# Supplementary Materials: Article Establishment of Plot-Yield Prediction Models in Soybean Breeding Programs Using UAV-Based Hyperspectral Remote Sensing

**Xiaoyan Zhang [1,2,†], Jinming Zhao [1,†], Guijun Yang [3], Jiangang Liu [3], Jiqiu Cao [1,2], Chunyan Li [1,2], Xiaoqing Zhao [3] and Junyi Gai [1,*]**

**Table S1.** The experiment design of four sets of lines tested in 2015-2016.

| Item | 1st YYT 2015 | 2nd YYT 2015 | 2nd YYT 2016 | NJRIKY 2015 |
|---|---|---|---|---|
| Number of tested lines | 532 | 274 | 297 | 441 |
| Design and replications | BIR, 3Reps | BIR, 3Reps | BIR, 3Reps | BIR, 3Reps |
| Number of plots | 1596 | 822 | 891 | 1323 |
| Row length and width | 4 m，0.4 m | 5 m，0.4 m | 5 m，0.4 m | 2 m，0.4 m |
| Plot area | 4 m × 1.6 m | 5 m × 2.0 m | 5 m × 2.0 m | 2 m × 1.6 m |
| Area harvested | 4 m × 0.8 m | 5 m × 1.2 m | 5 m × 1.2 m | 2 m × 0.8 m |
| Code of line set | A1 + B1 | A2 + B2 | A3 + B3 | A + B |
| Number of lines | A1 = B1 = 266 | A2 = B2 = 137 | A3 = 148,B3 = 149 | A = B = 211 |
| Function | calibration, validation | calibration, validation | calibration, validation | validation |

Note: 1stYYT 2015, 2ndYYT 2015, 2ndYYT 2016 and NJRIKY 2015: the first-year yield-test in 2015, the second-year yield-test in 2015, the second-year yield-test in 2016, and the NJRIKY (plant-to-lines population) yield-test in 2015, respectively. BIR represents the experimental design of blocks in replication which is analyzed using randomized complete blocks design as an approximation; 3Reps means 3 replications.

**Table S2.** Main parameters of digital camera and two kinds of hyperspectral reflectance measurement instrument.

| Instrument | Model | Brand | Weight(g) | Field angle | Pixel | Number of Channels | Spectral Wavebands | Function |
|---|---|---|---|---|---|---|---|---|
| Hyperspectral camera | UHD185 | Cubert | 470 | 15° | 4 nm@454 nm~950 nm | 125 | 454 nm~950 nm | hyperspectral reflectance collection |
| Digital camera | Sony DSC-QX100 | Canon | 356 | 63.4 × 49.7° | 3000 nm × 4000 nm | - | Red, green, blue | Panorama information, Image correction |
| Spectrometer | Field Spec 2500 | ASD | 8500 | 25° | 3 nm@350~1000 nm: 10nm@1000~2500 nm | 615 | 350~2500 nm | Precision correction, UAV based reflectance |

Note: The three sensors have different field-of-view angles. In order to avoid missing information, UAV flying route is planned according to the perspective of the hyperspectral camera.

**Table S3.** The reflectance-sampling unit-sizes for measuring the UAV hyperspectral reflectance in three yield test experiments.

| Code/Order | Length × Width of 2ndYYT 2015 (m×m) | Length × Width of 1stYYT 2015 (m×m) | Length × Width of NJRIKY 2015 (m×m) |
|---|---|---|---|
| 1 | 5.00 × 2.00 | 4.00 × 1.60 | 2.00 × 1.60 |
| 2 | 4.75 × 1.90 | 3.80 × 1.52 | 1.90 × 1.52 |
| 3 | 4.50 × 1.80 | 3.60 × 1.44 | 1.80 × 1.44 |
| 4 | 4.25 × 1.70 | 3.40 × 1.36 | 1.70 × 1.36 |
| 5 | 4.00 × 1.60 | 3.20 × 1.28 | 1.60 × 1.28 |
| 6 | 3.75 × 1.50 | 3.00 × 1.20 | 1.50 × 1.20 |
| 7 | 3.50 × 1.40 | 2.80 × 1.12 | 1.40 × 1.12 |
| 8 | 3.25 × 1.30 | 2.60 × 1.04 | 1.30 × 1.04 |
| 9 | 3.00 × 1.20 | 2.40 × 0.96 | 1.20 × 0.96 |
| 10 | 2.75 × 1.10 | 2.20 × 0.88 | 1.10 × 0.88 |

| | | | |
|---|---|---|---|
| 11 | 2.50 × 1.00 | 2.00 × 0.80 | 1.00 × 1.80 |
| 12 | 2.25 × 0.90 | 1.80 × 0.72 | 0.90 × 0.72 |
| 13 | 2.00 × 0.80 | 1.60 × 0.64 | 0.80 × 0.64 |
| 14 | 1.75 × 0.70 | 1.40 × 0.56 | 0.70 × 0.56 |
| 15 | 1.50 × 0.60 | 1.20 × 0.48 | 0.60 × 0.48 |
| 16 | 1.25 × 0.50 | 1.00 × 0.40 | 0.50 × 0.40 |
| 17 | 1.00 × 0.40 | 0.80 × 0.32 | 0.40 × 0.32 |
| 18 | 0.75 × 0.30 | 0.60 × 0.24 | 0.30 × 0.24 |
| 19 | 0.50 × 0.20 | 0.40 × 0.16 | 0.20 × 0.16 |
| 20 | 0.25 × 0.10 | 0.20 × 0.08 | 0.10 × 0.08 |
| 21 | Single Point | Single Point | Single Point |

Note: The location of the sampling area in each plot was at the center of a plot.

**Table S4.** The regression models of soybean yield on hyperspectral reflectance in terms of NDVI and RVI at R5 growth stage.

| Material Set | Equation Type | Regression Equation | Model Significance | Vegetation index (Spectrum) | $R_M^2$ |
|---|---|---|---|---|---|
| A1+B1 | Exponential Function | $y = 0.6601e^{4E-05x}$ | P<0.01 | RVI (618, 674) | 0.61 |
| | Linear Function | y = 3E-05x + 0.6526 | | | 0.61 |
| | Logarithmic Function | y = 0.1089ln(x) - 0.1145 | | | 0.60 |
| | Exponential Function | $y = 0.2292e^{-2E-04x}$ | | NDVI (618, 674) | 0.61 |
| | Linear Function | y = -2E-05x + 0.2055 | | | 0.61 |
| | Logarithmic Function | y = -0.07ln(x) + 0.698 | | | 0.60 |
| A1 | Exponential Function | $y = 0.6579e^{4E-05x}$ | P<0.01 | RVI(638, 674) | 0.61 |
| | Linear Function | y = 3E-05x + 0.6512 | | | 0.61 |
| | Logarithmic Function | y = 0.0993ln(x) - 0.0443 | | | 0.59 |
| | Exponential Function | $y = 0.2268e^{-2E-04x}$ | | NDVI(638, 674) | 0.61 |
| | Linear Function | y = -2E-05x + 0.207 | | | 0.61 |
| | Logarithmic Function | y = -0.064ln(x) + 0.658 | | | 0.59 |
| B1 | Exponential Function | $y = 0.6742e^{4E-05x}$ | P<0.01 | RVI(634, 678) | 0.58 |
| | Linear Function | y = 3E-05x + 0.668 | | | 0.58 |
| | Logarithmic Function | y = 0.1044ln(x) - 0.0709 | | | 0.58 |
| | Exponential Function | $y = 0.215e^{-2E-04x}$ | | NDVI(634, 678) | 0.58 |
| | Linear Function | y = -2E-05x + 0.1952 | | | 0.58 |
| | Logarithmic Function | y = -0.067ln(x) + 0.6664 | | | 0.31 |
| A2+B2 | Exponential Function | $y = 1.25e^{-4E-05x}$ | P<0.01 | RVI(514,606) | 0.49 |
| | Linear Function | y = -5E-05x + 1.239 | | | 0.49 |
| | Logarithmic Function | y = -0.162ln(x) + 2.3892 | | | 0.49 |
| | Exponential Function | $y = 0.3693e^{-7E-04x}$ | | NDVI(514, 606) | 0.48 |
| | Linear Function | y = -2E-05x + 0.1109 | | | 0.49 |
| | Logarithmic Function | y = -0.074ln(x) + 0.6368 | | | 0.49 |
| A2 | Exponential Function | $y = 1.2857e^{-5E-05x}$ | P<0.01 | RVI(514,614) | 0.56 |
| | Linear Function | y =-6E-05x + 1.2705 | | | 0.56 |
| | Logarithmic Function | y = -0.179ln(x) + 2.5319 | | | 0.55 |
| | Exponential Function | | | NDVI(514, 614) | |
| | Linear Function | y = -3E-05x + 0.1254 | | | 0.56 |
| | Logarithmic Function | y = -0.082ln(x) + 0.7019 | | | 0.55 |
| B2 | Exponential Function | $y = 1.1789e^{-3E-05x}$ | P<0.01 | RVI(514, 582) | 0.31 |
| | Linear Function | y = -3E-05x + 1.175 | | | 0.31 |
| | Logarithmic Function | y = -0.115ln(x) + 1.9911 | | | 0.31 |
| | Exponential Function | | | NDVI(514, 582) | |
| | Linear Function | y = -2E-05x + 0.0822 | | | 0.31 |
| | Logarithmic Function | y = -0.053ln(x) + 0.4599 | | | 0.31 |
| A3+B3 | Exponential Function | $y = 1.5422e^{1E-05x}$ | P<0.01 | RVI(534, 570) | 0.12 |
| | Linear Function | y = 2E-05x + 1.5425 | | | 0.13 |
| | Logarithmic Function | y = 0.0583ln(x) + 1.1347 | | | 0.13 |
| | Exponential Function | $y = 0.2127e^{3E-05x}$ | | NDVI(534, 570) | 0.11 |
| | Linear Function | y = 6E-06x + 0.2133 | | | 0.12 |
| | Logarithmic Function | y = 0.0177ln(x) + 0.0894 | | | 0.12 |
| A3 | Exponential Function | $y = 1.5539e^{1E-05x}$ | P<0.01 | RVI(538,570) | 0.22 |
| | Linear Function | y = 2E-05x + 1.5532 | | | 0.22 |
| | Logarithmic Function | y = 0.0503ln(x) + 1.2024 | | | 0.22 |
| | Exponential Function | $y= 0.2174e^{2E-05x}$ | | NDVI（538, 570） | 0.22 |
| | Linear Function | y = 5E-06x + 0.2169 | | | 0.22 |

| | | | | | |
|---|---|---|---|---|---|
| | Logarithmic Function | y = 0.0148ln(x) + 0.1136 | | | 0.22 |
| B3 | Exponential Function | $y = 1.5348e^{1E-05x}$ | P<0.01 | RVI(490,754) | 0.09 |
| | Linear Function | y = 2E-05x + 1.5362 | | | 0.09 |
| | Logarithmic Function | y = 0.0624ln(x) + 1.099 | | | 0.10 |
| | Exponential Function | $y= 0.2095e^{3E-05x}$ | | NDVI(490, 754) | 0.08 |
| | Linear Function | y = 6E-06x + 0.2109 | | | 0.09 |
| | Logarithmic Function | y = 0.0194ln(x) + 0.0749 | | | 0.09 |
| A4+B4 | Exponential Function | $y = 1.4434e^{-7E-05x}$ | P<0.01 | RVI(486, 618) | 0.44 |
| | Linear Function | y = -8E-05x + 1.4138 | | | 0.44 |
| | Logarithmic Function | y = -0.26ln(x) + 3.245 | | | 0.43 |
| | Exponential Function | | | NDVI(486, 618) | |
| | Linear Function | y = -4E-05x + 0.1827 | | | 0.44 |
| | Logarithmic Function | y = -0.112ln(x) + 0.972 | | | 0.43 |
| A4 | Exponential Function | $y = 3.7372e^{0.0001x}$ | P<0.01 | RVI(570, 730) | 0.45 |
| | Linear Function | y = 0.0007x + 3.3383 | | | 0.45 |
| | Logarithmic Function | y = 2.304ln(x) - 12.822 | | | 0.44 |
| | Exponential Function | $y = 0.5989e^{5E-05x}$ | | NDVI(570, 730) | 0.44 |
| | Linear Function | y= 3E-05x + 0.5923 | | | 0.45 |
| | Logarithmic Function | y = 0.1049ln(x) - 0.1444 | | | 0.45 |
| B4 | Exponential Function | $y = 1.3939e^{-6E-05x}$ | P<0.01 | RVI(494, 618) | 0.43 |
| | Linear Function | y = -7E-05x + 1.3728 | | | 0.43 |
| | Logarithmic Function | y = -0.229ln(x) + 2.9907 | | | 0.43 |
| | Exponential Function | | | NDVI(494,618) | |
| | Linear Function | y = -3E-05x + 0.1654 | | | 0.43 |
| | Logarithmic Function | y = -0.099ln(x) + 0.8649 | | | 0.43 |
| A5 | Exponential Function | $y = 1.8825e^{-9E-05x}$ | P<0.01 | RVI(486, 586) | 0.57 |
| | Linear Function | y = -0.0001x + 1.804 | | | 0.57 |
| | Logarithmic Function | y = -0.417ln(x) + 4.7582 | | | 0.54 |
| | Exponential Function | $y = 0.4452e^{-3E-04x}$ | | NDVI(486,586) | 0.59 |
| | Linear Function | y = -5E-05x + 0.3111 | | | 0.58 |
| | Logarithmic Function | y = -0.15ln(x) + 1.3748 | | | 0.55 |
| B5 | Exponential Function | $y = 7.316e^{0.0001x}$ | P<0.01 | RVI(478, 738) | 0.51 |
| | Linear Function | y = 0.0015x + 6.3126 | | | 0.50 |
| | Logarithmic Function | y = 4.7219ln(x) - 26.736 | | | 0.47 |
| | Exponential Function | $y = 0.7755e^{2E-05x}$ | | NDVI(478,738) | 0.51 |
| | Linear Function | y = 2E-05x + 0.773 | | | 0.51 |
| | Logarithmic Function | y = 0.0597ln(x) + 0.3549 | | | 0.49 |
| A6+B6 | Exponential Function | $y = 3.5614e^{0.0001x}$ | P<0.01 | RVI(554, 730) | 0.44 |
| | Linear Function | y = 0.0005x + 3.2772 | | | 0.44 |
| | Logarithmic Function | y = 1.7202ln(x) - 8.8977 | | | 0.42 |
| | Exponential Function | $y = 0.5796e^{4E-05x}$ | | NDVI(554, 730) | 0.44 |
| | Linear Function | y = 3E-05x + 0.5732 | | | 0.44 |
| | Logarithmic Function | y = 0.0917ln(x) - 0.0758 | | | 0.42 |
| A6 | Exponential Function | $y = 3.7277e^{1E-04x}$ | P<0.01 | RVI(638, 666) | 0.29 |
| | Linear Function | y = 0.0005x + 3.519 | | | 0.28 |
| | Logarithmic Function | y = 1.8753ln(x) - 10.051 | | | 0.30 |
| | Exponential Function | $y = 0.59e^{4E-05x}$ | | NDVI(638, 666) | 0.30 |
| | Linear Function | y =3E-05x + 0.5853 | | | 0.30 |
| | Logarithmic Function | y = 0.1003ln(x) - 0.1404 | | | 0.32 |
| B6 | Exponential Function | $y = 4.4126e^{2E-05x}$ | P<0.01 | RVI(694,722) | 0.05 |
| | Linear Function | y = 0.0001x + 4.4057 | | | 0.05 |
| | Logarithmic Function | y = 0.3582ln(x) + 1.8901 | | | 0.06 |
| | Exponential Function | $y = 0.6309e^{1E-05x}$ | | NDVI(694, 722) | 0.05 |
| | Linear Function | y = 7E-06x + 0.6308 | | | 0.05 |
| | Logarithmic Function | y =0.0218ln(x) + 0.4777 | | | 0.06 |

Note: A total of 17 material groups used in model construction are referred in Section 3.4.

**Table S5.** Regression model codes and data sets included.

| Model | Material Set | Line No. | Lines Included | Growth Stage |
|---|---|---|---|---|
| $M_{A1+B1}$ | A1 + B1 | 532 | Total lines of 1stYYT 2015 | R5 |
| $M_{A1}$ | A1 | 266 | First half of lines of 1stYYT 2015 | R5 |
| $M_{B1}$ | B1 | 266 | Second half of lines of 1stYYT 2015 | R5 |
| $M_{A2+B2}$ | A2 + B2 | 274 | Total lines of 2ndYYT 2015 | R5 |
| $M_{A2}$ | A2 | 137 | First half of lines of 2ndYYT 2015 | R5 |

| | | | | |
|---|---|---|---|---|
| $M_{B2}$ | B2 | 137 | Second half of lines of 2ndYYT 2015 | R5 |
| $M_{A3+B3}$ | A3 + B3 | 297 | Total lines of 2ndYYT 2016 | R5 |
| $M_{A3}$ | A3 | 148 | First half of lines of 2ndYYT 2016 | R5 |
| $M_{B3}$ | B3 | 149 | Second half of lines of 2ndYYT 2016 | R5 |
| $M_{A4+B4}$ | A4 + B4 | 1103 | Total lines of 2ndYYT 2015 ,1stYYT 2015 & 2ndYYT 2016 | R5 |
| $M_{A4}$ | A4 | 551 | First half of lines of 2ndYYT 2015 ,1stYYT 2015 & 2ndYYT 2016 | R5 |
| $M_{B4}$ | B4 | 552 | Second half of lines of 2ndYYT 2015 ,1stYYT 2015 & 2ndYYT 2016 | R5 |
| $M_{A5}$ | A5 | 165 | Lines of 1stYYT 2015 and upgraded to 2ndYYT 2016 | R5 |
| $M_{B5}$ | B5 | 48 | Lines of 2ndYYT 2015 and kept in 2ndYYT 2016 | R5 |
| $M_{A6+B6}$ | A6 + B6 | 426 | A5+B5 in 2015 and 2016 | R5 |
| $M_{A6}$ | A6 | 213 | A5+B5 in 2015 | R5 |
| $M_{B6}$ | B6 | 213 | A5+B5 in 2016 | R5 |
| $M_{A1+B1-2}$ | A1 + B1 | 532 | Total lines of 1stYYT 2015 | R5+R4 |
| $M_{A1-1}$ | A1 | 266 | First half of lines of 1stYYT 2015 | R5+R2 |
| $M_{A1-2}$ | A1 | 266 | First half of lines of 1stYYT 2015 | R5+R4 |
| $M_{A1-3}$ | A1 | 266 | First half of lines of 1stYYT 2015 | R5+R6 |
| $M_{B1-2}$ | B1 | 266 | Second half of lines of 1stYYT 2015 | R5+R4 |
| $M_{A2+B2-2}$ | A2 + B2 | 274 | Total lines of 2ndYYT 2015 | R5+R4 |
| $M_{A2-2}$ | A2 | 137 | First half of lines of 2ndYYT 2015 | R5+R4 |
| $M_{B2-2}$ | B2 | 137 | Second half of lines of 2ndYYT 2015 | R5+R4 |
| $M_{A3+B3-2}$ | A3 + B3 | 297 | Total lines of 2ndYYT 2016 | R5+R4 |
| $M_{A3-2}$ | A3 | 148 | First half of lines of 2ndYYT 2016 | R5+R4 |
| $M_{B3-2}$ | B3 | 149 | Second half of lines of 2ndYYT 2016 | R5+R4 |
| $M_{A4+B4-2}$ | A4 + B4 | 1103 | Total lines of 2ndYYT 2015 ,1stYYT 2015 & 2ndYYT 2016 | R5+R4 |
| $M_{A4-2}$ | A4 | 551 | First half of lines of 2nd YYT 2015 ,1stYYT 2015 & 2nd YYT 2016 | R5+R4 |
| $M_{B4-2}$ | B4 | 552 | second half of lines of 2nd YYT 2015 ,1stYYT 2015 & 2nd YYT 2016 | R5+R4 |
| $M_{A5-2}$ | A5 | 165 | Lines of 1stYYT 2015 and upgraded to 2ndYYT 2016 (two years data) | R5+R4 |
| $M_{B5-2}$ | B5 | 48 | Lines of 2nd YYT 2015 and kept in 2ndYYT 2016 (two years data) | R5+R4 |
| $M_{A6+B6-2}$ | A6 + B6 | 426 | A5+B5 in 2015 and 2016 | R5+R4 |
| $M_{A6-1}$ | A6 | 213 | A5+B5 in 2015 | R5+R2 |
| $M_{A6-2}$ | A6 | 213 | A5+B5 in 2015 | R5+R4 |
| $M_{A6-3}$ | A6 | 213 | A5+B5 in 2015 | R5+R6 |
| $M_{B6-2}$ | B6 | 213 | A5+B5 in 2016 | R5+R4 |

Note: R2, R4, R5 and R6 are growth stages of soybean at the full flowering stage (R2), the full podding stage (R4), the initial seed-filling stage (R5), and the full seed-filling stage (R6).

**Table S6.** The correlation relationship between yield and different vegetation index combinations at different growth stage combinations in the 1stYYT 2015 experiment.

| Growth Stages | Vegetation Index Number | Vegetation Index Included | Maximum $R^2$ |
|---|---|---|---|
| R2 | 2 | $NDVI_2$,$RVI_2$ | 0.56 |
| R4 | 2 | $NDVI_4$,$RVI_4$ | 0.28 |
| R5 | 2 | $NDVI_5$,$RVI_5$ | 0.66 |
| R6 | 2 | $NDVI_6$,$RVI_6$ | 0.48 |
| R2 + R5 | 2 | $NDVI_2$, $RVI_5$ | 0.68 |
| | 4 | $NDVI_2$, $NDVI_5$, $RVI_5$, $GNDVI_5$ | 0.68 |
| | 6 | $EVI_2$, $NDVI_5$, $RVI_5$, $GNDVI_5$, $EVI_5$, $DVI_5$ | 0.69 |
| | 9 | $NDVI_2$, $OSAVI_2$, $RDVI_2$, $DVI_2$, $NDVI_5$, $RVI_5$, $GNDVI_5$, $EVI_5$, $DVI_5$ | 0.73 |
| R2 + R4 | 2 | $NDVI_2$, $RVI_4$ | 0.53 |
| | 4 | $RDVI_2$, $GNDVI_4$, $DVI_4$, $NDVI705_4$ | 0.54 |
| | 6 | $RDVI_2$, $NDVI_4$, $RVI_4$, $GNDVI_4$, $OSAVI_4$, $NDVI705_4$ | 0.56 |
| | 9 | $NDVI_2$, $OSAVI_2$, $RDVI_2$, $DVI_2$, $GNDVI_4$, $OSAVI_4$, $RDVI_4$, $DVI_4$, $NDVI705_4$ | 0.58 |
| R2 + R6 | 2 | $NDVI_2$, $RVI_6$ | 0.63 |
| | 4 | $PVI_2$, $RDVI_2$, $OSAVI_6$, $VOG1_6$ | 0.63 |
| | 6 | $NDVI_2$, $OSAVI_2$, $RDVI_2$, $DVI_2$, $OSAVI_6$, $VOG1_6$ | 0.65 |
| | 9 | $NDVI_2$, $PVI_2$, $OSAVI_2$, $RDVI_2$, $DVI_2$, $NDVI_6$, $RVI_6$, $PVI_6$, $VOG1_6$ | 0.67 |
| R4 + R5 | 2 | $NDVI_4$, $RVI_5$ | 0.67 |
| | 4 | $RVI_5$, $GNDVI_5$, $EVI_5$, $RVI_4$ | 0.67 |
| | 6 | $RVI_5$, $GNDVI_5$, $NDVI_4$, $OSAVI_4$, $RDVI_4$, $DVI_4$ | 0.68 |
| | 9 | $NDVI_5$, $RVI_5$, $GNDVI_5$, $EVI_5$, $DVI_5$, $GNDVI_4$, $EVI_4$, $RDVI_4$, $NDVI705_4$ | 0.69 |
| R4 + R6 | 2 | $NDVI_4$, $RVI_6$ | 0.56 |
| | 4 | $RVI_4$, $GNDVI_4$, $NDVI705_4$, $RVI_6$ | 0.56 |
| | 6 | $GNDVI_4$, $OSAVI_4$, $RDVI_4$, $NDVI705_4$, $RVI_6$, $EVI_6$, | 0.58 |

| | | | |
|---|---|---|---|
| | 9 | $NDVI_4$, $RVI_4$, $GNDVI_4$, $OSAVI_4$, $RDVI_4$, $DVI_4$, $NDVI705_4$, $EVI_6$, $VOG1_6$ | 0.60 |
| R5 + R6 | 2 | $NDVI_5$, $RVI_6$ | 0.68 |
| | 4 | $GNDVI_5$, $EVI_5$, $RDVI_5$, $RVI_6$ | 0.68 |
| | 6 | $GNDVI_5$, $EVI_5$, $RDVI_5$, $NDVI_6$, $RVI_6$, $NDVI705_6$ | 0.68 |
| | 9 | $GNDVI_5$, $EVI_5$, $RDVI_5$, $RVI_6$, $PVI_6$, $EVI_6$, $RDVI_6$, $DVI_6$, $NDVI705_6$ | 0.69 |
| R2 + R4 + R5 | 2 | $NDVI_4$, $RVI_5$ | 0.67 |
| | 4 | $NDVI_2$, $NDVI_4$, $NDVI_5$, $RVI_5$ | 0.68 |
| | 6 | $NDVI_2$, $RVI_2$,$NDVI_4$, $RVI_4$,$NDVI_5$, $RVI_5$ | 0.69 |
| | 9 | $NDVI_2$, $RVI_2$,$NDVI_4$, $RVI_4$,$NDVI_5$, $RVI_5$, $GNDVI_5$, $EVI_5$, $DVI_5$, | 0.71 |
| R2 + R4 + R6 | 2 | $NDVI_4$, $RVI_6$ | 0.56 |
| | 4 | $NDVI_2$, $NDVI_4$, $NDVI_6$, $RVI_6$ | 0.60 |
| | 6 | $NDVI_2$, $RVI_2$,$NDVI_4$, $RVI_4$,$NDVI_6$, $RVI_6$ | 0.61 |
| | 9 | $NDVI_2$, $RVI_2$, $GNDVI_2$,$NDVI_4$, $RVI_4$, $GNDVI_4$,$NDVI_6$, $RVI_6$, $GNDVI_6$ | 0.64 |
| R2 + R5 + R6 | 2 | $NDVI_5$, $RVI_6$ | 0.68 |
| | 4 | $NDVI_2$, $NDVI_5$, $RVI_5$, $NDVI_6$ | 0.70 |
| | 6 | $NDVI_2$, $RVI_2$, $NDVI_5$, $RVI_5$, $NDVI_6$, $RVI_6$ | 0.71 |
| | 9 | $NDVI_2$, $RVI_2$, $NDVI_5$, $RVI_5$, $GNDVI_5$, $EVI_5$, $DVI_5$,$NDVI_6$, $RVI_6$, | 0.74 |
| R4 + R5 + R6 | 2 | $NDVI_4$, $RVI_5$ | 0.67 |
| | 4 | $NDVI_4$, $NDVI_5$, $RVI_5$, $NDVI_6$ | 0.69 |
| | 6 | $NDVI_4$, $RVI_4$, $NDVI_5$, $RVI_5$, $NDVI_6$, $RVI_6$ | 0.70 |
| | 9 | $NDVI_4$, $RVI_4$, $NDVI_5$, $RVI_5$, $GNDVI_5$, $EVI_5$, $DVI_5$,$NDVI_6$, $RVI_6$ | 0.71 |

Note: $NDVI_6$, $NDVI_5$, $NDVI_4$ and $NDVI_2$ represent the NDVI values at R6, R5, R4, and R2 growth period.

**Table S7. The** established regression models of yield on R5 single-period UAV hyperspectral reflectance data for various sets of breeding lines.

| Model Code | Sensitive Band (nm) | | Material No. | | Model Equation |
|---|---|---|---|---|---|
| | $\lambda 1$ | $\lambda 2$ | Model | Verification | Yield |
| $M_{A1+B1}$ | 618 | 674 | 266 | 266 | =29757.62-23120.817RVI+65508.242NDVI |
| $M_{A1}$ | 638 | 674 | 133 | 133 | =-62903.263+70479.378RVI-84058.771NDVI |
| $M_{B1}$ | 634 | 678 | 133 | 133 | =-95652.172+103253.618RVI-142033.498NDVI |
| $M_{A2+B2}$ | 514 | 606 | 137 | 137 | =-38987.728-119622.968NDVI+43443.623RVI |
| $M_{A2}$ | 514 | 614 | 68 | 69 | =-77814.78-193084.454NDVI+81411.213RVI |
| $M_{B2}$ | 514 | 582 | 68 | 69 | =-37853.445-133910.374NDVI+44659.167RVI |
| $M_{A3+B3}$ | 534 | 570 | 148 | 149 | =-219708.742-451555.645NDVI+221824.728RVI |
| $M_{A3}$ | 538 | 570 | 74 | 74 | =-212726.175-432698.919NDVI+214367.784RVI |
| $M_{B3}$ | 490 | 754 | 74 | 75 | =35230.011+793.02RVI-50667.347NDVI |
| $M_{A4+B4}$ | 486 | 618 | 551 | 552 | =-12425.524-51217.816NDVI+16691.474RVI |
| $M_{A4}$ | 570 | 730 | 275 | 276 | =-1440.212+493.209RVI+2613.014NDVI |
| $M_{B4}$ | 494 | 618 | 276 | 276 | =-26373.22-87800.116NDVI+31037.889RVI |
| $M_{A5}$ | 486 | 586 | 165[1] | 165[1] | =-23017.383-99064.229NDVI+30507.853RVI |
| $M_{B5}$ | 478 | 738 | 48[1] | 48[1] | =-64691.658+91396.792NDVI-753.035RVI |
| $M_{A6+B6}$ | 554 | 730 | 213 | 213 | =-9073.843+19974.886NDVI-166.114RVI |
| $M_{A6}$ | 638 | 666 | 106 | 107 | =38771.089+89475.17NDVI-32503.028RVI |
| $M_{B6}$ | 694 | 722 | 106 | 107 | =18215.449+4923.925RVI-59788.058NDVI |

Note: $\lambda 1$ and $\lambda 2$ are the two sensitive bands. The material sets of models are listed in Table S5.

[1]These two material sets were tested two years, therefore, the number of observations for modelling and verification are two times of the number of lines.

**Table S8.** The established major plot-yield prediction models using NDVI and RVI constructed from two growth-period UAV hyperspectral reflectance data.

| Model | Sensitive Bands(nm) | | | | Material No. | | Estimation Model |
|---|---|---|---|---|---|---|---|
| | R5 λ1 | R5 λ2 | R4 λ1 | R4 λ2 | Model | Verification | Yield |
| $M_{A1+B1-2}$ (R5+R4) | 618 | 674 | 750 | 770 | 266 | 266 | $=-629090.701-1420.184NDVI_5+17047.079RVI_5-1328100.953NDVI_4+620264.78RVI_4$ |
| $M_{A1-1}$ (R5+R2) | 638 | 674 | 722 | 730 | 133 | 133 | $=-167540.672-47877.546NDVI_5+44088.102RVI_5-357145.069NDVI_2+135407.577RVI_2$ |
| $M_{A1-2}$ (R5+R4) | 638 | 674 | 554 | 850 | 133 | 133 | $=37251.176+56472.489NDVI_5-16952.632RVI_5-27803.565NDVI_4+874.96RVI_4$ |
| $M_{A1-3}$ (R5+R6) | 638 | 674 | 586 | 698 | 133 | 133 | $=-82702.987-107911.331NDVI_5+82526.298RVI_5-30343.979NDVI_6+8888.904RVI_6$ |
| $M_{B1-2}$ (R5+R4) | 634 | 678 | 754 | 770 | 133 | 133 | $=2339262.164-211656.613NDVI_5+143625.5RVI_5+5412456.508NDVI_4-2484156.407RVI_4$ |
| $M_{A2+B2-2}$ (R5+R4) | 514 | 606 | 618 | 670 | 137 | 137 | $=2846.485-25154.581NDVI_5+464.404RVI_5-2054.024NDVI_4+1019.305RVI_4$ |
| $M_{A2-2}$ (R5+R4) | 514 | 614 | 518 | 570 | 68 | 69 | $=-151125.108-91908.83NDVI_5+35714.233RVI_5-345254.233NDVI_4+126139.329RVI_4$ |
| $M_{B2-2}$ (R5+R4) | 514 | 582 | 786 | 850 | 68 | 69 | $=2136176.83-55761.664NDVI_5+12284.668RVI_5+4209617.204NDVI_4-2140693.694RVI_4$ |
| $M_{A3+B3-2}$ (R5+R4) | 534 | 570 | 706 | 714 | 148 | 149 | $=48250.351+400337.251NDVI_4-164430.234RVI_4-373288.998NDVI_5+126157.287RVI_5$ |
| $M_{A3-2}$ (R5+R4) | 538 | 570 | 634 | 730 | 74 | 74 | $=491746.725+474014.196NDVI_5-292570.361RVI_5-322771.412NDVI_4+6392.508RVI_4$ |
| $M_{B3-2}$ (R5+R4) | 490 | 754 | 702 | 714 | 74 | 75 | $=-208279.959+4487.84NDVI_5+80.043RVI_5-2205442.208NDVI_4+470850.767RVI_4$ |
| $M_{A4+B4-2}$ (R5+R4) | 486 | 618 | 554 | 742 | 551 | 552 | $=6141.363-44797.441NDVI_5+13838.398RVI_5-31249.374NDVI_4+1098.632RVI_4$ |
| $M_{A4-2}$ (R5+R4) | 570 | 730 | 554 | 742 | 275 | 276 | $=-4719.513+15848.641NDVI_5-59.098RVI_5-7384.109NDVI_4+382.157RVI_4$ |
| $M_{B4-2}$ (R5+R4) | 494 | 618 | 642 | 678 | 276 | 276 | $=-170682.789-99795.663NDVI_5+36520.166RVI_5-251513.528NDVI_4+139574.114RVI_4$ |
| $M_{A5-2}$ (R5+R4) | 486 | 586 | 622 | 742 | 165[1] | 165[1] | $=-5536.644-92728.826NDVI_5+28265.883RVI_5+29006.518NDVI_4-15392.519RVI_4$ |
| $M_{B5-2}$ (R5+R4) | 478 | 738 | 634 | 738 | 48[1] | 48[1] | $=-69994.485+-69143.042NDVI_5+1035.776RVI_5+159930.208NDVI_4+-1350.794RVI_4$ |
| $M_{A6+B6-2}$ (R5+R4) | 554 | 730 | 622 | 738 | 213 | 213 | $=10382.312NDVI_5-23.337RVI_5-4620.438-1528.38NDVI_4+196.664RVI_4$ |
| $M_{A6-1}$ (R5+R2) | 638 | 666 | 754 | 770 | 106 | 107 | $=479764.671-56567.287NDVI_5+50191.075RVI_5+1137761.812NDVI_2-524750.404RVI_2$ |
| $M_{A6-2}$ (R5+R4) | 638 | 666 | 754 | 774 | 106 | 107 | $=2086038.623+254625.829NDVI_5-132239.08RVI_5+4247790.755NDVI_4-1955933.15RVI_4$ |
| $M_{A6-3}$ (R5+R6) | 638 | 666 | 554 | 710 | 106 | 107 | $=134411.421+254844.63NDVI_5-133966.665RVI_5-10753.791NDVI_6+3870.778RVI_6$ |
| $M_{B6-2}$ (R5+R4) | 694 | 722 | 706 | 774 | 106 | 107 | $=-691041.782-44791.193NDVI_5+3701.768RVI_5-2887422.05NDVI_4+857273.158RVI_4$ |

Note: λ1 and λ2 are the two sensitive bands. The material sets of models are listed in Table S5. $NDVI_6$, $NDVI_5$, $NDVI_4$ and $NDVI_2$ represent the NDVI values at R6, R5, R4 and R2 growth stage; $RVI_6$, $RVI_5$, $RVI_4$ and $RVI_2$ represent the RVI values at R6, R5, R4 and R2 growth period.

[1]These two material sets were tested two years, therefore, the number of observations for modelling and verification are two times of the number of lines.

**Table S9.** Comparisons of the verification RMSE in NJRIKY among models listed in Table 5.

| Model | Growth Period Range (d) | Yield Range (t ha$^{-1}$) | *RMSEv* of (A+B) (t ha$^{-1}$) |
|---|---|---|---|
| $M_{A1+B1-2}$ | 99~112.7 | 1.831~4.995 | 1.011 |
| $M_{A1-1}$ | 99~112 | 1.836~4.680 | 1.026 |
| $M_{A1-2}$ | 99~112 | 1.836~4.680 | 0.913 |
| $M_{A1-3}$ | 99~112 | 1.836~4.680 | 0.999 |
| $M_{B1-2}$ | 99.7~112.7 | 1.831~4.995 | 0.679 |
| $M_{A2+B2-2}$ | 103~116 | 1.656~4.917 | 1.841 |
| $M_{A2-2}$ | 106~116 | 1.656~4.757 | 2.321 |
| $M_{B2-2}$ | 103~116 | 2.043~4.917 | 1.987 |
| $M_{A3+B3-2}$ | 96~116 | 1.724~4.410 | 12.112 |
| $M_{A3-2}$ | 96~116 | 1.724~4.304 | 2.147 |
| $M_{B3-2}$ | 99~115 | 1.820~4.410 | 1.696 |
| $M_{A4+B4-2}$ | 96~116 | 1.656~4.995 | 1.467 |
| $M_{A4-2}$ | 96~116 | 1.656~4.757 | 0.940 |
| $M_{B4-2}$ | 99~116 | 1.820~4.995 | 1.524 |
| $M_{A5-2}$ | 99~114 | 2.380~4.925 | 0.714 |
| $M_{B5-2}$ | 96~116 | 3.283~4.558 | 1.057 |
| $M_{A6+B6-2}$ | 96~116 | 2.380~4.925 | 0.945 |
| $M_{A6-1}$ | 100.7~116 | 2.380~4.925 | 1.077 |
| $M_{A6-2}$ | 100.7~116 | 2.380~4.925 | 0.785 |
| $M_{A6-3}$ | 100.7~116 | 2.380~4.925 | 1.184 |
| $M_{B6-2}$ | 96~116 | 2.380~4.925 | 1.734 |

Note: *RMSEv*: the verification RMSE value. Model: All models are listed in Table 5.

**Table S10.** Comparisons of coincidence between the breeders' actual yield selection results and the model-predicted selection results among the 21 models listed in Table 5 for the NJRIKY yield test. (Coincidence rate expressed in % while actual selection results expressed in number of lines).

| Model and Selection Procedure | A+B | | | |
|---|---|---|---|---|
| | Eli | Res | Pro | Sum |
| Actual selection | 166 | 244 | 31 | 441 |
| $M_{A1+B1-2}$ | 15.1 | 29.9 | 71.0 | 27.2 |
| $M_{A1-1}$ | 0 | 26.6 | 83.9 | 20.6 |
| $M_{A1-2}$ | 56.3 | 61.5 | 0 | 56.5 |
| $M_{A1-3}$ | 97.6 | 5.7 | 0 | 39.9 |
| $M_{B1-2}$ | 15.1 | 16.8 | 32.3 | 17.2 |
| $M_{A2+B2-2}$ | 0 | 0.8 | 100.0 | 7.5 |
| $M_{A2-2}$ | 0 | 0.8 | 100.0 | 7.5 |
| $M_{B2-2}$ | 5.4 | 9.4 | 90.3 | 13.6 |
| $M_{A3+B3-2}$ | 0 | 0 | 0 | 0 |
| $M_{A3-2}$ | 0 | 0 | 100.0 | 7.0 |
| $M_{B3-2}$ | 0 | 10.7 | 100.0 | 12.9 |
| $M_{A4+B4-2}$ | 0 | 2.9 | 96.8 | 8.4 |
| $M_{A4-2}$ | 49.8 | 53.9 | 0 | 49.9 |
| $M_{B4-2}$ | 0 | 1.2 | 100.0 | 7.7 |
| $M_{A5-2}$ | 41.0 | 28.3 | 22.6 | 32.7 |
| $M_{B5-2}$ | 0.6 | 9.0 | 100.0 | 12.2 |
| $M_{A6+B6-2}$ | 0 | 7.0 | 90.3 | 10.2 |
| $M_{A6-1}$ | 0 | 2.5 | 96.8 | 8.2 |
| $M_{A6-2}$ | 13.3 | 33.6 | 74.2 | 28.8 |
| $M_{A6-3}$ | 0.6 | 11.1 | 96.8 | 13.2 |
| $M_{B6-2}$ | 0 | 10.3 | 87.1 | 11.8 |

Note: Comparisons of consistence between the breeders' actual yield selection results and the model-predicted yield selection results among the 21 models are listed in this table, the breeding lines were treated so as to be eliminated (Eli, yields lower than 2.00 t $ha^{-1}$) to be reserved (Res, yields between 2.00 t $ha^{-1}$ and 2.75 t $ha^{-1}$) and to be promoted (Pro, yields above 2.75 t $ha^{-1}$) in A + B. The models in column of model and selection procedure are those listed in Table 5 and Table S8.

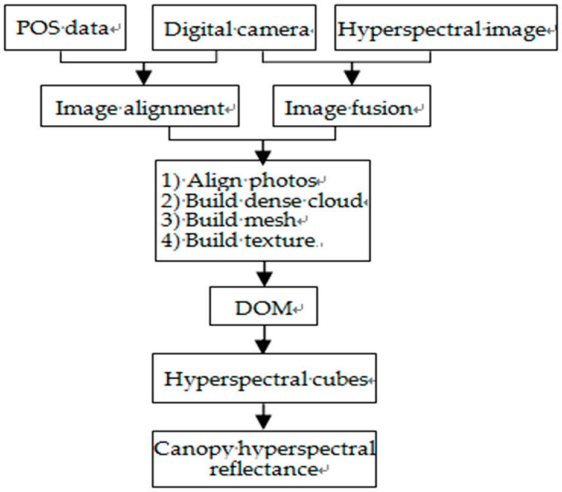


**Figure S1.** Flowchart showing the UAV data processing.

Note: POS: position and orientation system; DOM: digital orthophoto map.

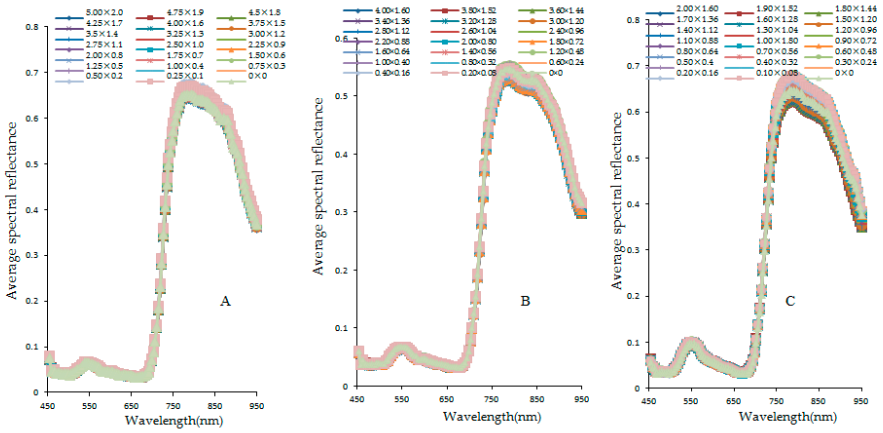


**Figure S2.** The canopy spectral reflectance from 21 different reflectance-sampling unit sizes in 2ndYYT 2015 (A), 1stYYT 2015 (B), NJRIKY test 2015 (C).

Note: 5.00 × 2.00, represent the sampling unit in a plot of 5 m length and 2 m width, and 21 sampling unit areas were defined in proper order. Single point (0 × 0) is the center of the plot, while all the sampling units are located in plot center.