

TABLE OF CONTENTS

Content	Page No
Acknowledgement	I-II
Abstract	III-IX
Table of Contents	X-XV
List of Tables	XVI-XVIII
List of Figures	XIX-XXII
List of Abbreviations and Symbols	XXII-XXV
CHAPTER 1: INTRODUCTION	1-27
1.1 Agriculture: Intensification and sustainability	1
1.2 Inputs for sustainable agriculture: Role of fertilizer	2-3
1.3 Growth of renewable energy and scope of utilization of bioenergy by-product in agriculture	4-10
1.3.1 Growth of renewable energy	4-5
1.3.2 Global bioenergy status and technological options for exploiting bioenergy	5-7
1.3.3 Bioenergy by-products: inevitable commodities of bioenergy conversion process and need of their management	7-8
1.3.4 Scope of utilization of by-products of anaerobic digestion and gasification in agriculture	8-10
1.4 Issues related to bioenergy by-product utilization	10-11
1.5 Closing of nutrient cycle through bioenergy by-product utilization in agriculture: an Indian perspective	11-15
1.5.1 India's energy concern and growth of renewable energy	11-13
1.5.2 Concerns related to agriculture in India	13-14
1.5.3 Integrating energy and agriculture through bioenergy by-product recycling	14-16
1.6 Objectives of research	16-17
1.7 Organization of thesis	17-19
References	20-27

CHAPTER 2: LITERATURE REVIEW**28-68**

2.1	By-products of anaerobic digestion process (anaerobic digestate)	28-43
2.1.1	Variation of digestate physico-chemical properties with respect to feedstocks and suitability as fertilizer	29-34
2.1.2	Application of digestate: effect on soil	35-36
2.1.3	Application of digestate: effect on crop	36-39
2.1.3.1	Effect of digestate application on physical growth of crop	36-38
2.1.3.2	Effect of digestate application on crop quality and nutrient uptake	38-39
2.1.4	Environmental risks from digestate application	39-41
2.1.5	Potential phyto-toxicity from digestate application	41-42
2.1.6	Application of biogas digestate through solid liquid separation	42-43
2.2	By-products of biomass gasification process	44-51
2.2.1	Biochar characteristics	44-47
2.2.2	Effect of application of biochar on soil	48
2.2.3	Effect of application of biochar on crop	49-51
2.2.4	Potential phyto-toxicity from biochar application	51
2.3	Summary	51-52
	References	53-68

CHAPTER 3: CHARACTERIZATION OF BIOENERGY BY-PRODUCT (ANAEROBIC DIGESTATE AND BIOCHAR) AS CROP PRODUCTION INPUT**69-144**

3.1	Introduction	69
3.2	Description of biomass considered	70-74
3.3	Feedstocks considered for co-digestion	74-76
3.4	Preparation and processing of bioenergy by-products	76-78
3.4.1	Collection and preparation of feedstock and their anaerobic digestion	76-77
3.4.2	By-product collection and processing from anaerobic digestion	77
3.4.3	Collection of by-products from gasification	77-78

Part A:	Physical and chemical characterization of bioenergy by-products	
3.5	Materials and Methods	78-82
3.5.1	Analytical methods used for biomass characterization	78-79
3.5.2	Analytical methods used for by-product characterization	79-91
3.5.3	Statistical analysis of data related to by-product characterization	81-82
3.6	Results and Discussions	82-104
3.6.1	Characteristics of biomass considered	82-83
3.6.2	Variation of total solid among BEBPs	83
3.6.3	Variation of pH and electrical conductivities among BEBPs	83-85
3.6.4	Variation of plant nutrients among BEBPs	85-91
3.6.5	Distribution of mass and major plant nutrients among solid liquid fractions of digestate	92-93
3.6.6	Variation of total organic carbon and C:N ratio among BEBPs	94-95
3.6.7	Variation of lignin, cellulose and hemicellulose content among BEBPs	95-97
3.6.8	Variation of heavy metals (Cr, Pb, As, Cd, Se) and Al among BEBPs	97-99
3.6.9	Statistical relation among different parameters of BEBPs	100-102
3.6.10	Comparison of major parameters of BEBPs of the present study with similar by-products reported in literature	103-204
Part B:	Characterization of bioenergy by-products using FTIR, XRD and SEM analysis	
3.7	Materials and Methods	105-107
3.7.1	FTIR analysis of BEBPs	105
3.7.2	XRD analysis of BEBPs	106
3.7.3	SEM analysis of BEBPs	106
3.7.4	Statistical analysis (Principle Component Analysis) of FTIR spectra data of BEBPs	107
3.8	Results & Discussions	107-123
3.8.1	FTIR investigation of BEBPs for presence of functional groups	107-115

3.8.1.1	FTIR spectra of solid and ash phase of digestates	107-109
3.8.1.2	FTIR spectra of liquid phase of digestates	110-111
3.8.1.3	Comparison of FTIR spectra of digestates with undigested feedstock	111
3.8.1.4	FTIR spectra of Rice husk and Rice husk Biochar	112
3.8.1.5	Principal Component analysis (PCA) and band intensity of ratio of digestate FTIR spectra	113-115
3.8.1.6	Possible influence of functional groups of BEBPs on soil properties	115-117
3.8.2	Identification of possible mineral phases in the BEBPs through XRD analysis	118-121
3.8.3	Morphological analysis of BEBPs using SEM	121-123

Part C: Potential phyto-toxicity of bioenergy by-products through seed germination test

3.9	Materials and Methods	123-124
3.10	Results and Discussions	124-129
3.10.1	Effect of BEBPs on seed germination	124-127
3.10.2	Effect of BEBPs on biomass accumulation	127
3.10.3	Factors affecting germination of seed	128-129
3.11	Summary	130
	References	131-144

CHAPTER 4: APPLICATION OF BIOENERGY BY-PRODUCTS AS CROP PRODUCTION INPUTS	145-219
--	----------------

4.1	Introduction	145
Part A: Application of bioenergy by-products as crop production input for maize and rapeseed		
4.2	Description of the experimental location	146-147
4.3	Description of the treatments	148
4.4	Description of experimental set up	148-157
4.5	Method of soil and plant sampling	152
4.6	Analytical methods	152-158

4.6.1	Analytical methods used for soil analysis	152-154
4.6.2	Measurement of plant parameters: Maize	155-157
4.6.3	Measurement of plant parameters: Rapeseed	157
4.6.4	Chemical analysis of plants	157-158
4.6.5	Statistical analysis on data related to soil and crop parameters	158
4.7	Results and Discussions: Maize pot experiment	159-183
4.7.1	Effect of BEBP application on soil	159-169
4.7.1.1	pH and electrical conductivity of maize grown soil	159-161
4.7.1.2	Organic carbon of maize grown soil	161-163
4.7.1.3	Total nitrogen and soil available nitrogen of maize grown soil	163-165
4.7.1.4	Available P concentration of maize grown soil	165-167
4.7.1.5	Available K concentration of maize grown soil	167-168
4.7.1.6	Micro nutrient (Cu, Fe, Mn, Zn) concentration of maize grown soil	168-169
4.7.2	Effect of soil application of BEBP on above ground biomass of maize	169-172
4.7.3	Effect of BEBP application on root development of maize	172-174
4.7.4	Effect of BEBP application on yield attributing characters and grain yield of maize	174-178
4.7.5	Biomass distribution in maize crop	178-179
4.7.6	Effect of BEBP application on crop nutrient uptake (N, P, K), grain protein concentration and nitrogen harvest index of maize	180-183
4.8	Results and Discussions: Rapeseed pot experiment	184-200
4.8.1	Effect of BEBP application on soil	184-192
4.8.1.1	pH and electrical conductivity of rapeseed grown soil	184-185
4.8.1.2	Organic carbon of rapeseed grown soil	185-187
4.8.1.3	Total nitrogen and soil available nitrogen of rapeseed grown soil	187-189
4.8.1.4	Available P concentration of rapeseed grown soil	189-190
4.8.1.5	Available K concentration of rapeseed grown soil	190-191
4.8.1.6	Micro nutrient (Cu, Fe, Mn, Zn) concentration of rapeseed grown soil	191-192
4.8.2	Effect of BEBP application on above ground biomass of rapeseed	192-194
4.8.3	Effect of BEBP application on yield attributing characters and grain yield of rapeseed	194-198

4.8.4	Effect of BEBP application on nutrient (N, P, K) uptake, grain protein concentration and nitrogen harvest index of rapeseed	198-200
-------	---	---------

Part B: Implications of AD by-products application: An analysis with special reference to rural India

4.9	Introduction	201-201
4.10	BEBPs as N source for a typical crop rotation	202-207
4.10.1	Land area considered for estimation	202
4.10.2	Crop rotation considered for estimation	202-203
4.10.3	Estimation method	203-204
4.10.4	BEBPs requirement, biogas plant size to supplement N demand of a typical crop rotation	204-207
4.11	N, P and K availability from different BEBPs	208-210
4.11.1	Plant size and crop considered for estimation	208
4.11.2	Estimation method	208
4.11.3	N, P, K availability from different BEBP options and potential area to be covered using BEBP as fertilizer	209-210
4.12	Summary	211
	References	212-219

CHAPTER 5: SUMMARY AND CONCLUSIONS	220-228
---	----------------

5.1	Characterization of bioenergy by-products as potential crop production input	221-224
5.2	Application of bioenergy by-product as input for crop production	224-226
5.3	Feasibility of field scale application of BEBPs	226-227
5.4	Conclusions	227-228
5.5	Suggestions for future work	228
	Appendix 4A	i-ii
	List of Publications	iii-iv