Experimental field data for modeling the growth response of tef to nitrogen fertilizer and water stress

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Abstract: Field data from six experiments covering a wide range of growing conditions were organized for tef growth and cropping systems modeling. The data included (i) an irrigation experiment at Mekelle and Ilala, Ethiopia, (ii) a cultivar trial at Fallon, NV, USA, (iii) a nitrogen fertilizer experiment in the Jamma District of Ethiopia, (iv) a nitrogen fertilizer experiment in the Ofla District of Ethiopia, (v) a nitrogen fertilizer experiment at Ude and Kajima, Ethiopia, and (vi) a nitrogen fertilizer experiment at Gare Arera, Ethiopia. The combined data set covered 40 experimental treatments and 131 observations. Time series data were limited to biomass data from two treatments from the Tigray region experiment. All other crop related data was measured at maturity. Daily weather data was taken primarily from satellite weather databases for Ethiopia, and from weather stations in the USA. These data have been used in various agronomic studies, as well as the calibration of the DSSAT Tef model. The results of this model calibration are also included in this paper. The objective of this paper was to present and preserve all of the field data used for calibrating the DSSAT Tef model, as well as the tef model's simulations of the field data.
Keywords: Crop Model, Teff, *Eragrostis tef*, DSSAT

1 INTRODUCTION: Field experimental data were assembled for calibrating the Decision Support System for Agrotechnology Transfer (DSSAT) Tef model. The field experimental data were selected from a range of published tef field experiments conducted in Mekelle, Ilala, Jamma District, Ofla District, Ude, Kajima, and Gare Arera, Ethiopia, as well as in Fallon, NV, USA. The climates for the experiments ranged from cool and semi-arid to hot and arid.

The data consists of 40 treatments and 131 replications. Model ready field data for tef is extremely rare and all of the experiments used were missing at least some data needed for crop modeling that had to be filled in from other sources. All of the data sets included grain yield data. Of the six experiments, one included days to emergence, four included days to heading or anthesis, five included days to maturity, five included total aboveground biomass at maturity, 3 included grain nitrogen at maturity, 2 included straw nitrogen at maturity, and 3 included total aboveground nitrogen at maturity. Reported crop management data included planting date, plant population density, fertilizer and irrigation rates and dates, and soil water and fertility information. Not all experiments reported all of this data, however. Agronomic management ranged from rainfed without fertilizer (sub-optimal) to irrigated with recommended fertilizer rates (optimal). Pests and diseases were controlled for most of the experiments.

The datasets represent low to high yielding growing conditions for tef. The observed grain yields across the various growing environments and management practices ranged from 350 to 3013 kg/ha (Table 1). The lowest yield was observed for the rainfed treatment at Ilala, Ethiopia (Araya et al., 2010). The highest yield was observed for the 69 kg N/ha treatment in the Ofla District in Ethiopia (Okubay, 2012). Both of these locations were cool and semi-arid with distinct rainy seasons.

Assembled data were quality checked and individually and partly published in earlier studies (Araya et al., 2010; Asfaw, 2012; Davison and Laca, 2010; Okubay, 2012; Tulema et al., 2007; Tulema et al., 2005). Not all experiments or treatments from the studies were used in this paper. All soil profiles were standardized to a depth of 210 cm. Soil data for the Ethiopian sites came from the experiments. Soil data from the American site came from the NRCS soil survey (NRCS, 2016). The objective of this paper was to present and preserve all of the field data used for calibrating the DSSAT Tef model, as well as the tef model's simulations of the field data.

Table 1. Summary of experiments and ranges of observed grain yields of tef adjusted to 0% grain moisture across diverse treatments

Experiments	Location	Number of treatments	Observed yield range (kg/ha)
Water deficit experiment with different irrigation rates	Mekelle and Ilala, Ethiopia	9	350-1950
Cultivar trial	Fallon, NV, USA	15	483-1729
Nitrogen application rate and type	Jamma District Ethiopia	5	665-2222
Nitrogen application rate and type	Ofla District, Ethiopia	5	1847-3013
Nitrogen application across two locations	Ude 1 and Kajima, Ethiopia	2	772-1925
Nitrogen application type across two soils	Gare Arera, Ethiopia	4	352-1496

2 IRRIGATION EXPERIMENT-MEKELLE AND ILALA, ETHIOPIA: An experiment with five different irrigation treatments that varied in timing and quantity was conducted during the growing season of 2008 and an experiment with three different irrigation treatments that varied in timing and quantity was conducted during the growing season of 2009 at Mekelle (13º 3' N and 39º 6' E), in the Tigray Region of Ethiopia, on a Cambisol soil (Araya et al., 2010). An experiment with one rainfed treatment was conducted during the growing season of 2008 at Ilala (13º 4' N and 39º 4' E), in the Tigray Region of Ethiopia, on a Vertisol soil (Araya et al., 2010). The tef cultivars DZ-974 (improved) and keyh (local) were sown on August 2nd, 2008 and August 5th, 2008 at the Mekelle and Ilala sites respectively. The keyh variety was sown on July 31st, 2009 at the Mekelle site. All treatments had 60 kg N/ha and 46 kg P/ha applied in a split application, with half of the N fertilizer applied at planting and the other half applied 30 days after planting. Irrigation treatments ranged from 0 to 9 irrigations and 0 to 95 mm applied water, depending on the year and the location (Table 2). Aboveground dry matter and grain yield were measured at maturity. Times series data for aboveground dry matter was measured in 2008 for the rainfed and 8 irrigation treatments at Mekelle.

Table 2. Irrigation dates and amount for water deficit experiment-Tigray Region, Ethiopia

Irrigation dates (yyyy-mm-dd)	**Irrigation (mm)**					
Mekelle, 2008	**Irrigation Treatments**					
	I0	I2	I4	I6	I8	I9
2008-09-17	0	10	10	10	10	-
2008-09-19	0	10	10	10	10	-
2008-09-21	0	0	12	12	12	-
2008-09-24	0	0	15	15	15	-
2008-09-29	0	0	0	12	12	-
2008-10-03	0	0	0	12	12	-
2008-10-07	0	0	0	0	12	-
2008-10-09	0	0	0	0	12	-
Total Irrigation (mm)	0	20	45	69	95	-

Table 2. Irrigation dates and amount for water deficit experiment-Tigray Region, Ethiopia (Continued)

Irrigation dates (yyyy-mm-dd)	**Irrigation (mm)**					
Mekelle, 2009	**Irrigation Treatments**					
	I0	I2	I4	I6	I8	I9
2009-09-17	0	-	10	-	-	10
2009-09-19	0	-	10	-	-	10
2009-09-20	0	-	10	-	-	10
2009-09-24	0	-	10	-	-	10
2009-09-27	0	-	0	-	-	10
2009-10-01	0	-	0	-	-	10
2009-10-03	0	-	0	-	-	10
2009-10-05	0	-	0	-	-	10
2009-10-07	0	-	0	-	-	10
Total Irrigation (mm)	0	-	40	-	-	90

3 YIELD TRIAL EXPERIMENT-FALLON, NV, USA: Field trials were conducted with 15 different tef cultivars planted on June 4th, 2009 in Fallon, NV, USA (39º 29' 20" N, 118º 49' 41" W) on a Dia loam soil (Davison and Laca, 2010). The cultivars used were Dessie, 347362, 494432, 193508, 273889, Uk. Brown, 557457, 494366, Uk. White, 193514, 195932, 494479, 494465, 329680, and 494433. No fertilizer use was reported. The plots were regularly flood irrigated between June 13th and harvest. The plots were sprayed with an herbicide to control broadleaved weeds on July 9th and regularly hand weeded. The grain yield at maturity was reported, but the total biomass was not reported.

4 NITROGEN FERTILIZER EXPERIMENT-JAMMA DISTRICT, ETHIOPIA: Field experiments with four nitrogen fertilizer rates and two types of nitrogen fertilizer were conducted during the growing season of 2011 in the Jamma District (10º 27'N, 39º 15' E) of Ethiopia (Asfaw, 2012). The original purpose of this study was to describe the study area soil and to compare the efficiency of slow release nitrogen fertilizer and conventional urea at increasing the yield and yield traits of wheat and tef. This data set only includes the slow release fertilizer treatments for tef. The soil type was a Vertisol (clay soil). The tef cultivar used was a local variety called Wajera. The slow release nitrogen rates ranged from 0% of the recommended rate to 150% of the recommended rate (Table 3). All slow release nitrogen was applied at planting, but the exact planting date was not provided in the publication. The planting date was assumed to be July 24th, 2011 based on the typical planting time frame for tef. The experiment measured the grain weight, straw weight, total aboveground biomass, grain N uptake, straw N uptake, and total aboveground N uptake at maturity.

Table 3. Summary of nitrogen fertilizer treatment experiment in the Jamma District of Ethiopia

Fertilizer Type	**N Applied (kg/ha)**
Urea Super Granule	0
Urea Super Granule	23
Urea Super Granule	46
Urea Super Granule	69

5 NITROGEN FERTLIZER EXPERIMENT-OFLA DISTRICT, ETHIOPIA: Field experiments with four nitrogen fertilizer rates and two types of nitrogen fertilizer were conducted during the growing season of 2011 in the Ofla District (12º 31' 58" N, 39º 30' 13" E) of Ethiopia (Okubay, 2012). The original purpose of this study was to describe the study area soil, to compare the performance of slow release nitrogen fertilizer and conventional urea for wheat and tef production, and to find the optimum slow release urea fertilizer rate for wheat and tef. This data set only includes the slow release fertilizer treatments for tef. The soil type was a Vertisol (clay soil). The tef cultivar used was an improved variety called DZ-cr-387, also known as Kuncho. The slow release nitrogen rates ranged from 0% of the recommended rate to 150% of the recommended rate (Table 4). All slow release nitrogen was applied at planting, but the exact planting date was not provided in the publication. The planting date was assumed to be July 24th, 2011 based on the typical planting time frame for tef. The experiment was rainfed. The experiment measured the grain weight, straw weight, total aboveground biomass, grain N uptake, straw N uptake, and total aboveground N uptake at maturity.

Table 4. Summary of nitrogen fertilizer treatment experiment in the Ofla District of Ethiopia

Fertilizer Type	N Applied (kg/ha)
Urea Super Granule	0
Urea Super Granule	23
Urea Super Granule	46
Urea Super Granule	69

6 NITROGEN FERTILIZER EXPERIMENT-UDE AND KAJIMA, ETHIOPIA: Field experiments measuring the fertilizer N use efficiency of tef were conducted at three sites in the Ada Area (8º 48' N, 39º 38' E) of the Oromiya Region in Ethiopia in 1997 with a constant fertilizer rate (Tulema et al., 2005). The Ude 2 site was not included in this data set, however, due to high weed pressure (Tulema et al., 2005), which the DSSAT model cannot account for. The soil types at the Ude 1 and Kajima locations were a Vertisol and an Andisol respectively. The recommended fertilizer rate of 64 kg N and 20 kg P per hectare was used at all locations. The experiment was rainfed. Planting occurred on July 22^{nd} and 23^{rd}. The cultivar used was DZ-01-354. Dry matter yield, grain yield, and total N yield were measured at maturity.

7 ORGANIC FERTILIZER EXPERIMENT-GARE ARERA, ETHIOPIA: Field experiments using three types of organic fertilizer, a synthetic fertilizer, and an unfertilized control were conducted on two soil types, in 2002, in Gare Arera (9º 3' N, 38º 30' E) in the Oromiya region of Ethiopia (Tulema et al., 2007). Only the control and the urea fertilizer treatments were included in this data set. The fertilizer rate for the urea treatment was 40 kg N/ha for the Nitisol soil, and 60 kg N/ha for the Vertisol soil. The experiments were rainfed. Cultivar DZ-01-354 was planted on July 24^{th} and 25^{th} on the Nitisol and Vertisol soils respectively. Biomass, grain yield, and grain N were measured at maturity.

8 CALIBRATING THE DSSAT TEF MODEL: The DSSAT Tef model was based on the DSSAT NWheat model, with changes to phenology, photoperiod response, radiation use efficiency, transpiration efficiency and atmospheric CO_2 response (Paff and Asseng, 2019). The DSSAT Tef model was calibrated using the field experiments listed above, as well as parameters from the tef literature and from the sorghum literature, whenever there was a gap in the tef literature (Paff and Asseng, 2019). The calibration used all treatments from the experiments in Mekelle, Ilala, and Fallon, NV (Araya et al., 2010; Davison and Laca, 2010). The slow release urea and unfertilized control treatments were used from Asfaw (2012) and Okubay Giday (2012). The Ude 1 and Kajima treatments were used from Tulema (2005). The control and the urea treatment were used from the Tulema (2007) experiment. Certain model parameters, such as radiation use efficiency, transpiration efficiency, and CO_2 response, were the same across all cultivars and were derived from values in the tef and sorghum literature (Paff and Asseng, 2019). Individual cultivars were calibrated first for phenology, then for biomass, and finally for grain yield (Paff and Asseng, 2019). The model accurately captured the time to anthesis and maturity for tef, with a root mean square error of 2.5 and 4.4 days respectively (Paff and Asseng, 2019). The model regularly overestimated biomass and grain yields, as it did not account for biological stresses, but did capture the general trends caused by increased irrigation and fertilizer. The relative root mean square error was 49.6% and 41.0% for total aboveground biomass and grain yield respectively (Paff and Asseng, 2019).

9 GUIDELINES FOR DATA USE: Details on crop management, weather, soil, and measured crop data are provided in the AgMIP JSON format (Rosenzweig et al., 2013). Table 5 lists the file names for input and measured data for each experiment location used for calibrating the DSSAT Tef model. All data are in text files. The file named Readme_Variable definition.txt defines the parameters and units used.

Table 5. File names for experimental data

Location		Input files			Observed data
	Latitude/Longitude	Weather	Soil	Management	
Mekelle, Ethiopia, 2008	13.05 N/ 39.1 E	ETMK0801	MK	CM_ETMK0801	Exp _Mekelle, Exp _Mekelle_TimeSeries
Mekelle, Ethiopia, 2009	13.05 N/ 39.1 E	ETMK0901	MK	CM_ETMK0901	Exp _Mekelle, Exp _Mekelle_TimeSeries
Ilala, Ethiopia	13.07 N/ 39.07 E	ETIL0801	IL	CM_ETIL0801	Exp _Ilala, Exp _Ilala_TimeSeries
Fallon, NV, USA	39.46 N/ -118.78 W	FNUS0901	FN	CM_USFN0901	Exp _Fallon, Exp _Fallon_TimeSeries
Jamma District, Ethiopia	10.45 N/ 39.25 E	ETJA1101	JD	CM_ETJD1101	Exp _Jamma, Exp _Jamma_TimeSeries
Ofla District, Ethiopia	12.5 N/ 39.52 E	ETON1101	OD	CM_ETOD1101	Exp _Ofla, Exp _Ofla_TimeSeries
Ude, Ethiopia	8.8 N/ 39.63 E	EADA9701	UD	CM_ETUD9701	Exp _Ada, Exp _Ada_TimeSeries
Kajima, Ethiopia	8.8 N/ 39.63 E	EADA9701	KJ	CM_ETUD9701	Exp _Ada, Exp _Ada_TimeSeries
Gare Arera, Ethiopia, Nitisol	9.05 N/ 38.5 E	EGAR0201	GN	CM_ETGA0201	Exp _GareArera, Exp _GareArera_TimeSeries
Gare Arera, Ethiopia, Vertisol	9.05 N/ 38.5 E	EGAR0201	GV	CM_ETGA0201	Exp _GareArera, Exp _GareArera_TimeSeries

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