Production Potential, Theoretical Ethanol Yield And Environmental Sustainability of Miscanthus as Biofuel Feedstock

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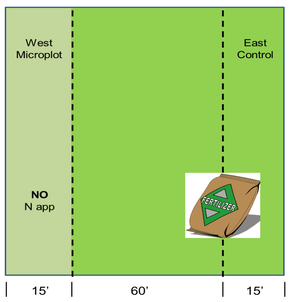
Abstract

Increasing concerns of global warming attracts more attention on bioenergy development. Miscanthus as designated bioenergy feedstock is a promising cellulosic biomass feedstock to ensure reliable and stable biomass feedstock supply. Miscanthus was established since 2008 at KBS, Michigan and Arlington, Wisconsin to evaluate its potential as bioenergy feedstock. The objectives of the study was to evaluate the yield and quality of biomass feedstock produced from Miscanthus system. Nitrogen effect on quantity and quality of five perennial cropping systems under study. Environmental performance for Miscanthus was also examined in this study.

Field Design and Picture

Figure 1. RCBD with split-plot has 10 treatments and 5 Blocks at KBS and Arlington, this study focused on perennial herbaceous cropping systems

G5: Switchgrass
G6: Miscanthus*
G10:Native Prairie
G7:Native Grass Mix
G9:Old Field



G5,G6,G7,G9:
mainplots&control:56 kg N ha-1
Microplots(west): No N app

G10:
Mainplot&control: No N app
Microplots(west):56 kg N ha-1

G10 Block 1 at KBS:
Mainplot&control: No N app
Microplots(east):56 kg N ha-1

Figure 2. Plot set-up

Climatological Summary of two locations

Location	Cropping Phase	Month	Mean Temperature (C) 2010	2011	2012	2013	2014	30-yrs Avg.
KBS	Growth Phase	Apr	13.2	7.9	9.3	8.2	8.4	9.7
		May	16.3	16.3	16.4	17.4	14.9	15.9
		Jun	22.1	21.4	21.5	20.4	21.4	21.2
		Jul	23.8	24.8	25.9	23.0	19.1	23.0
		Aug	22.7	21.7	21.7	21.1	20.7	21.8
		Sep	18.1	16.9	16.0	18.2	16.7	17.3
	Fall Harvest	Oct	12.9	11.4	10.1	11.9	11.3	11.2
		Nov	5.5	7.2	3.9	3.8	0.9	4.8
	Over-Winter Phase	Dec	-4.3	1.6	1.8	-3.8	0.1	-1.4
		Jan	-3.9	-6.6	-1.4	-2.1	-9.0	-3.7
		Feb	-3.7	-3.3	-0.1	-4.0	-7.4	-2.7
		Mar	5.4	1.1	10.9	0.7	-2.5	3.2

Location	Cropping Phase	Month	Total Precipitation (cm) 2010	2011	2012	2013	2014	30-yrs Avg.
KBS	Growth Phase	Apr	7.3	13.3	10.7	21.4	6.7	9.4
		May	3.0	17.2	7.3	11.3	8.1	9.7
		Jun	20.8	5.7	4.0	10.8	14.7	10.0
		Jul	15.2	23.2	3.9	11.7	10.4	10.1
		Aug	1.8	9.8	4.9	13.6	7.4	10.5
		Sep	9.4	7.6	3.8	1.9	6.6	10.6
	Fall Harvest	Oct	4.5	9.0	14.2	5.5	9.4	9.5
		Nov	4.6	10.4	1.4	11.3	8.2	8.3
	Over-Winter Phase	Dec	2.9	9.7	5.6	6.4	3.3	6.3
		Jan	2.2	2.7	8.3	5.1	7.5	5.9
		Feb	4.4	3.5	6.8	18.8	6.0	5.5
		Mar	2.7	7.3	10.4	2.9	5.2	6.3

Table 1. Monthly mean precipitation and temperature with 30-yr means at KBS

Location	Cropping Phase	Month	Mean Temperature (C) 2010	2011	2012	2013	2014	30-yrs Avg.
ARL	Growth Phase	Apr	-9.9	-10.6	-6.3	-8.7	-14.6	-8.1
		May	-6.9	-8.0	-2.9	-8.5	-13.6	-5.9
		Jun	1.9	-2.1	7.6	-5.3	-5.6	0.5
		Jul	9.1	5.2	6.4	4.1	4.9	7.7
		Aug	14.0	12.0	15.0	13.3	12.6	13.7
		Sep	18.9	18.2	19.8	17.9	19.2	19.5
	Fall Harvest	Oct	21.8	22.7	24.3	20.4	18.1	21.5
		Nov	21.4	19.9	19.4	19.2	20.6	20.2
	Over-Winter Phase	Dec	14.3	13.6	14.3	15.5	15.4	15.9
		Jan	10.0	9.7	6.8	7.9	8.9	9.2
		Feb	2.1	2.1	1.2	-0.8	-2.2	1.6
		Mar	-9.3	-2.9	-3.7	-10.6	-2.5	-5.4

Location	Cropping Phase	Month	Total Precipitation (cm) 2010	2011	2012	2013	2014	30-yrs Avg.
ARL	Growth Phase	Apr	4.3	1.5	2.0	5.7	1.9	2.9
		May	2.8	1.5	2.4	4.8	2.6	2.9
		Jun	2.6	8.6	6.2	6.0	2.4	4.9
		Jul	9.3	9.0	7.8	13.8	16.4	8.8
		Aug	10.5	6.1	7.5	15.3	7.1	9.4
		Sep	19.3	10.4	0.7	19.1	23.7	12.1
	Fall Harvest	Oct	23.6	6.3	10.1	7.6	4.8	10.1
		Nov	11.9	3.7	7.3	4.5	9.4	9.5
	Over-Winter Phase	Dec	11.5	9.8	2.6	7.5	4.5	8.9
		Jan	4.3	4.0	10.1	3.9	7.0	6.1
		Feb	3.6	8.3	2.8	6.7	4.4	5.7
		Mar	4.2	6.0	6.0	2.9	2.9	3.3

Table 2. Monthly mean precipitation and temperature with 30-yr means at ARL

Miscanthus Yield Results: Miscanthus yearly yields are analyzed for 5 growing seasons. *Means with the same lowercase letter(s) are not statistically different (α= 0.05)

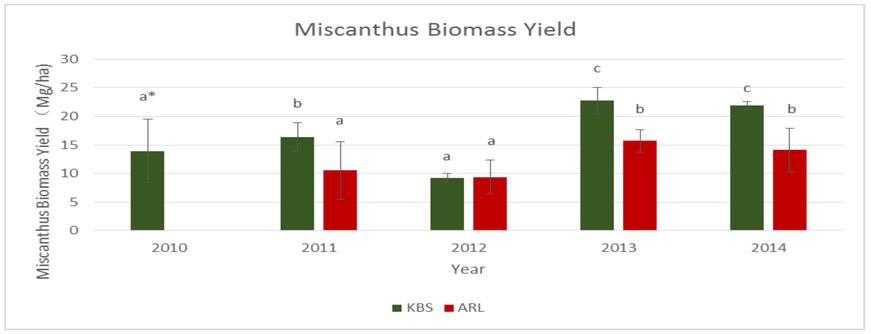


Figure 3. 2010-2014 Miscanthus Biomass Yield

Nitrogen effect on BIomass Yield Results: Nitrogen fertilizer effect on Biomass yields are analyzed from 5 different perennial cropping systems at two locations. *P ≤ 0.01, ** P ≤ 0.001.

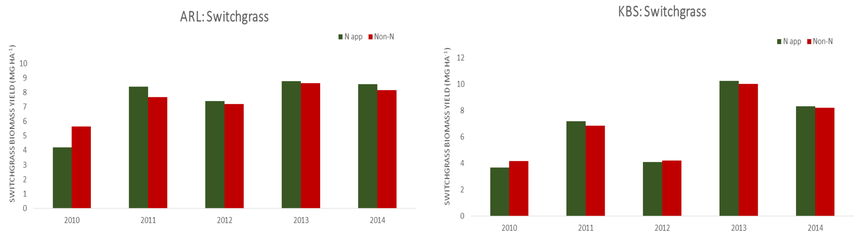


Figure 4. Switchgrass Yield of KBS & Arlington for 2010-2014 Growing Seasons

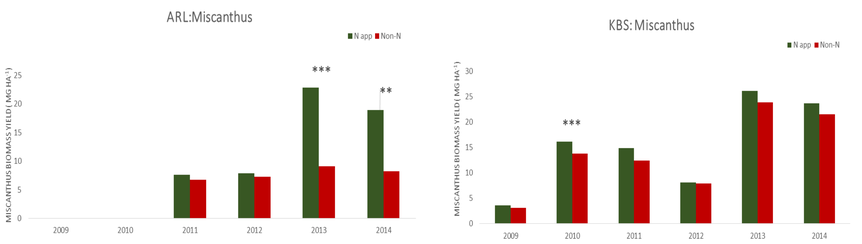


Figure 5. Miscanthus Yield of KBS & Arlington for 2010-2014 Growing Seasons

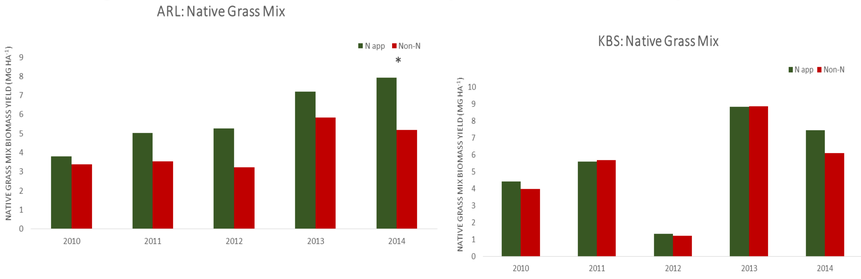


Figure 6. Native Grasses Mix Yield of KBS & Arlington for 2010-2014 Growing Seasons

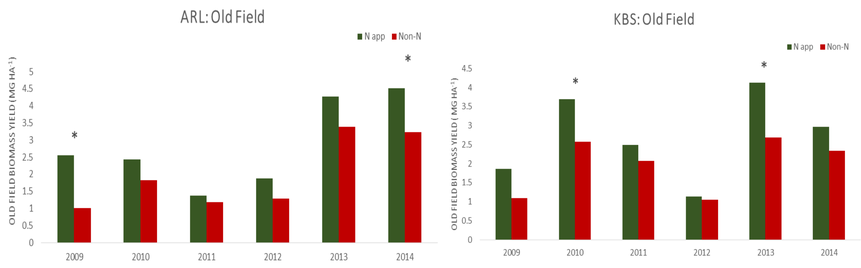


Figure 7. Old Field (Successional field) Yield of KBS & Arlington for 2010-2014 Growing Seasons

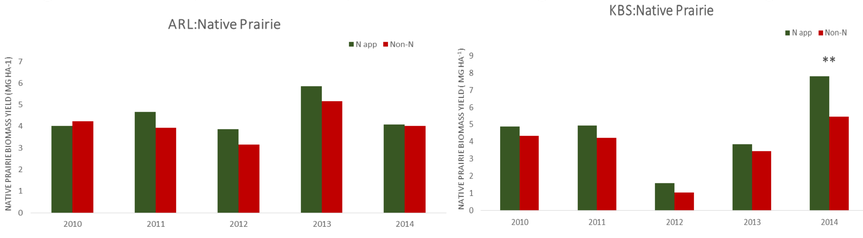


Figure 8. Native Prairie Biomass Yield of KBS & Arlington for 2010-2014 Growing Seasons

Theoretical Ethanol Yield Results:
Glucose, pentose and theoretical Biomass Ethanol yields of Miscanthus are analyzed. Theoretical Biomass Ethanol yields in unit of (g g^{-1}) and (Mg ha^{-1}) are analyzed. *Means with the same letter(s) are not statistically different (α= 0.05).

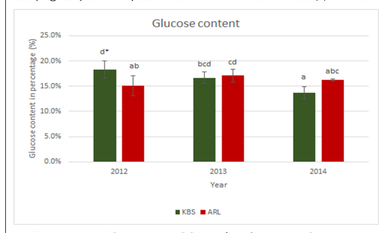


Figure 9. Glucose Yield(g g^{-1}) of Miscanthus across two locations and 3 years

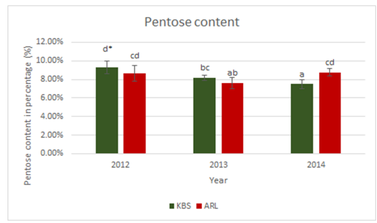


Figure 10. Pentose Yield(g g^{-1}) of Miscanthus across two locations and 3 years

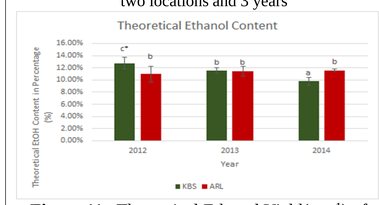


Figure 11. Theoretical Ethanol Yield(g g^{-1}) of Miscanthus across two locations and 3 years

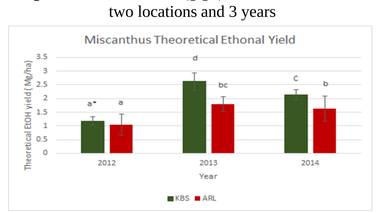


Figure 12. Theoretical Ethanol Yield(Mg ha^{-1} of Miscanthus across two locations and 3 years

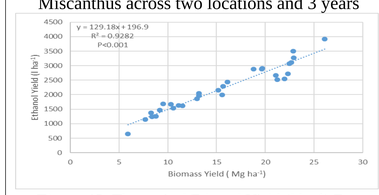


Figure 13. Theoretical Ethanol Yield (l ha^{-1}) For Biomass Yield(Mg ha^{-1})

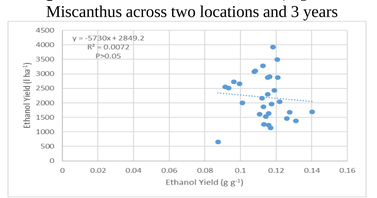


Figure 14. Theoretical Ethanol Yield (l ha^{-1}) For Theoretical Ethanol Yield(g g^{-1})

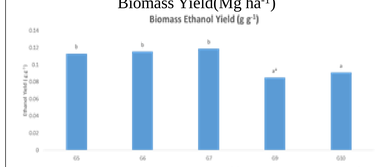


Figure 15. Cropping Systems Effect on Biomass Ethanol Yield(g g^{-1}) across two locations and 5 years

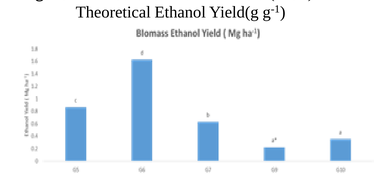


Figure 16. Cropping Systems Effect on Biomass Ethanol Yield(Mg ha^{-1}) across two locations and 5 years

Life Cycle Assessment:
Life Cycle Assessment (LCA) was performed using GaBi 6 Professional + Extension 2012 database (PE international). This study complies with ISO14000 and ISO 14040. TRACI 2.1 Impact Assessment Method is adopted to evaluate environmental burden of Global Warming Potential. Contribution analysis and sensitivity analysis were conducted for Micanthus at both location.

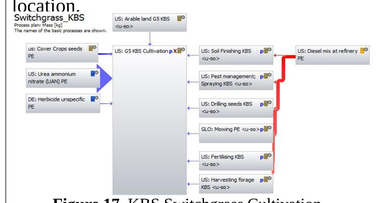


Figure 17. KBS Switchgrass Cultivation flow diagram

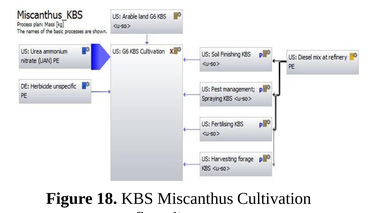


Figure 18. KBS Miscanthus Cultivation flow diagram

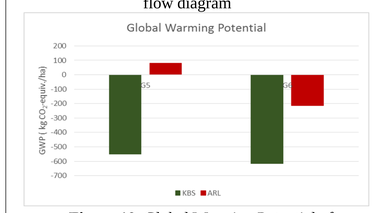


Figure 19. Global Warming Potential of Switchgrass and Miscanthus

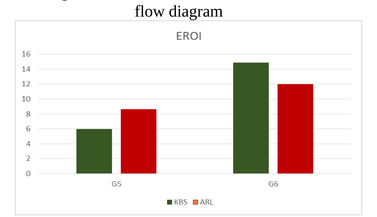


Figure 20. Energy return on investment for switchgrass and Miscanthus

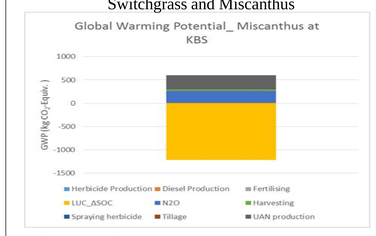


Figure 21. Contribution analysis for Miscanthus at KBS

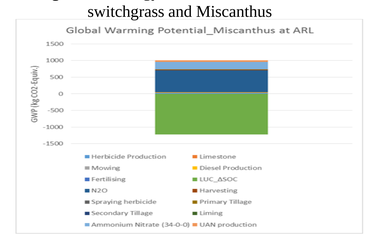


Figure 22. Contribution analysis for Miscanthus at ARL

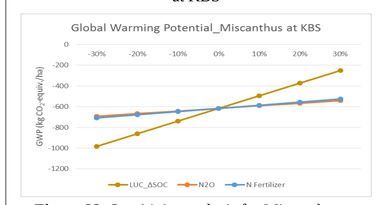


Figure 23. Sensitivity analysis for Miscanthus at KBS

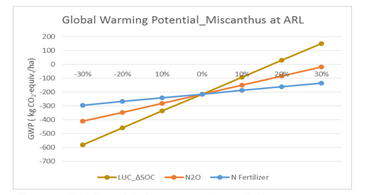


Figure 24. Sensitivity analysis for Miscanthus at ARL

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