Adapting the CSM-CERES-Maize Model for Ability to Simulate Maize Silage Production and Quality

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- Introduce CSM-CERES Maize model.
- Describe the need for a silage model, beyond grain yield
- Describe code modifications to predict DMC, quality, & harvest timing
- Show simulated outputs

Crop Simulation Models (what are they)

- Computer programs designed to simulate dynamic growth in response to daily weather, management, genetics.
- Based on understanding of plants, soil, weather, management interactions
  - Morphological, phenological development
  - Photosynthesis, respiration, growth
  - Root water uptake, stress effects on growth processes
- Predict daily growth, yield, timing (Outputs)
- Existing maize models simulate to maturity, but lack ability to predict fresh weight yield, dry matter concentration, and timing of optimum harvest for silage quality.
- DMC of grain and total crop is well related to progression of milk line (moving transition from liquid to starch).
- Goal: to adapt CERES-Maize model for these features to simulate milk line, DMC of organs, & timing of silage harvest.

CERES Maize Model

- DSSAT (Decision Support System for Agrotechnology Transfer) software includes CERES models (for 6 cereals), CROPGRO models (for 9 grain legumes, canola, carinata, cotton, sunflower, tomato and vegetables), CROPGRO-Perennial Forage model (4 perennial grasses and alfalfa).
- CERES model simulates daily growth and development of 6 cereal crops: maize, wheat, barley, millet, sorghum, rice
- Uses daily RUE approach: Ps = f(light interception, Sol. Rad, RUE)
- All models share the same "typing bucket" soil water balance, soil N balance, & SOC module (CENTURY or PAPRAN)
- Simulate water stress, N stress, response to temperature
- Require information about site, management, genetics
  - Daily weather
  - Management
  - Soil characteristics
  - Cultivar traits

Materials and Methods: Field Experiments

- **Asturias, Spain:** Three maize hybrids of FAO-200, FAO-300, FAO-400 maturity grown rainfed at 9 plants/m2 under 200 kg N/ha in 2012, 2013, 2014 at four sites. Harvested silage at 50% milk-line. N=30 cases
  - **Data:** Fresh and dry matter yield, %DMC of ear, veg, and whole plant, % CP, % starch, % OM digestibility
- **Citra, Florida Variety Trials:** Five hybrids grown in spring and summer sowings in 2018-2023, under full irrigation, 300 kg N/ha, at 8.9 seeds/m2. Harvested at 50% milk-line (assumed). N=39 cases
  - **Data:** Fresh and dry matter yield, %DMC of whole plant, % CP, % starch, % OM digestibility (not available)

CSM-CERES-Maize – Model Simulations

Table 1. Estimated cultivar coefficients for maize hybrids						
Cultivars	P1	P2	P5	G2	G3	PHINT
FAO 200	175	0.3	695	880	8.4	40
FAO 300	255	0.3	675	880	8.4	40
FAO 400	255	0.3	695	880	8.4	40
Spring-UF	325	0.5	730	830	12.0	40
Summer-UF	320	0.3	850	350	7.0	40

New Code for Simulating Silage & its Quality

- Simulate milk-line progression as f(GDD) after begin-grain. Zero milk-line occurs shortly after soft dough stage. Zero milk-line was set to occur 195 GDD (MILKZ0) after beginning of P5 phase.
- Rate of progression of milk-line set by SLPMLK (=1.3) to reach 50% milk-line by typical silage harvest date (calibrated to Asturias data) achieving 1.0 before maturity.
- Grain DMC is function of initial DMC (same as current veg DMC) at zero MILKLN and increases as a function of MILKLN multiplied by SLPGRN. Grain DMC typically is about 60% at 50% MILKLN. See graph of MILKLN and GRNDMC over time (Wisc & Spain).
- DMC of ear (EARDMC) and total plant (TOTDMC) were calibrated to Asturias data, where DMC of cob (COBDMC) and vegetative (VEGDMC) vary as f(MILKLN) progression.

New Code for Simulating Silage & its Quality

```
IF (ISTAGE .EQ. 5) THEN
      IF (SUMDTT .GE. MILKZ0) THEN
        MILKLN = SLPMLK * (SUMDTT - MILKZ0) / P5
      ENDIF
      VEGDMC = CVGDMC + SLPVEG * MILKLN
      COBDMC = COBDMCIS4 + SLPCOB * MILKLN
      GRNDMC = VEGDMC + SLPGRN * MILKLN
!
      SDFWT = SDWT / GRNDMC
      EARFWT = (EARWT - SDWT) / COBDMC + SDFWT
      TOTFWT = (TOPWT - EARWT) / VEGDMC + EARFWT
      TOTDMC = TOPWT / TOTFWT
      EARDMC = EARWT / EARFWT

      STACON = STAGRN*MILKLN+ STAVEG
      OMDIG = 100.0*(STACON + 6.25 * WTNCAN/TOPWT + CONDIG)
 ENDIF
```

Milk line (GDD)

MILKZ0=195
SLPMLK=1.30

DMC of organs

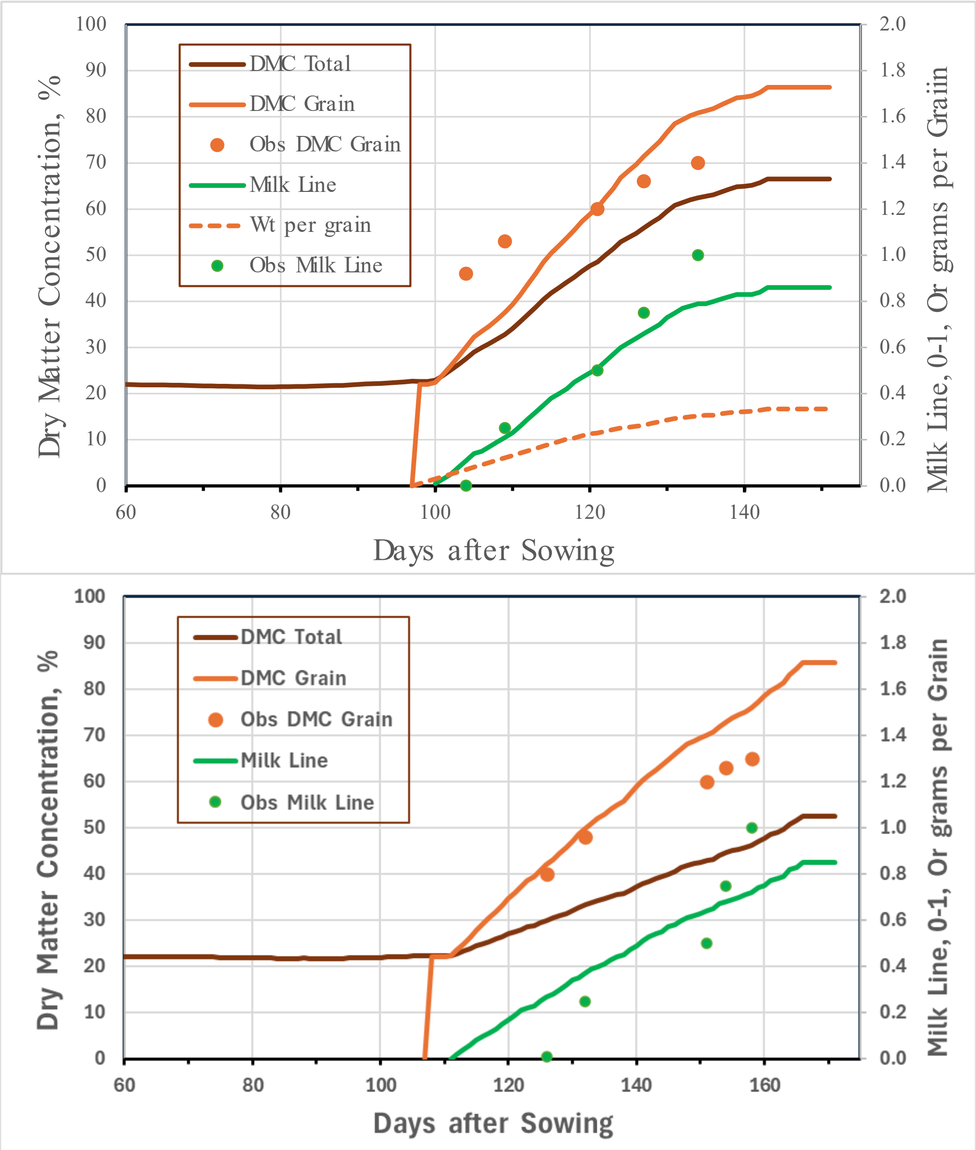
CVGDMC=0.22
SLPVEG=0.11
SLPCOB=0.75
SLPGRN=0.64

Starch% & OMD

STAGRN=0.23
STAVEG=0.21
CONDIG=0.235

CSM-CERES-Maize – Silage Yields & Quality

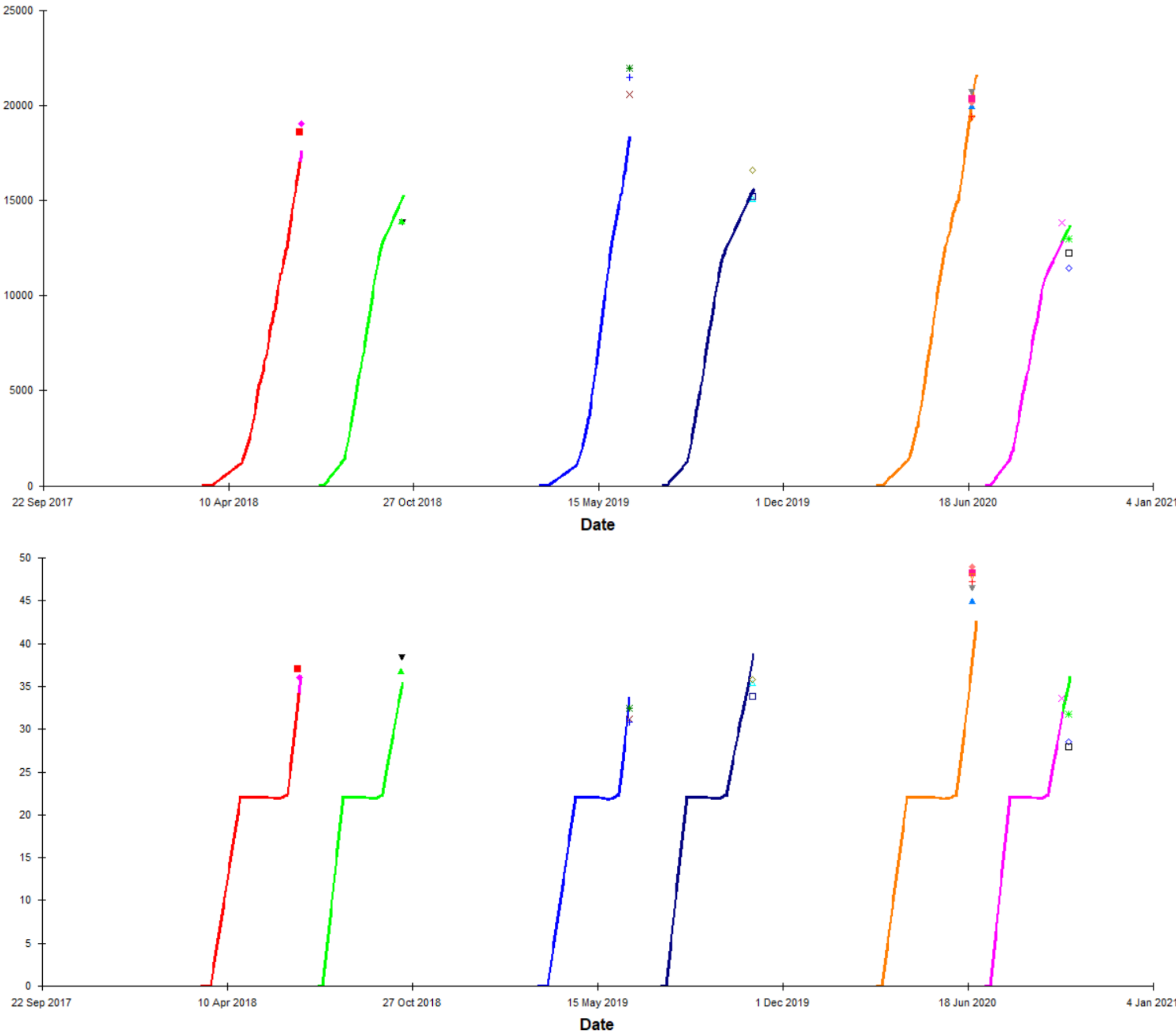
Table 2. Simulated and Observed Silage Yield & Quality Traits				
Observation	**Observed**	**Simulated**	**RMSE**	**d-Stat.**
	Asturias, Spain			
Crude protein, %	6.82	7.56	1.19	0.563
Top wt, kg/ha	19678.00	19859.00	3312.55	0.612
Top DM conc, %	39.51	40.44	7.28	0.425
Total Fresh, kg/ha	51170.00	49516.00	12801.55	0.503
Ear wt, kg/ha	10727.00	10869.00	2873.99	0.579
Ear DM conc, %	60.85	63.13	7.34	0.602
Ear Fresh, kg/ha	17749.00	17213.00	3885.19	0.706
Ear/top ratio	0.55	0.54	0.13	0.248
Starch conc, %	32.66	33.45	4.70	0.528
OM digest-pl, %	63.64	64.50	3.71	0.460
	Citra, Florida			
Crude protein, %	8.26	7.31	1.67	0.559
Tops wt, kg/ha	16267.00	17678.00	2866.26	0.799
Top DM conc, %	38.64	39.26	5.45	0.669
Starch conc, %	35.46	36.15	5.48	0.576



Simulated time-course of grain growth, milk line progression, DMC of grain, and DMC of total plant. For sites in Spain (upper: Flores Calvete,) and Wisconsin (lower: Wiersma).

MILKZ0=195 GDD after begin grain. Then as milk line progresses, the DMC of Grain increases. It is 60% at 50% milkline. DMC of total plant increases mostly from increasing DMC-Grain

Starch of grain also increases as milk line progresses



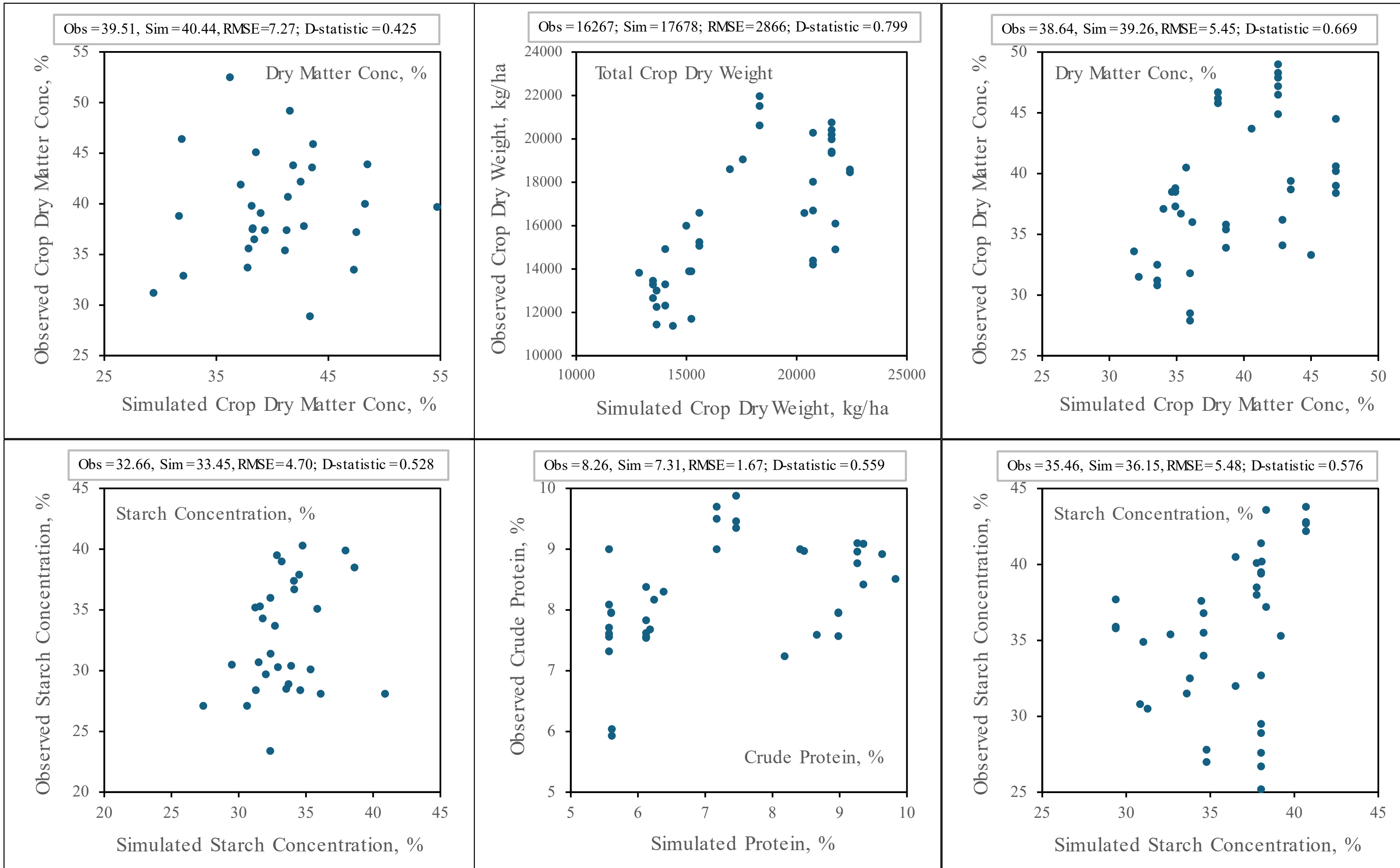
Simulated and observed DM-Yield (upper graph) and DMC Plant (lower graph) at observed silage harvest dates for spring and summer sowing at Citra, Florida

Plots of crop DM, DMC-Plant, CP%, Starch % for Spain & Citra.

Asturias

Citra

Citra



Seasonal Analysis over 25 years of weather at Citra, Florida showed that days to harvest (at optimum milk line of 0.5-0.66 and 35% DM), decreased from 107 to 86 days from early spring to summer plantings, while silage yield decreases from almost 19 to 17 Mg ha^{-1} DM (Simulations by Nicolas Caram, Ph.D. project).

At Citra: Response to N fertilization up to 300 kg N/ha and was greater for spring compared to summer sowing and increased CP%.

Early harvests (at 0.2 milk line) gave higher CP% but lower yields and OMD%. Conversely, late harvests (at 0.9 milk line) increased DM yield and OMD, but also decreased the CP% and increased DM%.

(Simulations by Nicolas Caram, Ph.D. project).

Conclusion

- Successfully adapted CSM-CERES-Maize for simulating silage yield and quality
- Simulated time-course of DMC in organs is connected to milk line progression during grain growth. Milk line progression starts at 195 GDD after beginning grain (P5 phase in CERES).
- Advancing DMC of grain, cob, vegetative, and starch% concentration of grain are driven by advancing milk line.
- Optimum harvest timing (DMC) is at 0.5 milk line
- Model was calibrated to n=30 (4 sites, 3 years, 3 cultivars) in Spain.
- With no further calibration, model performed well for Citra, Florida (n= 39, spring-summer, 5 hybrids sown in 6 years)
- Model will be published and released in future DSSAT.