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LARGE AREA YIELD ESTIMATES FROM PLANT SIMULATION MODELS

Sharon LeDuc,[1] Tom Hodges[2] and Vikki French[2]

Abstract

This is an initial progress report on the feasibility of using simulation models for large area crop yield estimation. The TAMW (Texas A&M Wheat) model was selected and modified for simulation of spring wheat growth. The model was applied to nine North Dakota crop reporting districts (CRD's) and to nine counties, one selected from each of the nine CRD's, for the years 1955-1976. Results indicate that while the accuracy of the individual components leading to the final yield estimate are unknown, the final yield estimates themselves closely follow annual changes in observed yields. An anticipated bias in observed yields due to technological improvements (trend) was also noted. Some problems with the model have been detected, and improvements are being considered.

Introduction

The use of plant process simulation models to provide an estimate of yield (production per unit area) of a large area has been proposed for several years. The availability of such models and the data to test them however, were two requirements that were not met until recently. This paper presents a progress report of the current status, problems encountered and problems expected in future work that deals with the application of these process models for estimating large area production in areas other than locations where the model was developed.

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[1] Statistician, Center for Environmental Assessment Services, NOAA; Agronomist and Statistician, Atmospheric Science Department, University of Missouri-Columbia; Columbia, Missouri.

[2] Research Associate, Atmospheric Science Department, University of Missouri Columbia, Columbia, Missouri.

Simulation Models

Crop yields are affected by many plant processes (Hodges, 1982). Models simulating these critical processes have been developed to estimate yields. The true values for these processes and their actual effects on observed yield are generally unknown and extremely difficult to determine, even experimentally. Because of this, many of the important errors involved in estimating the value from each process in the simulation are unknown. Only the error between the observed yield and its final estimated value can be measured. The accumulation of errors within the simulations leading to the final, measurable error cannot be determined.

Evaluation of Simulation Models

Model selection criteria have been developed (Hodges, 1982) which may also be used for evaluation of simulation models. These criteria include:

1) theoretical accuracy - how well the model agrees with plant physiological theory.
2) completeness - inclusion in the model of all critical processes.
3) simplicity - ease of use and understandability of the model.
4) sophistication - the degree of detail with which processes and interactions of processes are simulated.
5) structure - how a model has been implemented in computer code.
6) timeliness - the capability of the model to produce yield forecasts as needed.
7) reliability - the closeness of a model's predicted yields to the true observed yields in an independent test.
8) objectivity - the freedom of a model from subjective inputs by the user.

To a great extent, these criteria have not been formalized, and much work is needed in this area to determine useful evaluation techniques.

TAMW Model

Each simulation model emphasizes a different set of critical processes. The model selected in this study for initial testing is referred to as TAMW (Texas A&M Wheat) (Maas and Arkin, 1980). This model was selected because of its complete documentation and because of the interest in a wheat model for use in the AgRISTARS (Agriculture and Resources Inventory Surveys through Aerospace Remote Sensing) program.

TAMW simulates the daily growth and development of wheat plants based on temperature, photoperiod, soil moisture, and plant density. Information generated by the model during the growing season includes the length of the vegetative, reproductive, and grain filling phases; number of productive and unproductive shoots per plant; and spikelet number, grain number, and grain weight per head. Water stress and canopy light interception components are included which impact both growth and yield. Root growth is simulated within the confines of a soil moisture budget. Nutrient stress is not considered. The model was developed for winter wheat, but the developers believe it is appropriate for spring wheat when modified according to their specifications (Maas and Arkin, 1982, personal communication).

The model is coded in FORTRAN in a modular structure. A main program selects appropriate code for each growth stage and calls subroutines for additional calculations. The main program structure and descriptions of subroutines are given in Table 1. The subroutines called for each growth stage are shown in Table 2.

Documentation is contained in a Texas Agricultural Experiment Station report, No. 80-3, "TAMW: A Wheat Growth and Development Simulation Model." Information needed by the model (Table 3) includes sowing date and depth, plant and row spacing, latitude, soil albedo, 13 genetic rate or duration functions (one of these was changed in the modification for spring wheat), soil moisture parameters, and daily weather (precipitation, maximum and minimum temperature, solar radiation and snow depth). The model counts individual leaves, tillers and spikelets and provides a leaf area index, floret number, grain number, and grain weight. Phenology of the plant is determined in the model by the use of temperature and daylength.

Model Applications

Inputs other than planting date and the meteorological data which are required for the model were not changed from year to year. These included: distance between plants (1.0 cm), distance between rows (20.3 cm), sowing depth (2.54 cm), and initial soil albedo (0.09). Sets of genetic coefficients were available only for four winter wheat varieties. The different sets produced only minor changes in model performance. One set was selected, and one of its functions was modified following the suggestion of the model developers to adapt the model for spring wheat. The initial soil moisture value was estimated for each location. This was done by running the model once for odd years cropped and once for even years cropped with alternate years fallowed. This means that on alternate years, fields were not cropped but were left idle. This management practice allows accumulation of moisture in the soil profile in areas of marginal precipitation. An initial soil moisture was estimated for each location for "previous year cropped" and for "previous year fallowed" from the average values of the preliminary 11 year model run. When the model is run continuously

[illegible] is more normal · 1 → 20.3 ⇒ 493/m² which is way to de over several years, the December 31 soil moisture amount can be retained for use on January 1. After several years, the soil moisture value becomes independent of the initial value. The model also uses two constant ? inputs controlling the rate of evaporation from the soil surface.

The model was developed and intended for use on small plots with the required inputs available at the site. For large area yield estimating, these data must be derived through other methods. For example, temperature and precipitation data may be extrapolated from the dense network of meteorological stations. In this study the inverse distance method (Crosiar, 1982) was used. The model also requires solar radiation; however, it is measured at very few locations (about one per state), so that extrapolation is not meaningful. For this study, daily solar radiation is estimated from normal annual distributions for a location and relationships with precipitation and temperature values (Richardson, 1981).

isn't needed for 'thru' anyway unless there's a lot of water stress

Although the mean values for solar radiation agree with local mean values (Richardson, 1981), the standard deviations are too small. The effects of this on model performance needs to be investigated. Until solar radiation can be estimated by other means (e.g. satellite), the use of available surface data provides a convenient and accessible way of incorporating solar radiation into existing models.

Not all fields in a large area are managed in the same way. Numerous options exist and the model has the potential for evaluating the difference in yield which results from some of these options. The option which has the greatest effect on dryland spring wheat yields is believed to be whether there is continuous cropping or whether the field is fallowed every other year to allow for the accumulation of moisture in the soil. This effect can be seen in Figure 1, in which yield for summer fallowed acreage is consistently higher than for continuously cropped acreage. Another option is irrigation; however, this was not included. One must estimate the extent to which these and other options were utilized at the various locations. Also included in the management of a field is the planting date. This is not easily available for large areas and must be estimated from meteorological variables which indicate when it is physically possible to plant in an area. For this study, planting dates were estimated by a spring small grains planting model (Artley et al, 1981). This is another source of error, as the fields in an area may not have been planted at that time.

Another factor which changes over several years is the portion of the acreage in a region that is planted to each different crop variety. During a five year period use of a popular variety may decrease rapidly as farmers adopt a new, presumably higher-yielding variety. This change may be included by changing some of the 13 varietal coefficients or by adjusting the regional yield estimates for trend.

The model was applied to the years 1955-1965 to adjust any input parameters that could have affected the performance of the model. This was done to insure that the statistics from the test years, 1966-1976, would be an independent test of the model. Because of the massive climatic data requirements in applying the model, the analysis was limited to nine counties (see Figure 2), one from each Crop Reporting District. A separate analysis averaged the daily temperature and precipitation over all the counties within a Crop Reporting District and then used those averages as inputs to the model. The nine counties randomly selected, one from each CRD, are shown in Figure 2.

Model Evaluation

The model was executed only for summer fallow conditions. This required two computer simulations for each location since both options, cropped and fallowed, had to be considered. The initial soil moisture for the year when a crop is grown must be estimated from the precipitation and moisture loss during the year the land was fallow. The extent of area fallowed changed during the test period. In 1955 the ratio of continuously cropped area to summer fallowed area was 1.0. By 1970, this had decreased to .2. It was anticipated that this change would be reflected in increased observed yields, and, hence, an increasing difference between estimated and observed yields. Initially, eleven years (1955-1965) were simulated. It was anticipated that these results might indicate that model adjustments would be necessary. However, the estimates derived from the nine counties were fairly close, so no adjustments were made. During the next eleven years (Figure 3) these differences appeared to become larger, indicating the expected trend due to gradual implementation of different cropping practices. If the trend were removed, these errors would be substantially reduced. The largest error derived from using the counties was -7.9 q/h in 1974, which also had the largest error from the CRD estimate -8.5 q/h. Late planting (which was not estimated well by the planting date model used) could account for some of the yield reduction. The estimate using the CRD data was a better indicator of the loss than the estimate from the simulations for counties. On the other hand, the county estimates were better indicators of the reduction in 1961, a year of severe drought.

why are high values [illegible]. The [illegible] have to be [illegible]

Estimated yields were found to be especially sensitive to those factors which affect water stress. If the initial soil moisture was set very high or very low, then yields were increased or decreased respectively for several year until the stored soil moisture reached a stable value. The model was also sensitive to solar radiation. Yields were reduced with high solar radiation values, probably through the effect of solar radiation on water use and on the amount of stored soil moisture. Whenever drought conditions occurred in the model simulation, the duration of the heading to maturity period was greatly reduced due to the effects of water stress on the plant development algorithm. When the duration of this period was reduced, yield was reduced proportionately It is possible that a problem exists in the soil water balance subroutine (SWBAL). The soil water balance may be being depleted by excessive soil surfac evaporation.

as compared to what?

The only effect s.r. has is on soil water

Conclusions

The model yields show an encouraging positive relationship with observed yields. The state-level yields estimated from either the county or the CRD model runs show a comparable direction and magnitude of change with observed yields in most years (Figure 2). While estimated yields are consistently smaller than observed yields, this is due to anticipated differences in slope o the two curves. The positive slope of observed yields is most likely due to changes in technology and management practices which are not included in the model. Additionally, the model will require calibration ~~to the level of~~ 1970's technology. I doubt it.

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Summary

To investigate feasibilty of using crop simulation models for large area yield forecasting, the TAMW (Texas A&M Wheat) was selected and modified simulation of spring wheat growth. The model was applied to 9 North Dakota Crop Reporting Districts (CRD's) and to one county randomly selected from each CRD, for the years 1955-1976. Results indicate that while the accuracy of the individual components to the final yield estimate are unknown, the final yield estimates themselves closely follow annual changes in observed yield. An anticipated bias in observed yields, due to technological changes (Trend) was also noted. Some problems with the model have been detected and improvements are being considered.

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Table 1. Structure of main program and description of subroutines.

Main Program	Description of Subroutines called
Call PARAM	Initializes values of location and variety parameters.
Initialize location and plant variables	
Begin Yearly Loop	
Begin Daily Loop	Makes Daily Growth Calculations
Call SOL	Estimates daily solar radiation from correlations with precipitation and temperature values
Call CLIMATE	Calculates daylength from latitude and day of year.
Call SWBAL	Estimates Transpiration, Evaporation, and available soil moisture.
Begin Tiller Growth Loop for each Tiller (stem)	
Branch to block for current Growth Stage	
Call EMERG	Estimates progress of seed to emergence
Call COMP	Estimates competition between plants
Call TINIT	Estimates initiation of new Tillers (stems)
Call WLEAF	Estimates Leaf Growth
Call TEMERG	Estimates Tiller Emergence from Main Stem
Call FLORET	Estimates Head and Flower Growth before flowering.
Call TDEATH	Estimates death of Tillers
Call SENES	Estimates death of Leaves
Call GRFILL	Estimates rate of Grain Filling after flowering.
Call STRSS1	Estimates degree of Water Stress
End Tiller Growth Loop	
End Daily Loop	
Make Final Yield Estimate	Yield = Plants/Ha * Tillers/Plant * Grains/Tiller * Weight/Grain
End Yearly Loop	
End Main Program	

Table 2. Subroutines called for each growth stage.

Stage	1 Planting	2 Emergence	3 Floral Initiation	4 Flowering	5 Maturity
Subroutines	SOL CLIMATE SWBAL EMERG	SOL CLIMATE SWBAL COMP TINIT WLEAF TEMERG STRSS1 SENES	SOL CLIMATE SWBAL COMP WLEAF FLORET TDEATH STRSS1 SENES	SOL CLIMATE SWBAL COMP WLEAF GRFILL STRSS1 SENES	SOL CLIMATE SWBAL

Table 3. Initial and daily inputs to TAMW model.

INITIAL INPUTS

Starting date of daily meteorological data
Sowing date
Between row space
Within row space
Seeding depth
Latitude
Soil Albedo
13 genetic rate or duration functions
Upper limit of stage 1 soil evaporation
Coefficient of cumulative soil evaporation
Actual available soil water in each layer of soil profile
Maximum extractable soil water in each layer of soil profile

DAILY INPUTS

Precipitation
Maximum and Minimum Temperatures
Solar Radiation

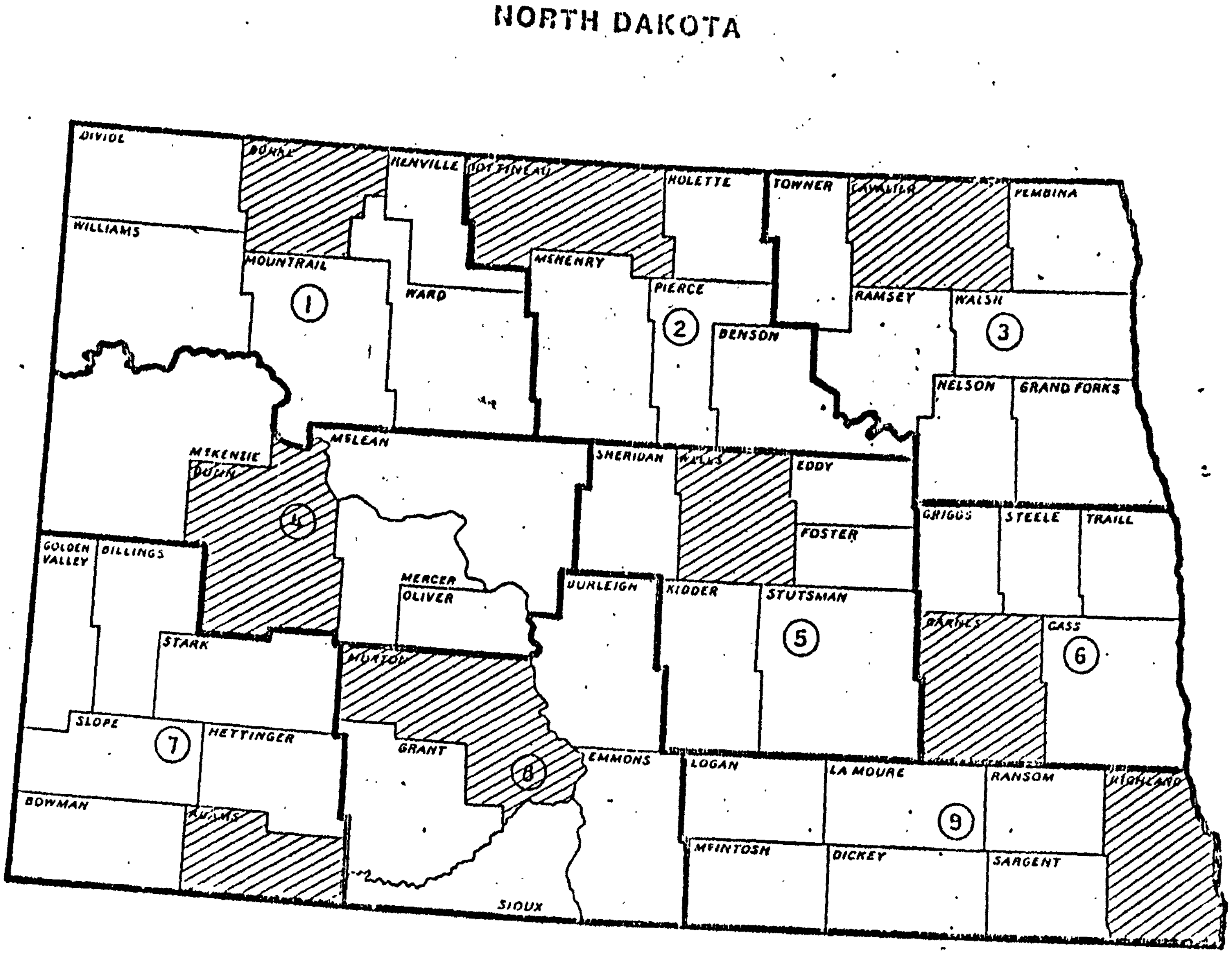

Figure 1. Counties in North Dakota for which Yield was simulated.

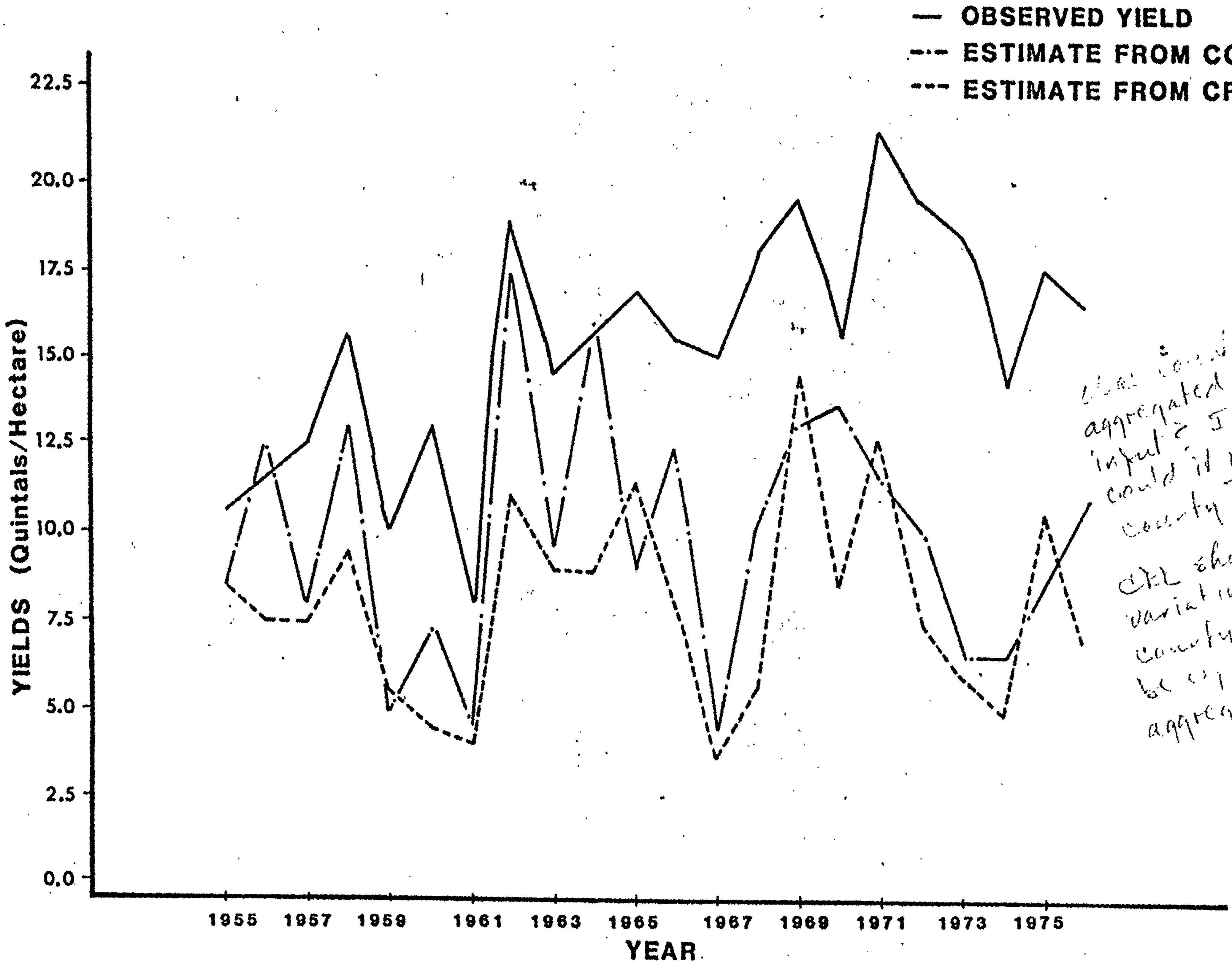

Figure 2. North Dakota State-Level Yields.

Was county data aggregated or raw input? If raw, how could it represent county?

CEL shows less variation than county as would be expected with aggregated input