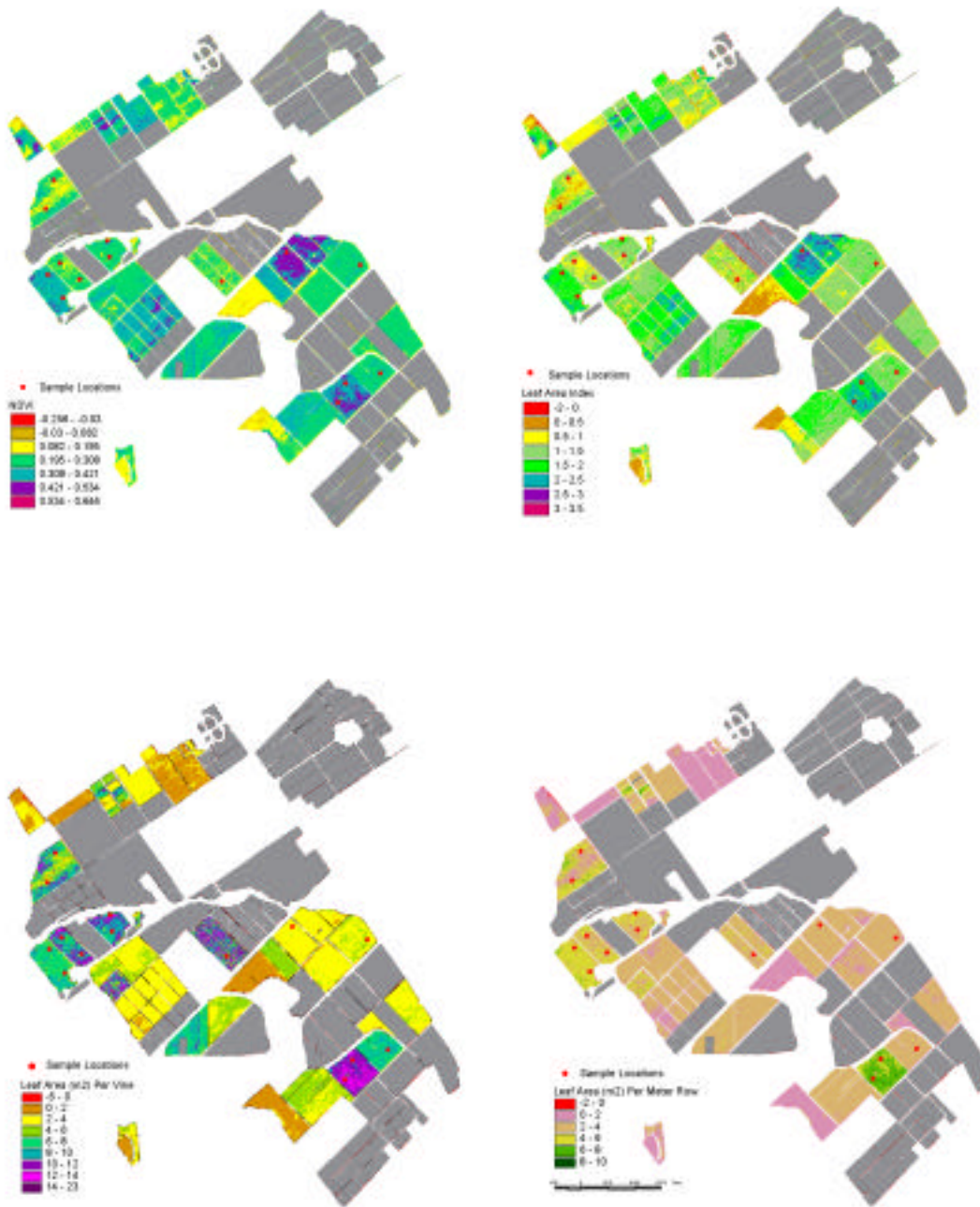Figure 2. Relationship between *in-situ* per-vine pruning weight and *in-situ* per-vine leaf area.

Plate 1. Tokalon study area. Upper left – NDVI (effective range ~0-0.6); upper right - LAI (~0-3.5 m²m⁻²); lower left - leaf area (~0-14 m²) per vine; lower right- leaf area (~0-8 m²) per meter of row. Validation sites as red dots. Gray areas - missing GIS data.

Plate 2. Huchica Hills study area. Upper left – NDVI (effective range ~0-1); upper right - LAI (~0-3.5 m² m⁻²); lower left - leaf area (~0-14 m²) per vine; lower right- leaf area (~0-8) m² per meter of row. Validation sites as red dots. Gray areas - missing GIS data.
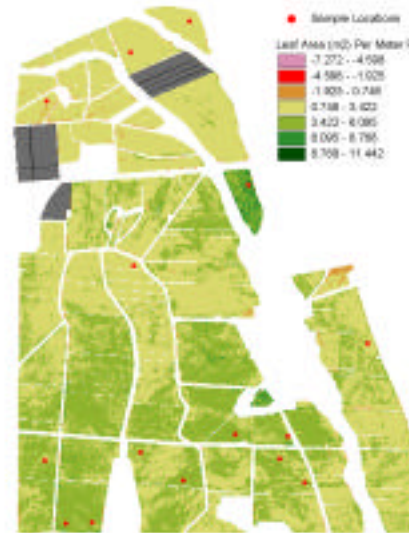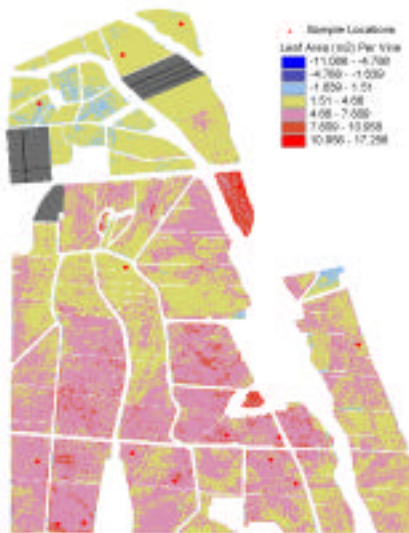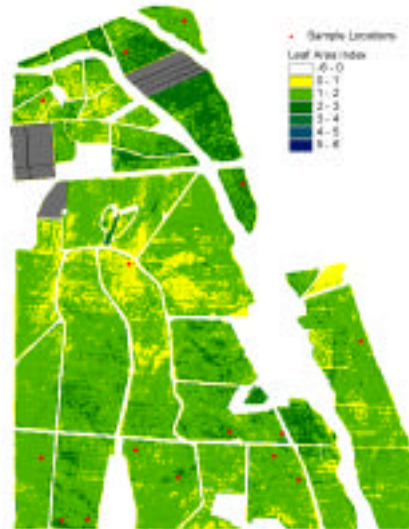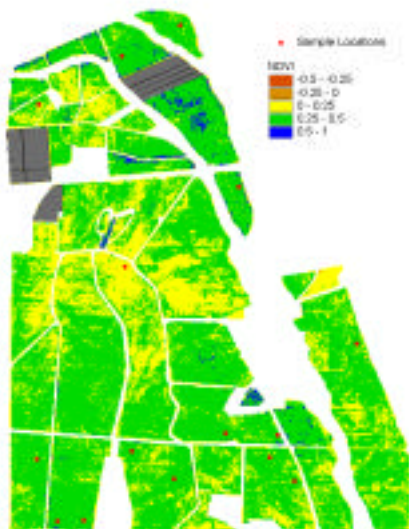
Table 1. Validation data, sorted by pruning weight. Variety: CH=Chardonnay, PN=Pinot Noir, CS=Cabernet Sauvignon, ZN=Zinfandel, ME=Merlot, CF=Cabernet Franc, SB=Sauvignon Blanc. Trellis type: V=vertical, Y=split, S=sprawl. All leaf area (LA) in m^2.

						LAI		LA vine^{-1}		LA m^{-1} row	
site	variety	trellis	vine sp (ft)	row sp (ft)	prun wt/ (kg)	grnd	img	grnd	img	grnd	img
1	CH	V	4	4	0.11	0.94	1.33	1.40	2.00	1.15	1.63
2	PN	V	4	4	0.11	0.94	1.19	1.40	1.78	1.15	1.45
3	CS	V	4	4	0.28	1.53	2.08	2.28	3.09	1.87	2.53
4	ZN	V	5	6	0.30	0.85	1.45	2.38	4.03	1.56	2.64
5	ME	V	5	8	0.31	0.66	1.15	2.45	4.26	1.61	2.81
6	PN	V	5	8	0.32	0.66	0.81	2.47	3.01	1.62	1.99
7	CH	V	4	4	0.35	1.77	2.11	2.64	3.16	2.16	2.57
8	ME	V	5	8	0.56	1.01	1.50	3.74	5.57	2.45	3.67
9	CF	S	5	9	0.59	0.92	1.55	3.85	6.47	2.52	4.24
10	ME	V	5	7	0.65	1.28	1.25	4.18	4.08	2.74	2.67
11	CH	V	5	8	0.67	1.15	1.38	4.29	5.10	2.81	3.36
12	CS	S	6	12	0.68	0.65	0.81	4.32	5.44	2.36	2.97
13	CS	S	8	10	0.75	0.63	0.88	4.69	6.53	1.92	2.68
14	CH	V	5	8	0.82	1.36	1.58	5.05	5.83	3.31	3.85
15	CF	S	5	9	0.84	1.23	1.89	5.16	7.90	3.39	5.18
16	CF	S	8	12	1.02	0.68	0.99	6.08	8.82	2.50	3.62
17	ME	V	5	8	1.11	1.76	1.53	6.52	5.65	4.28	3.73
18	CH	V	5	8	1.20	1.88	2.27	7.00	8.38	4.59	5.53
19	ME	V	5	8	1.27	1.98	1.73	7.36	6.40	4.83	4.22
20	CS	V	5	8	1.32	2.05	1.56	7.62	5.77	5.00	3.81
21	CF	S	8	12	1.33	0.86	1.09	7.69	9.71	3.15	3.98
22	CS	S	8	10	1.43	1.10	1.58	8.18	11.74	3.36	4.82
23	CS	V	10	6	1.52	1.55	1.38	8.65	7.69	2.84	2.52
24	ME	V	5	8	1.56	2.38	2.30	8.85	8.50	5.81	5.60
25	CS	Y	6	10	1.65	1.67	1.99	9.31	11.11	5.09	6.07
26	CS	Y	6	10	2.08	2.06	2.00	11.50	11.16	6.29	6.10
27	SB	S	10	10	2.11	1.26	0.53	11.68	4.95	3.83	1.62
28	CH	Y	5	10	2.50	2.94	1.83	13.68	8.42	8.98	5.58
29	CS	S	6	12	2.55	2.08	1.27	13.94	8.46	7.62	4.63

LAI

y = 0.62992 + 0.68539x   R^2 = 0.673

image (m2/m2)

ground (m2/m2)

rmse=0.37

Leaf Area per Vine

y = 1.4327 + 0.90558x   R^2 = 0.781

image (m2)

ground (m2)

rmse=1.6

Leaf Area/m row

y = 1.1986 + 0.78493x   R^2 = 0.740
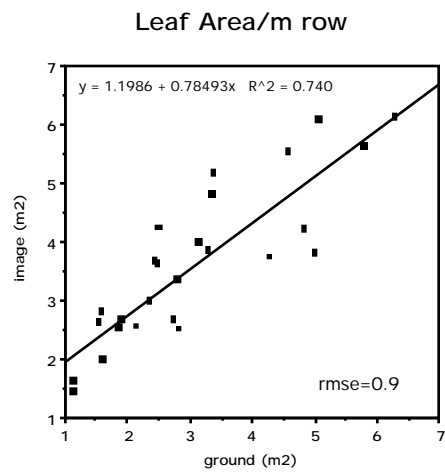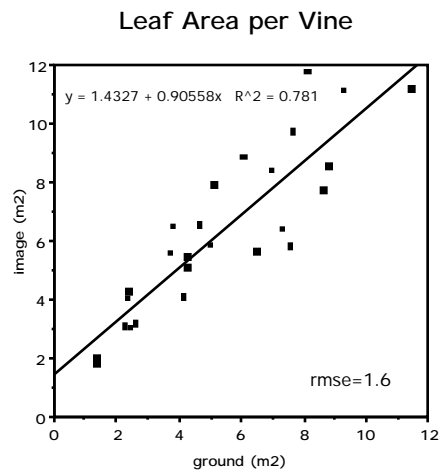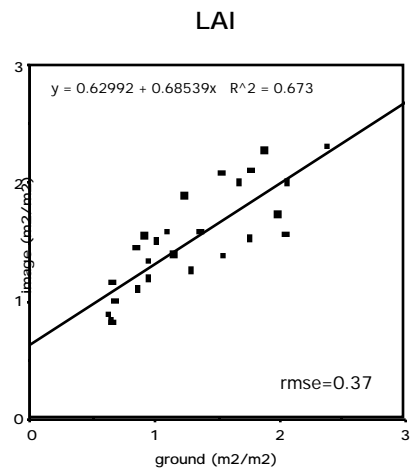
image (m2)

ground (m2)

rmse=0.9

Figure 3. Validation results, ground vs. satellite estimates, excluding sites 27-29.