

CONTENS

	page
Acknowledgement	c
Abstract in Thai	d
Abstract in English	f
List of Tables	J
List of Figures	L
List of Abbreviations and Symbols	n
Chapter 1 Introduction	1
Chapter 2 Literature reviews	
2.1 Water footprint (WF)	
2.1.1 Definition and concept of water footprint (WF)	3
2.1.2 Component of water footprint (WF)	4
2.1.3 Overview of water footprint (WF) assessment for crop cultivation	6
2.1.4 CROPWAT 8.0; tool for water footprint calculation	13
2.1.5 The trend of water footprint (WF) study circles	15
2.1.6 Case study	21
2.2 Cadmium	
2.2.1 Cadmium contamination is soil	24
2.2.2 Absorption and toxicity of cadmium in organism	25
2.2.3 Cadmium accumulation in the study sites, Mae Sot District, Tak Province, Thailand	25
2.3 Sugarcane (<i>Saccharum officinarum</i> L.)	28

Chapter 3 Methodology	
3.1 Water footprint assessment	
3.1.1 Data requirement for WF calculation	31
3.1.2 Water footprint calculation	34
3.2 Heavy metal analysis	
3.2.1 Sampling sites and collection	37
3.2.2 Heavy metals of analysis in laboratory	40
Chapter 4 Results and discussion	
4.1 Water footprint assessment	
4.1.1 Data requirement for WF calculation	43
4.1.2 Water footprint calculation	51
4.1.3 Total of WF of sugarcane in Mae Sot District, Tak Province, Thailand	55
4.2 Determination of heavy metal and trace element in soil and sugarcane root sample	
4.2.1 Method validation for analysis of heavy metals and trace elements.	57
4.2.2 Concentrations of heavy metals and trace elements in soil and sugarcane root samples	60
Chapter 5 Conclusion	71
References	73
Appendix	
Appendix A	86
Appendix B	89
Appendix C	81
Appendix D	95
Curriculum Vitae	96

LIST OF TABLES

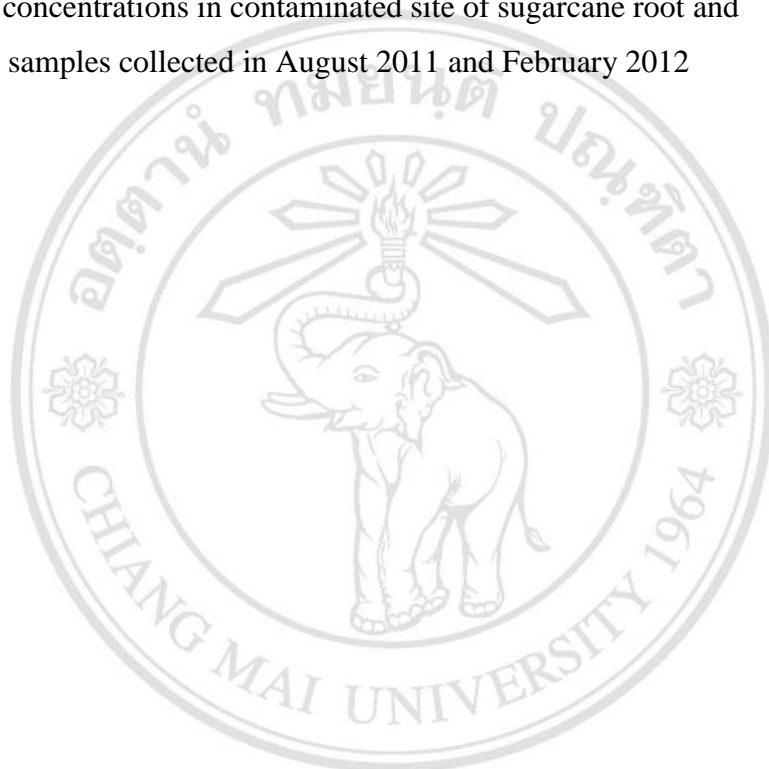
	page
Table 2.1 Total green-blue water evapotranspiration of wheat in Northwest India based on the CWR output table of CROPWAT 8.0.	10
Table 2.2 The CWR table from CROPWAT 8.0 model results in ET_{green} served by the Jokioinen weather station to calculate for the growth period of oats in Finland.	10
Table 2.3 Total green-blue water evapotranspiration based on the CWR output table of CROPWAT 8.0 in Appendix of WFA manual.	11
Table 2.4 The water footprint studies in Thailand among 2011-2013	19
Table 3.1 The useful information for calculations of green and blue water footprints in CROPWAT 8.0 model	31
Table 3.2 Site information	37
Table 3.3 Number of sampling both soil and sugarcane root in study sites	40
Table 3.4 Certificated values of SRMs Pepperbush NIES No.1 and clay soil RTC 051	42
Table 4.1 Climate data's output since October 2011 to September 2012 by CROPWAT 8.0.	44
Table 4.2 Correlation of climate parameter and precipitation	48
Table 4.3 Correlation of crop co-efficiency (K_c), ET_c , P_{eff} and the ET_{green} and precipitation	48
Table 4.4 ET_{green} and results based on the CWR output from CROPWAT 8.0 since October 2011 to September 2012 (along growth season)	49
Table 4.5 Average fertilizer application rate obtained by the interviews with farmers in Mae Sot (2011-2012)	51
Table 4.6 Overview of all major green and blue components of the WF	53
Table 4.7 Data and calculation of the grey water component for sugarcane in Mae Sot District, Tak Province in 2011-2012	54
Table 4.8 Average WFs of sugarcane cultivation in global scale and Thailand	54

Table 4.9 Recovery of elements obtained from pepperbush NIES 1	58
Table 4.10 Recoveries of elements obtained from Clay soil RTC 051	58
Table 4.11 Calibration equation and variation coefficient of elements	60
Table 4.12 Cd concentrations of heavy metal and trace element in soil samples	61
Table 4.13 Comparison the concentration of Cd between sites each month	61
Table 4.14 Comparison the concentration in soil between contaminated site and control site of heavy metal and trace element in August 2011 and February 2012	65
Table 4.15 Comparison the concentration each age of sugarcane root between contaminated site and control site of heavy metal and element in August 2011	66
Table 4.16 Comparison the concentration each age of sugarcane root between contaminated site and control site of heavy metal and element in February 2012	66
Table 4.17 Comparison the average concentration of Cd and Zn concentrations in sugarcane root in first and third year sugarcane	68
Table 4.18 Comparison the average concentration of Cd and Zn concentrations in sugarcane root in August 2011 and February 2012.	68

LIST OF FIGURES

	page
Figure 2.1 The total volume of the freshwater that is used during the production process	5
Figure 2.2 Diagram to show the relationship among 3 components that make the total	6
Figure 2.3 The four steps for water footprint calculation reviewed by Kaenchan and Gheewala (2013)	8
Figure 2.4 Generalized crop coefficient curve for the single crop coefficient approach	12
Figure 2.5 Comparison of LCA and WFA, illustrating the large similarity and the difference in quantitative indicators	18
Figure 2.6 Hypothetical growth curve for Florida sugarcane	28
Figure 2.7 Crop growth phases	29
Figure 3.1 Sugarcane fields in Mae Sot District, Tak Province beneath MSCE Company supported	35
Figure 3.2 Sampling sites for samples in Mae Sot District, Tak province	39
Figure 3.3 Double layer Teflon digestion vessel (Qiuquan <i>et al.</i> 2003)	41
Figure 3.4 Diagram of analytical methods for elemental analysis	42
Figure 4.1 The minimum temperature and the maximum temperature during October 2011 to September 2012	44
Figure 4.2 Relation between humidity and rainfall during October 2011 to September 2012	45
Figure 4.3 Correlations between Humidity and ET_0 during October 2011 to September 2012	46
Figure 4.4 Correlations between K_c and ET_c during October 2011 to September 2012	47
Figure 4.5 Standard calibration curves of heavy metal and elements	59

Figure 4.6 Ratio of heavy metals and trace elements absorbed by sugarcane root of contaminated site and soil in contaminated site in August 2011 and February 2012	62
Figure 4.7 Ratio of heavy metals and trace elements absorbed by sugarcane root of control site and soil in control site in August 2011 and February 2012	63
Figure 4.8 Cd concentrations in contaminated site of sugarcane root and soil samples collected in August 2011 and February 2012	69



ลิขสิทธิ์มหาวิทยาลัยเชียงใหม่
 Copyright© by Chiang Mai University
 All rights reserved

LIST OF ABBREVIATIONS AND SYMBOLS

L	Litter
°C	degree Celsius
AOAC	Association of analytical chemistry
AR	application rate of a chemical (fertilizer or pesticide) per unit of land
ATSDR	Agency for Toxic Substances and Disease Registry Division of Toxicology
CAC	Codex Alimentarius Commission
cm	Centimeter
C_{max}	maximum acceptable concentration of a chemical in a receiving water body
C_{nat}	actual concentration of a chemical in a water body from which water is abstracted
Cont.	Continue
CWR	crop water requirements
CWU	Crop water use
CWU_{blue}	blue crop water use
CWU_{green}	green crop water use
DHHS	U.S. Department of Health and Human Services
DOA	Department of agriculture of Thailand
E	East
EEC	European Economic Commission
EFSA	European Food Safety Authority
EPA	Environmental Protection Agency
ET_0	Reference crop evapotranspiration
ET_{blue}	blue water evapotranspiration
ET_c	crop evapotranspiration
ET_{green}	green water evapotranspiration
EU	European Union

FAO	Food and Agriculture Organization
FC - WP	Total available soil moisture (FC - WP)
IAEA	International Atomic Energy Agency
IARC	International Agency for Research on Cancer
ICP-OES	inductively coupled plasma
IFC	International Finance Corporation, Washington, DC
IR	irrigation requirement
K_c	Crop coefficient
$K_{c \text{ end}}$	Crop coefficient at the end of the late season stage
$K_{c \text{ ini}}$	Crop coefficient at the initial stage
$K_{c \text{ mid}}$	Crop coefficient at the mid-season stage
kg/ha	Kilogram per hectare
km	Kilometer
K_y	Yield response factor
LCA	Life cycle assessment
m	Meter
m/s	Meter per second
m^3/ha	Cubic meter per hectare
m^3/ton	Cubic meter per ton
Max	Maximum
mg/kg	Milligram per kilograms
mg/L	Milligram per Litters
mgCd/kg	Milligram Cadmium per kilograms
Min	Minimum
$MJ/m^2/day$	Mega joules per square meter per day
ml	Milliliter
ML	maximum level
mm/day	Millimeter per day
mm/dec	Millimeter per decade
mm/meter	Millimeter
MP	Maximum Permissible
MSCE	Mae Sot Clean Energy
N	north

ND	Not Detected
NTP	National Toxicology Program
PC	Plant in control site
PCD	Pollution Control Department
Peff	Effective rainfall
PP	Plant in polluted site
ppm	part per million
r	Correlation
R ²	Linear equation and values of variation coefficient
RID	Royal Irrigation Department of Thailand)
SD	Standard Deviation:
CRM	Certified reference materials
TAM	Initial soil moisture depletion (% TAM)
ton/ha	Ton per hectare
UNESCO-IHE	United Nations Educational, Scientific and Cultural Organization- International Institute for Hydraulic and Environmental Engineering
USDA SCS	Soil Conservation Service of the United States Department of Agriculture
USEPA	U.S. Environmental Protection Agency
WF	Water footprint
WFA	Water footprint assessment
WF _{blue}	blue water footprint
WF _{green}	green water footprint
WF _{grey}	grey water footprint
WFN	Water Footprint Network
WF _{proc}	water footprint of a product
\bar{X}	Average
Y	crop yield
α	leaching-run-off fraction, i.e. fraction of applied chemicals reaching freshwater bodies
μm	Micro milliliter