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OPTIMISE Final Conference, 21–23 February 2018, Sofia, Bulgaria

Global Challenge of Phenotyping

How to enhance annual yield gains of maize from 1.6% to 2.4% on essentially the same land area, and as climates change and the costs of fertilizer, water, and labor increase?



RGB, Red, Green and Blue broad-band visible light reflectance

Meaningful data can be had from these normal digital images, especially considering 1. excellent color calibration during production covering photosynthetically active radiation (PAR) and 2. very high spatial resolution (mm).







CIMMYT Maize Scanner

RGB field-based phenotyping (http://github.com/george-haddad/CIMMYT)

Calculates a number of RGB based indexes for estimating disease impacts, crop vigor, LAI, biomass at the leaf and canopy scale, including Breedpix (GA and GGA), Triangle Greeness Index (TGI), and Normalized Green Red Difference Index (NGRDI)

University of Barcelona HTPP



The ARF OktoXL 6S12 More power for higher expectation









Lumix GX7 16 MP RGB

Also AIRINOV MultiSpec 4 NDVI/PRI, SonyQX1 and Tetracam MCA-6 custom

Improved processing techniques: 3D models and image segmentation

Computer intensive processes should be batched remotely.

Semi-automatic process should be as efficient and consistent as possible.

Agisoft Photoscan 3D and University of Barcelona MosaicTool built as a plug-in within FIJI (ImageJ)





Dense cloud creation and dense cloud classification (DSM)



3D wireframe "mesh" and triangulated surface model



Benefits of 3D models for UAV plant phenotyping

- Orthorectifaction of UAV
 movement/terrain effects
- 3D related data products
- Costs of 3D models for UAV plant phenotyping
- High computing requirements (CPU+GPU)
- Commercial software options (educational discounts can be great)
- Required high percentage of image overlap (continuous capture)

Dense cloud model over 3D mesh with texture



200 million points per ha, 1.5 cm xy

MosaicTool: University of Barcelona FIJI Plugin (ImageJ)

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Allows for segmenting (and processing!) exact same ground spatial area for hundreds of plots in less than one student/hour. Supports RGB, Multispectral (4-12 bands) and TIR sensor indexes.

Field season post-processing down from 9 months to 6 weeks!!!



Kefauver et al. In preparation

RGB comparisons from UAV and ground for low N phenotyping Zimbabwe







Figure 3. Examples of the differences in resolution between the images of maize taken at ground level and aerial level. A) maize plants at ground level. B) maize image at ground level with GA (Green Area). C) maize image at ground showing GGA (Greener Green Area). D) maize image at aerially. E) maize aerial image with GA (Green Area). F) maize aerial image with GGA (Greener Green Area).

Buchaillot et al., in preparation



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RGB comparisons from UAV and ground for low N phenotyping Zimbabwe



Buchaillot et al., in preparation

Multivariate models assessments

Estimations of Grain Yield (GY) with different categories of remote sensing traits including: RGB ground and aerial level and agronomic data, such as ASI (Anthesis Silking Interval), AD (Anthesis Data), MOI (Moisture), SEN (Canopy Senescence) and PH (Plant Height).

	R ²	Р
RGB ground	0.249	***
RGB ground+ Field sensors	0.403	***
RGB aerial	0.239	***
RGB aerial + Field sensors	0.384	***
Agronomic + RGB ground	0.559	***
Agronomic + RGB aerial	0.560	***
		***. <i>P</i> <0.001

Buchaillot et al., MS thesis

Multispectral sensors for UAVs

Working with multiple sensors each with a specific bandpass filter. Tetracam sensors with real-time calibration to reflectance with a matching micro filter array in the incident light sensor.

Mosaic ortho-rectification of 11 bands using Agisoft PhotoScan, which permits 11 band multispectral 3D point clouds.





Multispectral Indexes

Normalized Difference Vegetation Index (NDVI)	(R840-R670)/(R840+R670)	(Rouse et al., 1973)	
Soil Adjusted Vegetation Index (SAVI)	(R840- R670)/(R840+R670+L)*(1+0.5)	(A. R. Huete <i>,</i> 1988)	all the second
Optimized soil-adjusted vegetation index (OSAVI)	((1+0.16)*(R780- R670))/((R780+R670+0.16))	(Rondeaux et al., 1996)	in the co
Renormalized Difference Vegetation Index (RDVI)	(R840 - R670) / ((R840 + R670)^1/2)	(Roujean and Breon, 1995)	
Enhanced Vegetation Index (EVI)	2.5*(R840-R670)/(R840+(6*R670)- (7.5*R450)+1)	(Huete et al., 2002)	Soilmask
Photochemical Reflectance Index (PRI)	(R550-R570)/(R550+R570)	(Gamon et al., 1997)	JUIITIUSK
Modified Chlorophyll Absorption Ratio Index (MCARI)	[(R700-R670)-0.2*(R700- R550)]*R700/R670	(Daughtry, 2000)	NDVI 0.4-1
Transformed Chlorophyll Absorption in Reflectance Index (TCARI)	3*(R700-R670)-0.2*(R700- R550)*(R700/R670)	(Haboudane et al., 2002)	N' mar al anno
Anthocyanin Reflectance Index 2 (ARI2)	R840*(1/R550-1/R700)	(Gitelson et al., 2001)	antioted from the
Carotenoid Reflectance Index 2 (CRI2)	1/R550-1/R700	(Gitelson et al., 2002)	
Water Band Index (WBI)	R950/R900	(Peñuelas et al., 1993)	

RGB and multispectral measurements from the UAV and ground compared against yield in low and optimum Phosphorous treatments





Gracia-Romero et al., 2017 Frontiers in Plant Science https://doi.org/10.3389/fpls.2017.02004

Comparisons of Sensors for Ground and Aerial (UAV) Phenotyping



RGB and multispectral measurements from the UAV and ground compared against yield in low and optimum Phosphorous treatments

		Grain yiek	P content			
	NPF	OP	Comb.	NPF	OP	Comb.
RGB IND	CES/GROU	ND				
Intensity	0.194	-0.217	-0.084	-0.014	-0.067	-0.041
Hue	0.777***	0.732***	0.827***	0.336	-0.370	0.594*
Saturation	0.468*	-0.027	-0.179	0.065	0.247	-0.429*
Lightness:	0.459*	-0.014	0.205	0,086	-0.152	0.126
a'	-0.601**	-0.725***	-0.818***	-0.334	0.405*	-0.643**
b^*	0.572**	0.226	0.171	0.110	-0.020	-0.157
u*	-0.300	-0.729***	-0,786***	-0.267	0.425*	-0.667**
10th	0.642***	0.362	0,434**	0.151	-0.152	0.094
GA	0.816***	0.817***	0.878***	0.111	-0.369	0.707**
GGA	0.822***	0.816***	0.877***	0.122	-0.367	0.711**
RGB IND	CES/AERIA	L				
Intensity	-0.223	-0.715***	-0.620***	0.166	0.021	-0.359
Hue	0.731***	0.798***	0.868***	-0.082	-0.361	0.624**
Saturation	0.149	0.266	-0.235	-0.539*	-0.112	-0.581*
Lightness	-0.102	-0.653***	-0.526***	0.109	-0.047	-0.316
a*	-0.856***	-0.784***	-0.883***	-0.284	0.339	-0.750**
b*	0.192	0.002	-0.292*	-0.466*	-0.221	-0.575*
U*	-0.830***	-0.777***	-0.873***	-0.424*	0.284	-0.777**
10 ¹⁶	0.318	0.084	0.016	-0.333	-0.337	-0.283
GA	0.837***	0.814***	0.891***	0,139	-0.343	0.693**
GGA	0.790***	0.752***	0.837***	0.206	-0.309	0.697**

Correlations were studied across plots within the non-phosphorus fertilization (NPF) and the optimal phosphorus (OP) trials, as well as both in combination (Comb.). Levels of signification: P < 0.05: P < 0.01; P < 0.001.

		P Content				
	NPF	OP	Comb.	NPF	OP	Comb.
MULTISPECT	RAL INDIC	ES	1.0.000			
NDVI.ground	0.734***	0.711***	0.883***	0.058	-0.423	0.669***
NOVI	0.629***	0.643***	0.823***	0.324	-0.347	0.800***
SAVI	0.652***	0.644***	0.823***	0,159	-0.269	0.790***
OSAM	0.657**	0.655**	0.829***	0.216	-0.303	0.797***
RDM	0.658***	0.650***	0.829***	0.198	-0.286	0.795***
EVI	0.613***	0.529**	0.798***	0.119	-0.220	0.782***
PRI	0.039	0.312	0.406**	0,428*	0.032	0.466*
MCAR	0.358	-0.019	0.452**	-0.035	-0.033	0.463*
TCARL	0.172	-0.200	0.238	-0.147	0.055	0.314
TCAR/OSAVI	-0.401*	-0.618**	-0.748***	-0.368	0.283	-0.700***
ARI2	-0.012	0.286	-0.133	-0.286	-0.002	-0.363
CRI2	0.018	0.359	-0.091	-0.162	-0.064	-0.364
WEV	0.241	0.596**	0.598***	-0.014	-0.064	0.414*
MULTISPECT	FRAL BANE	xs	Transfer.	-		0100-000
B450	-0.348	-0.688***	-0.638***	-0.459	0.318	-0.383
8550	0.261	-0.505**	-0.102	-0.205	0.371	0.036
B570	0.032	-0.529**	-0.419**	-0.498*	0.212	-0.354
B670	-0.302	-0.566**	-0.739***	-0.540*	0.398	-0.731***
B700	-0.116	-0.525**	-0.602***	-0.463*	0.324	-0.567**
B720	0.269	-0.045	0.153	-0.319	0.125	0.047
8780	0.465*	0.477*	0.741***	-0.020	-0.122	0.688***
B840	0.496*	0.550**	0.779***	0.010	-0.137	0.744***
6880	0.442*	0.492*	0.753***	-0.061	-0.129	0.736***
B900	0.425*	0.537**	0.761***	-0.063	-0.083	0.739***
B950	0.390*	0.411*	0.724***	-0.024	-0.091	0.741***

Constitutions were studied across plots within the non-phosphona furtilization (NPF) and the optimal phosphonus (DP) trails, as well as both in combination (Comb.). Levels of signification: P < 0.05; P < 0.01; P < 0.001.

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RGB and multispectral measurements from the UAV and ground compared against grain yield in low and optimum phosphorous treatments

		Non-phosphor	us application	Optimum phosphorus		
	RGB ground	GY = -1.26 - 1.3 440.53 ·GA +	38* + 0.72 ·∪* - 469.95 ·GGA	GY = 4.80 + 13.26 ·GGA		
	indices	R ² = 0.762***	RSE= 0.535	R ² = 0.665***	RSE= 0.593	
ele	RGB aerial	GY = 12.90) - 0.77 ·a*	GY = 12.30 - 0.12 Lightness + 9.97 GA		
<u>Y</u>	indices	R ² = 0.732***	RSE= 0.531	R ² = 0.704***	RSE= 0.569	
Ŀ.	Multispectral	GY = 7.07 + 0.69	·B840 - 0.69 ·B900	GY = 12.40 - 0.89 ·B450 + 0.37 ·B670 + 0.14 ·B900		
D	bands	R ² = 0.360**	RSE= 0.838	R ² = 0.668***	RSE= 0.616	
Ū	Multispectral indices	GY = -0.52 +11.95·SAVI		GY = -19.27 - 1476.63 ·NDVI+ 1011.59 ·SAVI + 16.54 ·WBI - 14.96 ·OSAVI		
		R ² = 0.396**	RSE= 0.798	R ² = 0.558*	RSE= 0.728	

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Conclusions Low N and P Maize Phenotyping with UAVs

- Maize breeding shows promise for improving GY in low N environments, variability in performance suggests potential for further improvements.
- RGB sensors are functional technology from the ground or UAV, similar to SPAD or NDVI, but complimentary to some agronomic measurements.
- Growth stage timing is critical in order to optimize HTPP benefits to plant breeding. Gains with new technologies in larger breeding platforms.
- We need to take advantage of known effects of low N on physiological processes to focus our efforts to bring HTPP to low N breeding.

In collaboration with:



UNIVERSITAT DE

BARCELONA







Thank you for your attention

CGIAR

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