Supplementary Material

Phenological Stage and Vegetation Index for Predicting Corn Yield under Rainfed Environments

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# Supplementary Tables

# Supplementary Table 1. Summary of UAV data collection during the growing seasons along with associated growth stages.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **2020** | | | **2021** | | | **2022** | | |
| **Growth stage** | **DAP\*** | **GDD\*\*** | **Growth stage** | **DAP\*** | **GDD\*\*** | **Growth stage** | **DAP\*** | **GDD\*\*** |
| V5 | 36 | 297 | V5 | 37 | 298 | V6 | 38 | 327 |
| V13 | 56 | 574 | V7 | 44 | 378 | V10 | 50 | 487 |
| Vn | 71 | 791 | V11 | 55 | 515 | Vn | 67 | 741 |
| R1 | 77 | 891 | Vn | 72 | 766 | R1 | 78 | 920 |
| R2 | 91 | 1132 | R1 | 83 | 935 | R3 | 93 | 1199 |
| R4 | 100 | 1299 | R2 | 96 | 1141 | R5 | 108 | 1476 |
| R5 | 107 | 1422 | R5 | 119 | 1536 |  |  |  |

Note: V5, V6, V7, V10, V11, and V13, represent the number of visible leaf collars in the main stem, where Vn refers to leaf collars greater than 13. In addition, data were collected at the reproductive stage, including R1, R2, R3, R4, and R5, which correspond to the silk, blister, milk, dough, and dent stages, respectively. A base temperature of 10 °C is used for calculating growing degree days.

\*DAP: days after planting corresponds to UAV data collection

\*\*GGD: Growing degree days

# Supplementary Table 2. List of vegetation indices used in this study.

| **Vegetation Index** | **Category** | **Reference** |
| --- | --- | --- |
| Anthocyanin Reflectance Index (ARI) | Anthocyanins | (Gitelson and Merzlyak, 2004) |
| Blue Green Blue Orange (BGBO) | Lutein zeaxanthins | (Fyfe, 2003) |
| Carotenoids Reflectance Index (CRIrededge) | Carotenoids | (Gitelson and Merzlyak, 2004) |
| Chlorophyll Vegetation Index (CVI) | Chlorophyll | (Vincini et al., 2008) |
| Dark Green Color Index (DGCI) | Greenness | (Karcher and Richardson, 2003; Rorie et al., 2011) |
| DATT | Chlorophyll | (Datt, 1998) |
| Enhanced Vegetation Index (EVI) | Green Bio estimation | (Huete et al., 2002) |
| Green – Red (G-R) | Ground cover, biomass | (Prabhakara et al., 2015) |
| Green Chlorophyll Index (CIgreen) | Chlorophyll | (Gitelson et al., 2005) |
| Green Chlorophyll Reflectance Index (RIgreen) | Chlorophyll | (Gitelson, 2004; Costa et al., 2021) |
| Green Leaf Index (GLI) | Crop cover | (Louhaichi et al., 2001) |
| Green Normalized Difference Vegetation Index (GNDVI) | Green biomass and Coverage; chlorophyll | (Gitelson et al., 1996; Gitelson and Merzlyak, 1998) |
| Greennees Index (GI) | Chlorophyll a, b | (Zarco-Tejada et al., 2005) |
| Leaf Chlorophyll Index (LCI) | Chlorophyll | (Pu et al., 2008) |
| Lichtenthaler Index (LIC) | Short term heat stress | (Lichtenthaler et al., 1996) |
| MERIS Terrestrial Chlorophyll Index (MTCI) | Chlorophyll | (Dash et al., 2010) |
| Modified Anthocyanin Reflectance Index (mARI) | Anthocyanins | (Gitelson et al., 2009) |
| Modified Chlorophyll Absorption Ratio Index (MCARI2) | Green leaf area index | (Haboudane et al., 2004) |
| Modified Chlorophyll Absorption in Reflectance Index (MCARI) | Chlorophyll | (Daughtry et al., 2000; Haboudane et al., 2004) |
| Modified Green Red Vegetation Index (MGRVI) | Biomass | (Bendig et al., 2015a) |
| Modified NDVI for Hyperspectral (mNDVI673) | Biomass | (Bargain et al., 2012) |
| Modified Normalized Difference at 705 (mND705) | Chlorophyll | (Sims and Gamon, 2002) |
| Modified Simple Ratio at 705 (mSR705) | Chlorophyll | (Sims and Gamon, 2002) |
| Modified Soil Adjusted Vegetation Index (MSAVI) | Minimize soil background influences, LAI, chlorophyll | (Qi et al., 1994) |
| Normalized Area Vegetation Index (NAVI) | Chlorophyll | (Carmona et al., 2015) |
| Normalized Difference Spectral Index (NDSI) | Nitrogen nutrition index | (Zhao et al., 2018) |
| Normalized Difference Vegetation Index (NDVI) | Green Biomass and Coverage | (Rouse, 1973) |
| Normalized Green Red Difference Index (NGRDI) | Biomass, leaf water content, chlorophyll | (Tucker, 1979) |
| Normalized Total Pigment Chlorophyll a Ratio (NPCI) | Chlorophyll-a | (Peñuelas et al., 1993) |
| Optimized Soil-Adjusted Vegetation Index (OSAVI) | Minimize soil background influences, LAI, chlorophyll | (Rondeaux et al., 1996) |
| Plant Biochemical Index (PBI) | Dry weight, ground cover | (Rao et al., 2008) |
| Ratio Vegetation Index (RVI) | Monitoring vegetation cover | (Pearson and Miller, 1972) |
| Red Edge Chlorophyll Index (CIrededge) | Canopy chlorophyll | (Clevers and Kooistra, 2012) |
| Red Edge Chlorophyll Reflectance Index (RIrededge) | Chlorophyll | (Gitelson and Merzlyak, 2004; Costa et al., 2021) |
| Red Edge Normalized Difference Vegetation Index (reNDVI) | Chlorophyll | (Gitelson and Merzlyak, 1994) |
| Red Edge Ratio (SR478) | Rededge | (Sims and Gamon, 2002; Costa et al., 2021) |
| Red Green Blue Vegetation Index (RGBVI) | Biomass | (Bendig et al., 2015b) |
| Renormalized Difference Vegetation Index (RDVI) | Fpar | (Roujean and Breon, 1995) |
| Simple Ratio (SR) | Leaf area index, chlorophyll a | (Jordan, 1969) |
| Simple Ratio at 445 (SR445) | Anthocyanins | (Thorhaug et al., 2015) |
| Simple Ratio at 700 (SR700) | Chlorophyll | (Chappelle et al., 1992) |
| Simple Ratio at 705 (SR705) | Chlorophyll | (Gitelson and Merzlyak, 1994) |
| Soil Adjusted Vegetation Index(L=-0.2) (SAVI2) | Aboveground living biomass | (Ren et al., 2018) |
| Soil Adjusted vegetation Index(L=0.5) (SAVI) | Eliminated soil-induced variations in vegetation indices, LAI, chlorophyll | (Huete, 1988) |
| Soil cover | Soil cover | (Bunnik, 1981) |
| Structure Independent Pigment Index (SIPI) | Chlorophyll-a, carotenoid | (Penuelas et al., 1995; Costa et al., 2021) |
| TCARI/OSAVI | Chlorophyll | (Haboudane et al., 2002) |
| Triangular Greenness Index (TGI) | Chlorophyll, Leaf area index | (Hunt Jr. et al., 2011) |
| Triangular Vegetation Index (TVI) | Green leaf area index, chlorophyll | (Broge and Leblanc, 2001) |
| Vegetative Index (VEG) | Vegetation coverage | (Hague et al., 2006) |
| Visible Atmospherically Resistant Index (VARI) | Vegetation fraction | (Gitelson et al., 2002) |
| Wide Dynamic Range Vegetation Index (WDRVI) | Vegetation fraction | (Gitelson, 2004) |

Note: *B, G, R, RE, and NIR represent the reflectance for the blue, green, red, red-edge and near-infrared bands, respectively.*

# Supplementary Table 3. List of vegetation indices that showed a number of times significant correlations across three years of study.

|  |  |  |  |
| --- | --- | --- | --- |
| **Vegetation index** | **No. of times VIs show r ≥0.7** | | |
| **2020** | **2021** | **2022** |
| Anthocyanin Reflectance Index (ARI) | - | - | 4 |
| Green Chlorophyll Index (CIgreen) | - | 5 | 6 |
| Red Edge Chlorophyll Index (CIrededge) | - | - | 6 |
| Carotenoids Reflectance Index (CRIrededge) | - | - | 4 |
| Chlorophyll Vegetation Index (CVI) | - | 7 | - |
| Enhanced Vegetation Index (EVI) | 2 | - | 5 |
| Green Normalized Difference Vegetation Index (GNDVI) | - | - | 6 |
| Leaf Chlorophyll Index (LCI) | 4 | 7 | 5 |
| Modified Anthocyanin Reflectance Index (mARI) | - | - | 4 |
| Modified Chlorophyll Absorption Ratio Index (MCARI2) | 2 | - | 6 |
| Modified Normalized Difference at 705 (mND705) | 3 | 6 | 6 |
| Modified Soil Adjusted Vegetation Index (MSAVI) | 2 | - | 6 |
| Modified Simple Ratio at 705 (mSR705) | 3 | 6 | 6 |
| MERIS Terrestrial Chlorophyll Index (MTCI) | 4 | 7 | 5 |
| Normalized Area Vegetation Index (NAVI) | - | - | 6 |
| Normalized Difference Vegetation Index (NDVI) | - | - | 6 |
| Optimized Soil-Adjusted Vegetation Index (OSAVI) | 2 | - | 6 |
| Plant Biochemical Index (PBI) | - | 5 | 6 |
| Renormalized Difference Vegetation Index (RDVI) | 2 | - | 6 |
| Red Edge Normalized Difference Vegetation Index (reNDVI) | - | 6 | 6 |
| Green Chlorophyll Reflectance Index (RIgreen) | 2 | 6 | - |
| Red Edge Chlorophyll Reflectance Index (RIrededge) | 3 | 6 | 6 |
| Ratio Vegetation Index (RVI) | - | - | 6 |
| Soil Adjusted vegetation Index(L=0.5) (SAVI) | 2 | - | 6 |
| Simple Ratio (SR) | - | - | 6 |
| Simple Ratio at 445 (SR445) | - | - | 6 |
| Simple Ratio at 705 (SR705) | - | 6 | 6 |
| Tcari/Osavi | - | - | 4 |
| Triangular Greenness Index (TGI) | - | 5 | - |
| Triangular Vegetation Index (TVI) | - | - | 4 |
| Wide Dynamic Range Vegetation Index (WDRVI) | - | - | 6 |

# Supplementary Table 4. Association between stable VIs and corn yield influenced by cover crop collected at R1 stages and corn yield under rainfed environments.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Vegetation Index** | **2020** | | | **2021** | | | **2022** | | |
| **Cover crop** | **R2** | **MAPE** | **Cover crop** | **R2** | **MAPE** | **Cover crop** | **R2** | **MAPE** |
| **LCI** | NCC | 0.54ns | 0.53 | NCC | 0.97\* | 2.2 | NCC | 0.92\* | 2.16 |
| Peas | 0.41ns | 3.69 | Peas | 0.89\*\*\* | 4.09 | Peas | 0.74\*\* | 4.42 |
| Radish | 0.81\*\* | 2.1 | Radish | 0.53\* | 3.89 | Mixed | 0.59\* | 7.16 |
| Rye | 0.45ns | 2.2 | Rye | 0.93\*\*\* | 1.26 | Rye | 0.43ns | 7.06 |
| **mND705** | NCC | 0.49ns | 0.55 | NCC | 0.97\* | 1.71 | NCC | 0.9ns | 2.25 |
| Peas | 0.4ns | 3.79 | Peas | 0.83\*\* | 4.9 | Peas | 0.67\* | 4.99 |
| Radish | 0.85\*\* | 1.8 | Radish | 0.3ns | 4.61 | Mixed | 0.5ns | 7.73 |
| Rye | 0.43ns | 2.25 | Rye | 0.82\*\* | 1.89 | Rye | 0.47ns | 6.94 |
| **mSR705** | NCC | 0.49ns | 0.55 | NCC | 0.97\* | 1.86 | NCC | 0.87ns | 2.67 |
| Peas | 0.38ns | 3.85 | Peas | 0.85\*\* | 4.54 | Peas | 0.65\* | 5.09 |
| Radish | 0.85\*\* | 1.83 | Radish | 0.31ns | 4.63 | Mixed | 0.49ns | 7.68 |
| Rye | 0.43ns | 2.25 | Rye | 0.82\*\* | 1.86 | Rye | 0.44ns | 7.18 |
| **MTCI** | NCC | 0.53ns | 0.54 | NCC | 0.98\* | 1.7 | NCC | 0.9ns | 2.59 |
| Peas | 0.39ns | 3.75 | Peas | 0.9\*\*\* | 3.69 | Peas | 0.71\*\* | 4.57 |
| Radish | 0.81\*\* | 2.03 | Radish | 0.54\* | 3.83 | Mixed | 0.58\* | 7.15 |
| Rye | 0.45ns | 2.21 | Rye | 0.92\*\*\* | 1.31 | Rye | 0.4ns | 7.3 |
| **RIrededge** | NCC | 0.49ns | 0.55 | NCC | 0.97\* | 1.86 | NCC | 0.87ns | 2.67 |
| Peas | 0.38ns | 3.85 | Peas | 0.85\*\* | 4.54 | Peas | 0.65\* | 5.09 |
| Radish | 0.85\*\* | 1.83 | Radish | 0.31ns | 4.63 | Mixed | 0.49ns | 7.68 |
| Rye | 0.43ns | 2.25 | Rye | 0.82\*\* | 1.86 | Rye | 0.44ns | 7.18 |

Note: Leaf Chlorophyll Index (LCI), MERIS Terrestrial Chlorophyll Index (MTCI), Red Edge Chlorophyll Reflectance Index (RIrededge), Modified Simple Ratio at 705 (mSR705) and Modified Normalized Difference at 705 (mND705). \*, \*\* and \*\*\* indicate the regression is significant at *p*<0.05, *p*<0.01 and *p*<0.001 respectively. ‘ns’ indicates non-significant. MAPE: mean absolute percentage error.

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