

# Contents

Figures .....	17
Tables.....	21
Acronyms.....	23
 <b>Part I: Introduction .....</b>	<b>25</b>
 <b>Chapter 1: The General context.....</b>	<b>27</b>
1.1 Overview.....	27
1.2 The development of transgenic crops .....	29
1.3 Transgenic crop cultivation worldwide .....	30
1.4 The aims of the Ghana case study.....	31
1.4.1 Study objectives.....	32
1.4.2 Study hypotheses .....	33
 <b>Chapter 2: Risk assessment of transgenic crops.....</b>	<b>37</b>
2.1 Risk implication analyses in the context of transgenic crop cultivation.....	37
2.2 Regulatory requirements of biosafety at the international level and sub-regional contexts .....	38
 <b>Part II: Method development in the international context.....</b>	<b>41</b>
 <b>Chapter 3: Methodological approaches adapted from the international     contexts.....</b>	<b>43</b>
3.1 Estimations of outcrossing probability between oilseed rape fields (and feral/ volunteer hybridization partners) using distribution frequency and neighbour- hood distance analysis.....	43
3.1.1 Introduction- The 6th EU Framework Research Project SIGMEA.....	43
3.1.2 Methodology.....	46
3.1.3 Results and discussion .....	48
3.1.4 Conclusions .....	57
3.2 Analysis of the spatial density and neighbourhood distances of cultivated oilseed rape (Brassica napus) fields in Northern Germany .....	58
3.2.1 Introduction .....	58
3.2.2 Methodology.....	58
3.2.3 Results .....	58
3.2.4 Discussion.....	62
3.2.5 Conclusions .....	62

<b>Part III: The Ghana case study on small-scale maize farming</b> .....	63
<b>Chapter 4: Background</b> .....	65
4.1 The context of small-scale agriculture in Ghana and relevance for a biosafety monitoring concept in maize crop production .....	65
4.2 Specific terms of reference to transgenic maize contamination events in the past decade .....	67
4.3 The maize plant ( <i>Zea mays</i> L.).....	70
4.3.1 Origin.....	70
4.3.2 Production.....	70
4.3.3 Usage .....	70
4.3.4 Reproductive biology .....	71
4.4 Studies on pollen mediated gene flow/ outcrossing.....	73
4.5 Factors influencing gene flow.....	74
4.5.1 Pollen viability and competitive ability.....	74
4.5.2 Pollination vectors .....	75
4.5.3 Environmental factors .....	75
4.5.4 Buffer crops .....	76
4.5.5 Size of pollen source and sink .....	76
4.5.6 Temporal congruence of pollen and receptor plants .....	76
4.5.7 Volunteers.....	76
4.6 Hybridization and gene introgression .....	77
4.7 Urban agriculture in the developing world .....	77
<b>Chapter 5: Methodology</b> .....	79
5.1 The study area of Accra .....	79
5.2 Spatial analysis with the help of Geographic Information System (GIS).....	80
5.2.1 Concept of the Global Positioning System (GPS).....	80
5.2.2 Ground surface data gathering.....	81
5.3 Crop fields, volunteers, feral/ wild relative demography .....	84
5.3.1 Cultivation density.....	84
5.3.2 Classification of varieties grown.....	84
5.3.3 Phenological classification .....	85
5.3.4 Vitality of maize stands .....	85
5.3.5 Farm type.....	87
5.3.6 Characterization of feral stands.....	87
5.3.7 Photo documentation .....	88
5.4 Modeling methods .....	88
5.4.1 The Maize Model (MaMo).....	88
5.4.2 Model parametisation .....	89
5.4.3 Map specification and investigated scenarios .....	92
5.4.4 Estimating duration of pollen availability .....	93
5.5 Socio-economic survey with smallholder farmers.....	93
5.6 Molecular genetic methods .....	95
5.6.1 Plant materials .....	95
5.6.2 Preservation and storage.....	96

5.6.3	Experimental steps.....	96
5.7	Statistical evaluation and softwares used.....	98
<b>Chapter 6: Results</b>	.....	<b>101</b>
6.1	Geographic Aspects .....	101
6.1.1	Nearest neighbour distance analyses .....	101
6.1.2	Spatial characterization of maize stands with the help of GIS .....	105
6.1.3	Spatial distribution of farms and ferals across larger distances.....	105
6.1.4	Number of farm neighbours across larger distances .....	110
6.1.5	Number of feral neighbours across larger distances.....	111
6.1.6	GIS-based registration of maize field polygons .....	112
6.1.7	Field size distribution analysis .....	119
6.1.8	Site characterization of finding places .....	119
6.2	Crop Demographic Aspects .....	124
6.2.1	Stand frequencies and site characterization.....	124
6.2.2	Farm neighbourhood frequencies under specified buffer conditions .....	125
6.2.3	Crop phenological status and feral development data.....	127
6.2.4	Summary of results of geographical and crop demographic data .....	133
6.3	Ecological Modeling of Cross-Pollination Probabilities .....	134
6.3.1	Simulation of regional cross-pollination between GM and conventional small-scale maize cropping systems.....	134
6.3.2	Summary of results from modeling approaches .....	148
6.4	Socio-economic Aspects.....	149
6.4.1	Demographic profile of respondents .....	149
6.4.2	Classification of farmer resource capacity at the household level .....	151
6.4.3	Gender effects and farmers' socioeconomic circumstances.....	154
6.4.4	Farmers' seed selection criteria .....	155
6.4.5	Analysis of seed acquisition and farmers' selection criteria .....	159
6.4.6	If seeds are bought, are hybrids eventually re-planted? .....	159
6.4.7	Cultivation period and seasonality: .....	161
6.4.8	Demographic factors associated with farm type orientation .....	162
6.4.9	Intra-household factors influencing seed type utility .....	164
6.4.10	Farmers land rights .....	166
6.4.11	Implication of land tenure and land rights on cropping intensity.....	166
6.4.12	Crop rotational measures.....	167
6.4.13	Analysis of socioeconomic background of farmers in relation to farm land holdings .....	168
6.4.14	Summary results of socio-economic data.....	170
6.5	Molecular Genomic Aspects.....	172
6.5.1	DNA concentration and absorbance measurements .....	172
6.5.2	SSR analysis .....	174
<b>Chapter 7: Discussion</b>	.....	<b>179</b>
7.1	Relevance of the study for the African biosafety context.....	179
7.2	Genetically modified organisms in agriculture and issues of risk assessment .....	180

7.3 The spatial pattern of maize cultivation practices and implications for gene flow .....	182
7.3.1 The methodological approach .....	182
7.3.2 Assessment of maize field neighbourhood distances .....	183
7.3.3 Assessment of feral distances from flowering field neighbours .....	183
7.3.4 Analysis of field acreage and spatial distribution.....	184
7.3.5 Number of farms within certain distances and implications for monitoring over larger areas.....	186
7.4 Crop population demography and implications for gene flow .....	186
7.4.1 Crop growing areas.....	186
7.4.2 Flowering synchrony of farms.....	187
7.5 Quantifying the spatial spread of transgenes (modeling cross-pollination).....	188
7.5.1 Quantitative models.....	188
7.5.2 Simulation of regional cross-pollination through ecological modeling (The case of the Maize Model, MaMo).....	189
7.6 Assessing the socioeconomic background of farmers and implications of gene flow .....	189
7.6.1 Demographic characterization of the local farmer population .....	191
7.6.2 Seed acquisition criteria and technology access.....	191
7.6.3 Features of the subsistence and commercial farming contexts .....	193
7.6.4 Analysis of land ownership rights and gender factors.....	193
7.6.5 Socio-economic implications of gene flow .....	194
7.7 Analytical procedure for maize seed variety differentiation at the molecular genomic level .....	197
7.7.1 Experimental genomic steps and limitations.....	197
7.7.2 Relevance of molecular DNA markers in gene flow estimation.....	198
7.8 Potential agronomic and environmental impacts of gene flow.....	198
<b>Chapter 8: Conclusion.....</b>	<b>201</b>
8.1 Ecological and biosafety management implications.....	201
8.2 Limitations and recommendations for further research .....	204
<b>References .....</b>	<b>207</b>
<b>Appendices .....</b>	<b>223</b>
Appendix 1: Study background .....	225
Appendix 2: Study methods and protocols.....	228
Appendix 2.1: Geographical aspects and crop demography .....	228
Appendix 3: Documentation of reagents, materials and instruments used.....	235
<b>Acknowledgements .....</b>	<b>239</b>