

Table of Contents

Table of Contents	i
List of Tables	iv
List of Figures.....	v
List of Symbols and Abbreviations	xi
CHAPTER ONE: GENERAL INTRODUCTION	1
1.1 Overview	1
1.2 Phosphorus reserves, consumption and new scenarios and technologies	1
1.2.1 Global phosphate rock reserves	2
1.2.2 Phosphorus consumption, population trends and nutrition	3
1.3 Phosphorus recycling.....	4
1.3.1 Processes to recover P in Germany	5
1.3.1.1 Precipitation as magnesium-ammonium-phosphate (MAP): Seaborne Process	5
1.3.1.2 Crystallization of P as a calcium phosphate: P-RoC-technology.....	6
1.3.1.3 Phosphorus recovery from sewage sludge and meat-bone meal: Mephrec process	6
1.3.1.4 Phosphorus recovery from sewage sludge: the SUSAN project	7
1.4 Phosphorus dynamics in soil.....	8
1.4.1 The soil solution	8
1.4.2 Phosphorus cycle and phosphorus forms in soil.....	8
1.4.3 Phosphorus concentration in soil solution and P dissociation depending on pH value	9
1.4.4 Phosphorus precipitation and adsorption.....	10
1.4.5 Phosphorus fractionation	13
1.5 Methods to evaluate the phosphorus availability to plants	17
1.5.1 Chemical extractants	17
1.5.2 Isotopic exchange of phosphorus in soils.....	19
1.6 Objectives of the study.....	20
CHAPTER TWO: EFFECTIVENESS OF P FERTILIZERS FROM P RECYCLING IN FIELD EXPERIMENTS.....	21
2.1 Introduction	21
2.2 Materials and methods	23
2.2.1 Products from P recycling as P fertilizers	23
2.2.2 Description of the experimental location	23
2.2.3 Soil and plant material sampling.....	25
2.2.4 Analytical procedure.....	25
2.2.5 Data analysis and experimental design	25
2.3 Results	27
2.3.1 Crop yield and P uptake.....	27
2.3.2 Phosphorus in soil solution and plant available phosphorus extracted by calcium-acetate-lactate (CAL-P)	33
2.4 Discussion.....	38
2.4.1 Yield and P uptake.....	38

2.4.2 Phosphorus in the soil solution and CAL-P.....	40
2.5 Conclusions	42
CHAPTER THREE: EFFECTIVENESS OF P FERTILIZERS FROM P RECYCLING IN POT	
EXPERIMENTS.....	43
3.1 Introduction	43
3.2 Materials and methods	46
3.2.1 Products from P recycling as P fertilizers	46
3.2.2 Description of the experiment.....	49
3.2.3 Soil and plant material sampling	49
3.2.4 Analytical procedure.....	50
3.2.5 Data analysis and experimental design.....	50
3.3 Results	52
3.3.1 Phosphorus uptake and dry matter yield.....	52
3.3.2 Phosphorus soil solution concentration and CAL-P.....	56
3.3.3 Phosphorus uptake as related by P soil solution concentration and CAL-P ...	63
3.3.4 Relative fertilizer efficiency (RFE)	65
3.4 Discussion.....	68
3.4.1 Phosphorus uptake and dry matter yield.....	68
3.4.2 Phosphorus soil solution concentration and CAL-P.....	70
3.4.3 Phosphorus uptake as a function of P availability.....	71
3.4.4 Relative fertilizer efficiency (RFE)	72
3.5 Conclusions	74
CHAPTER FOUR: DYNAMICS OF P IN SOIL FROM P COMPOUNDS OF THE P RECYCLING IN	
COMPARISON TO STANDARD FERTILIZERS AS EVIDENCED BY SOIL P	
FRACTIONATION, ISOTOPICALLY EXCHANGEABLE P AND P UPTAKE BY MAIZE (<i>ZEA</i>	
<i>MAIS</i> L.).....	
4.1 Introduction	75
4.2 Materials and methods	78
4.2.1 Soil characteristics and P uptake by maize plants	78
4.2.2 Analytical procedure.....	79
4.2.3 Data analysis and experimental design.....	82
4.3 Results	83
4.3.1 Fate of P from fertilizers applied to Düşhorn soil.....	83
4.3.2 Fate of P from fertilizers applied to Gieboldehausen soil.....	86
4.3.3 Changes of P fractions as affected by maize growth in Düşhorn soil	89
4.3.4 Changes of P fractions as affected by maize growth in Gieboldehausen soil	92
4.3.5 Isotopically exchangeable P in soils fertilized with P recycled fertilizers and	
affected by maize growth.....	95
4.3.6 Phosphorus fractions compared with the isotopically exchangeable P	95
4.3.7 Comparison among P fractions, isotopically exchangeable P and phosphorus	
uptake	97
4.4 Discussion.....	103
4.4.1 Fate of P from different fertilizers applied to the soil.....	103
4.4.2 Changes in soil P fractions as affected by plant growth	110

4.4.3 Isotopically exchangeable P (IEP) as affected by plant growth and its relation to P fractions.....	115
4.5 Conclusions	119
4.6 Appendix.....	120
SUMMARY.....	124
ZUSAMMENFASSUNG	128
RESUMEN	132
REFERENCES.....	136
ACKNOWLEDGEMENTS	143
CURRICULUM VITAE	144