Nutrient cycling and nutrient use efficiency in urban and peri-urban agriculture of Kabul, Afghanistan

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Table of contents

Table of contents ... iii

Dedication ... v

Acknowledgements ... vi

Summary ... viii

Deutsche Zusammenfassung ... xi

Chapter 1. General introduction, research objectives and hypothesis ... 1
- 1.1. General introduction ... 2
  - 1.1.1. Urban agriculture and research ... 2
  - 1.1.2. Horizontal matter fluxes and nutrient balances in UPA ... 3
  - 1.1.3. Leaching losses in UPA of Kabul ... 3
  - 1.1.4. Bio contamination and environmental pollution of UPA in Kabul ... 4
  - 1.1.5. Economic analyses of UPA ... 4
- 1.2. Research purposes ... 5
- 1.3. References ... 6

Chapter 2. Horizontal matter fluxes and leaching losses in urban and peri-urban agriculture of Kabul, Afghanistan ... 10
- Abstract ... 11
- 2.1. Introduction ... 12
- 2.2. Materials and methods ... 13
  - 2.2.1. Study area and site selection ... 13
  - 2.2.2. Measurements of nutrient inputs, outputs and leaching losses ... 14
  - 2.2.3. Chemical analyses ... 16
  - 2.2.4. Estimation of mineral N and P leaching in vegetable gardens ... 16
  - 2.2.5. Calculations of nutrient fluxes and apparent nutrient use efficiencies ... 17
  - 2.2.6. Statistical analyses ... 18
- 2.3. Results ... 19
  - 2.3.1. Soil chemical properties ... 19
  - 2.3.2. Inputs of N, P, K and C ... 19
  - 2.3.3. Outputs ... 22
  - 2.3.4. Leaching losses ... 25
  - 2.3.5. Horizontal N, P, K, and C balances ... 25
  - 2.3.6. Apparent nutrient use efficiency ... 27
- 2.4. Discussion ... 28
  - 2.4.1. Leaching of mineral N and P ... 28
  - 2.4.2. Nutrient outputs and partial balances ... 29
- 2.5. Conclusions ... 29
- 2.6. References ... 30

Chapter 3. Heavy metal and pathogen loads in sewage irrigated vegetables of Kabul, Afghanistan ... 35
- Abstract ... 36
- 3.1. Introduction ... 37
- 3.2. Methodology ... 37
  - 3.2.1. Agro-ecological setting and physical structure of the area ... 37
  - 3.2.2. Measurements of heavy metal and pathogen contamination ... 42
  - 3.2.2.1. Vegetables ... 42
  - 3.2.2.2. Irrigation water ... 42
- 3.3. Results ... 44

3.3.1. Heavy metals 44
3.3.2. Parasites and microbes 45
3.4. Discussion 49
3.4.1. Heavy metal loads 49
3.4.2. Contamination with parasites and microbes 49
3.5. Conclusions 49
3.6. References 50

Chapter 4. Economic analysis of cereal, vegetable, and grape production systems in urban and peri-urban agriculture of Kabul, Afghanistan 54
Summary 55
4.1. Introduction 56
4.2. Materials and methods 56
4.2.1. Site conditions and UPA activities 56
4.2.2. Data collection and calculations 58
4.2.3. Statistical analysis 59
4.3. Results 60
4.3.1. Cereal production 60
4.3.2. Vegetable production 60
4.3.3. Grape production in vineyards 60
4.3.4. Price fluctuations during the study period 61
4.3.5. Farm-based analyses of key economic parameters 61
4.3.5.1. Total cost of production 61
4.3.5.2. Revenues, gross margins, and net profits 61
4.3.6. Site-based key economic parameters 62
4.3.6.1. Costs of production 62
4.3.6.2. Revenue, gross margin, and net profit 62
4.4. Discussion 69
4.4.1. Farm based key economic parameters 69
4.4.1.1. Costs of operation 69
4.4.1.2. Revenues 69
4.4.1.3. Gross margins and net profits 69
4.4.2. Site specific differences in key economic factors 70
4.5. Conclusions 70
4.6. References 71

Chapter 5. General discussion, conclusions and recommendations 73
5.1. Evaluation of nutrient fluxes in UPA of Kabul 74
5.2. Leaching losses of mineral N and P 74
5.3. Heavy metal and pathogen contaminations of vegetables and sewage irrigation water: implication for safety of UPA production systems 75
5.4. Profitability of cereal, vegetable and grape production systems 75
5.5. Clustering of UPA households 76
5.6. Conclusions 77
5.7. References 78

Annexes 79

Curriculum vitae 93

List of publications 94

Affidavit 95

Dedication

To my father Al-Haj Muhammad Islam Khan

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and to

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Summary

Nutrient cycling and nutrient use efficiency in urban and peri-urban agriculture of Kabul, Afghanistan

Urban and peri-urban agriculture (UPA) has for many years determined the livelihood strategies of urban households in developing countries. Its role expanded rapidly within the last 20 years as a response to the economic crises exacerbated by the structural adjustment programs and increasing migration. Nutrient monitoring is a multi-disciplinary and multi-scale approach, addressing the problem of soil nutrient depletion and pollution. Like elsewhere also in Kabul, Afghanistan UPA has often been accused of being resource inefficient and cause negative externalities to public health and the environment. These arise from the inappropriate use of agricultural inputs, including often pesticides and raw city wastes containing heavy metal residues and pathogens.

To address these issues, this study aimed at the quantification of carbon (C), nitrogen (N), phosphorus (P) and potassium (K) fluxes, the assessment of heavy metal and pathogen loads of UPA produce and an economic analysis of UPA activities from April 2008 to October 2009 in Kabul. These can be summarized as follows:

A study of horizontal matter fluxes was conducted in conventional mixed crop production systems of UPA in Kabul from April 2008 to October 2009. Which were representing the three dominating crop types of vegetables (12), cereals (15), and vineyards (12). Nitrogen (N), phosphorus (P), potassium (K), and carbon (C) inputs in the form of organic and inorganic fertilizer, irrigation water, crops seed and their outputs were quantified. As well, leaching losses of mineral N and P were measured in two vegetable gardens. Across farming systems average biennial inputs reached 375 kg N ha^{-1}, 155 kg P ha^{-1}, 145 kg K ha^{-1}, and 15,255 kg C ha^{-1} while via harvests 305 kg N ha^{-1}, 40 kg P ha^{-1}, 330 kg K ha^{-1}, and 7,124 kg C ha^{-1} were removed.

Biennial net balances in vegetable production systems were 80 kg N ha^{-1}, 75 kg P ha^{-1}, -205 kg K ha^{-1}, and 3,927 kg C ha^{-1}, whereas in cereal production systems biennial horizontal balances amounted to -155 kg N ha^{-1}, 20 kg P ha^{-1}, -355 kg K ha^{-1}, and 4,900 kg C ha^{-1}. In vineyards corresponding values were 295 kg N ha^{-1}, 235 kg P ha^{-1}, 5 kg K ha^{-1}, and 3,362 kg C ha^{-1}. Yearly leaching in two selected vegetable gardens varied from 70 - 205 kg N ha^{-1} and 5-10 kg P ha^{-1}. Manure and irrigation water contributed on average 12-79% to total Inputs of N, P, K and C, 10-53% to total Inputs of C in the gardens and fields.

To examine potential long term side effects of UPA in Kabul, we have also quantified the concentration of cadmium (Cd), lead (Pb), copper (Cu), and zinc (Zn) and of faecal pathogens [Coliform bacteria, *Salmonella sp*., *Shigella sp*., *Ascaris lubricoides*. *Entamoeba sp.* and pinworms (*Oxyuris vermicularis*; *Enterobius vermicularis*)] in soil, irrigation water, and marketed vegetables from six centrally oriented vegetable farms. For analysis of heavy metals, soils were sampled twice $year^{-1}$, irrigation water at each irrigation event (April 2008 to October 2009), and vegetable biomass at each harvest. Samples for pathogen analysis of irrigation water and edible parts of vegetables were taken twice in 2008. The results yielded Pb and Zn concentrations in leafy vegetables of 1-5 and 33-160 mg kg^{-1} dry weight (DW) that was several-fold above the respective international thresholds of 0.3 mg Pb kg^{-1} and 50 mg Zn kg^{-1}. Tissue concentration of Cu (except for spinach in one farm) was below threshold limits in all samples. Microbes and parasites on vegetables were above thresholds in five out of six gardens with coliforms ranging from 0.5-2 x 10^7 cells 100 g^{-1} fresh weight (FW), but no salmonella and shigella were found. Loads of 0.2 x 10^7 eggs 100 g^{-1} FW of ascaris was detected on produce of three farms and critical concentrations of entamoeba in a single case while *Oxyuris vermicularis* and *Enterobius vermicularis* were found on three and four farms, respectively. Irrigation water had ascaris, coliforms, salmonella, shigella, entamoeba, *Oxyuris vermicularis*, and *Enterobius vermicularis* ranging from 0.35 x 10^7 – 2 x 10^7 cells l^{-1}.

The elevated levels of heavy metal and microbial loads on fresh UPA vegetables reflected contamination from increasing traffic, deposits of the past decades of war and lacking treatment of sewage which call for solutions to protect consumer and producer health.

Data were also collected on the profitability of 15 mixed cropping UPA farms (42 plots) from a sample of 100 surveyed households, which were characterized by cropping of cereals (15 plots), vegetables (15 plots), and grapes (12 plots). These farms reflected diversified management, farming practices, and farming types leading to different economic returns. A cost-revenue analysis of all inputs and outputs over two years (April 2008 to October 2009) showed substantial differences in net household income. Differences were mainly due to production type and crops grown and revealed differences in market prices for produce. Cereal production yielded a total bi-annual of 9,627 US$ ha^{-1}, a gross margin and a net profit of 8,767 US$ ha^{-1} was compared to vegetable farming with an average bi-annual revenue of 27,898 US$ ha^{-1}, a gross margin of 26,325 US$ ha^{-1}, and a net profit of

25,532 US\$ ha^{-1}. Vineyards had lowest returns with a revenue of 5,400 US\$ ha^{-1}, a gross margin and net profit of 4,478 US\$ ha^{-1}.

To confirm these results, more detailed studies are needed, but tailoring the application of inputs to crop needs will significantly enhance farmer's better revenues as will as environmental and produce quality.

Deutsche Zusammenfassung

Nährstoffkreislauf und Nährstoffnutzungseffizienz in städtischer und stadtnaher Landwirtschaft in Kabul, Afghanistan

Städtische und stadtnahe Landwirtschaft (English: Urban and Peri-urban Agriculture, UPA) liefert seit Jahren wesentliche Beiträge zur Existenzgrundlage städtischer Haushalte in Entwicklungsländern. Sie breitete sich in den letzten 20 Jahren aufgrund wirtschaftlicher Krisen aus, die wiederum durch Strukturmaßnahmen und Migrationbewegungen verstärkt wurden. Vor allem in Kabul, Afghanistan, wurden städtischen und stadtnahen Erzeugerbetrieben Nährstoffineffizienz und die Verschmutzung von Umwelt und landwirtschaftlichen Produkten mit Schwermetallen und Fäkalkeimen zur Last gelegt. Dies sind vermutlich Ergebnisse unsachgemäßen Umgangs mit landwirtschaftlichen Betriebsmitteln, einschließlich Pestiziden and Rohmüll, welcher Schwermetallrückstände und Pathogene enthält. Um diese Probleme zu quantifizieren, wurden zeitgleich Untersuchungen zu Nährstoffverlust und -anstieg, deren Ein- und Austrag, Ursprung, Intensität und deren Auswirkung auf Umwelt und Wirtschaft durchgeführt. Die Ergebnisse, die innerhalb von zwei Jahren zwischen April 2008 und Oktober 2009 in UPA genutzten Flächen erhoben wurden, lassen sich wie folgt zusammenfassen:

Auf Mischkulturflächen, auf denen Gemüse (12 Flächen), Getreide (15 Flächen) und Weinreben (12 Flächen) angebaut wurden, betragen die Einträge von Stickstoff (N)-, Phosphat (P)-, Kalium (K)- und Kohlenstoff (C) aus organischem und anorganischem Dünger, Bewässerungswasser, Kultursamen über zwei Jahre durchschnittlich, 375 kg N ha^{-1}, 155 kg P ha^{-1}, 145 kg K ha^{-1} und 15,255 kg C ha^{-1}, wohingegen der Austrag 305 kg N ha^{-1}, 40 kg P ha^{-1}, 330 kg K ha^{-1} und 7,124 kg C ha^{-1} ergab.

Auf Gemüseäckern betrug die zweijährige Nettobilanz 80 kg N ha^{-}, 75 kg P ha^{-1}, -205 kg K ha^{-1} und 3,927 kg C ha^{-1}, auf Getreideäckern jedoch -155 kg N ha^{-1}, 20 kg P ha^{-1}, -355 kg K ha^{-1} und 4,900 kg C ha^{-1}. Auf den untersuchten Weinanbauflächen wurden Bilanzen von 295 kg N ha^{-1}, 235 kg P ha^{-1}, 5 kg K ha^{-1} und 3,362 kg C ha^{-1} gemessen. Die jährlichen Nährstoffverluste in zwei untersuchten Gemüsegärten variierten zwischen 70–205 kg N ha^{-1} und 4-10 kg P ha^{-1}. Dung und Bewässerungswasser trugen zu hohen Nährstoffeinträgen (N, P, K und C) in den Gärten und Feldern bei, durchschnittlich 12 bis 79% bzw. 10 bis 53%.

Ebenfalls bestimmt wurde die Konzentration von Cadmium (Cd), Kupfer (Cu), Blei (Pb) und Zink (Zn) und die von Fäkalerregern (Kolibakterien, *Salmonella* sp., *Shigella* sp.,

Ascaris lubricoides, *Entamoeba* sp. und Madenwürmer [*Oxyurus vermicularis*; *Enteroius vermicularis*]) im Boden, Bewässerungswasser und Verkaufsgemüse von sechs zentral gelegenen Gemüseanbauflächen. Für die Schwermetallanalyse wurde der Boden zweimal jährlich, das Bewässerungswasser zu jedem Zeitpunkt der Bewässerung und die Gemüsebiomasse pro Ernte ein Jahr lang (April bis Oktober 2009) beprobt. Bewässerungswasserproben und Proben essbarer Pflanzenteile zur Pathogenuntersuchung wurden zweimal in Zeiten kritisch hoher Belastungen entnommen Die Ergebnisse zeigen, dass die Blei- und Zinkkonzentrationen im Sproß mit 1-5 und 33-160 mg kg^{-1} ein mehrfaches der international zulässigen Grenzwerte (0,3 mg Pb kg^{-1} und 50 mg Zn kg $^{-1}$) überschritten. Die Gewebekonzentration von Kupfer (außer Spinat [*Spinacia oleracea*] in einer Anbaufläche) lag unter den üblichen Grenzwerten in allen Anbauflächen. In fünf von sechs Gärten wurden Pathogene und Parasiten auf Gemüse gefunden, die deutlich über den Grenzwerten lagen. Kolibakterien waren mit einer Konzentration von 0,5-2 x 10^7 Zellen 100 g^{-1} Frischgewicht (FG) vertreten, wohingegen *Salmonella* sp. und *Shigella* sp. nicht nachgewiesen werden konnten. Die Kontamination mit Spulwurmeiern betrug 0,2 x 10^7 100 g^{-1} FG in drei Anbauflächen, wohingegen *Entamoeba* sp. nur in einem Fall, *Oxyuris vermicularis* in drei Fällen und *Enterobius vermicularis* in vier Fällen nachgewiesen wurde. Im Bewässerungswasser wurden Spulwürmer, Kolibakterien, *Salmonella* sp., *Shigella* sp., *Entamoeba* sp., *Oxyuris vermicularis* und *Enterobius vermicularis* in Konzentrationen zwischen 0,35 x 10^7 und 2 x 10^7 l^{-1} gefunden.

Der erhöhte Gehalt an Schwermetallen und Pathogenen auf frischem UPA Gemüse lässt sich mit wachsendem Straßenverkehr, Altlasten des jahrzehntelangen Krieges und mangelnder Abwasserbehandlungung erklären. Es bedarf dringender Lösungsansätze, um Konsumenten- und Erzeugergesundheit zu gewähren.

Eine abschließende Untersuchung umfasste die Rentabilität von 15 Mischkulturflächen (42 Kleinflächen) aus einer Auswahl von 100 untersuchten UPA Haushalten in Kabul, die mit Getreide (15 Untersuchungsflächen), Gemüse (15 Untersuchungsflächen) und Weinreben (12 Untersuchungsflächen) bepflanzt waren. Diese Flächen unterschieden sich hinsichtlich ihrer Bewirtschaftungsweise, der Anbaumethoden und der wirtschaftlichen Erträge.

Die Getreideproduktion ergab über zwei Jahre einen Umsatz von 9,627 US\$ ha^{-1}, mit einem Brutto- und Nettogewinn von 8,767 US\$ ha^{-1}. Sie war damit ökonomisch weniger erfolgreich als die Gemüseproduktion, bei der durchschnittlich 27,898 US\$ ha^{-1} Umsatz, ein

Bruttogewinn von 26,325 US$ ha^{-1} und ein Nettogewinn von 25,532 US$ ha^{-1} erzielt wurde. Weinanbau führte zu einem Umsatz von lediglich 5,400 US$ ha^{-1} und einem Brutto- und Nettogewinn von 4,478 US$ ha^{-1}. Dieses Ergebnis zeigt, dass Gemüseanbau, aufgrund der Lage der Standorte und des höheren Marktpreises, im Vergleich zu Getreideprodukten und Weinanbau am rentabelsten war.

Zusammenfassend lässt sich sagen, dass UPA in Kabul wirtschaftlich sinnvoll ist, ökologisch gesehen jedoch noch bedeutend verbessert werden muss. Der übermäßige Einsatz von N und P begünstigt N- und C- Verluste und Grundwasserverschmutzung durch Auswaschung. Hinzu kommt, dass Gemüseprodukte aus UPS trotz ihres hohen wirtschaftlichen Wertes oft stark mit Schwermetallen und Pathogenen kontaminiert waren. Weitere detaillierte Untersuchungen sind jedoch nötig, um die beschriebenen Befunde zu bestätigen, wobei eine zielgenaue Anwendung landwirtschaftlicher Betriebsmittel zu signifikanten Verbesserungen des Erlöses, der Umweltwirkung und der Qualität des landwirtschaftlicher Erzeugnisse führen könnte.

Chapter 1.

General introduction, research objectives and hypothesis

1.1. General introduction

1.1.1. Urban agriculture and research

Urban and peri-urban agriculture (UPA) contributes significantly to the livelihood strategies of urban households in many developing countries. This development reflects the economic crisis exacerbated by increasing population pressure. It is expected that by 2050 70% of world's population will live in cities (UN, 2008). This is also true for central Asian countries, especially Afghanistan with a growth rate of urbanization approximately 15% per year since 1999. The projected rates for the next years is 5% (2% migrants and 3 % natural growth) which is substantially higher than the country's overall (3.5%) population growth (UNICEF, 2000-2010) leading to a prospective total population of Kabul of 5.1 million by 2015 (World Bank, 2005). Such development poses an ever increasing challenge for city planners given problems of large scale construction, under-employment, transportation, food supply and environmental pollution.

An additional reason for the recently increasing interest in UPA is the fact that it provides alternative employment for poor city dwellers and food for urban markets as well as fresh produce for consumers (Niang et al., 2002; Drechsel et al., 2006 and 2007; Nguni and Mwila, 2007; van Veenhuizen and Danso, 2007; Thornton, 2008). It thus offers a coping strategy for the urban poor (Oludare and Ademiluyi, 2009). There also is growing evidence that rural areas alone, often biophysically and structurally disadvantaged, will not be able to achieve the increase in food production needed to meet the growing food demand. Intensification of agriculture will, therefore, primarily take place in areas with good infrastructure and strong input and output markets. In contrast to the extensive agro-pastoral production systems that often prevail in rural hinterlands, UPA seems to be characterized by high input intensities leading to concerns about food safety, environmental contamination and sustainability of the production systems (Thys et al., 2005; Assogba-Komlan et al., 2007; Drechsel et al., 2007; Graefe et al., 2008).

Yet, research into UPA has so far been mostly qualitative, focusing either on its pro-poor livelihood aspects and economic benefits, or on public hazards caused by heavy metals and pathogens being introduced into the food chain through the use of organic municipal waste and sewage for crop production and keeping animals in proximity to man. There is a deficiency of quantitative data on the use and use-efficiency of internal and external resources in UPA, particularly from countries such as Afghanistan, as likely drivers of environmental and human health problems.

1.1.2. Horizontal matter fluxes and nutrient balances in UPA

Intensive UPA production systems are accused to lead to negative externalities such as heavy metals (Binns et al., 2003), and pathogens (Keraita and Drechsel, 2002; Amoah et al., 2005) from organic and inorganic fertilizers, pesticides, industrial and municipal wastes, and sewage sludges. They may also question the sustainability of land use and environmental quality by volatile N losses due to denitrification and leaching (Mander and Forsberg, 2000; Huang et al., 2006; Akegbejo-Samsons, 2008).

Published assessments of matter and nutrient flows in UPA so far are based on the extrapolation of estimated input and output values, or on partial balances for specific production sectors. Therefore, Drechsel et al. (1999) advocated an in-depth analysis of nutrient flows to determine the sustainability and environmental safety of agricultural production in urban areas as such comprehensive studies are still lacking.

To enumerate nutrient use efficiencies in UPA systems and to make well-versed decisions about the potential of management measures to reduce nutrient losses by leaching and volatilization, the measurement of horizontal fluxes and establishment of nutrient balances at the field and farm level has been often advocated (Öborn et al., 2003; Oenema et al., 2003). Presently urban agriculture may, therefore, be regarded as models for development of productive small-scale modes of agricultural production, for which, however, problem-based regulatory frameworks are urgently needed to minimize negative environmental effects and to foster produce quality.

1.1.3. Leaching losses in UPA of Kabul

Nutrient leaching to low soil layers are a major concern for nutrient management, ground water safety and resources use efficiency. Leaching losses are larger in sandy soil than in fine textural soils and accelerated by frequency of irrigation. In contrast to horizontal nutrient flows the determination of vertical losses requires a more elaborate setup. If successfully accomplished, it will facilitate the calculation of nutrient balances in the farming environment. Predotova et al. (2010) reported leaching losses of 5.9 kg ha^{-1} of N, and 0.7 kg ha^{-1} of P from a study in Niamey (Niger), while 32 kg ha^{-1} NO_3-N and 7 kg HPO_4-P were determined by Stork et al. (2003) for sub-surface drip irrigation of raised-bed tomato production in northern Victoria, Australia. Contamination of groundwater with nitrate in Kabul has previously been reported by Houben et al. (2009).

1.1.4. Bio contamination and environmental pollution of UPA in Kabul

As an important subsistence and profit generating activity UPA is rapidly increasing. Despite its clear benefits, produce quality in UPA has been negatively affected by an excess use of intercity liquid and solid wastes as soil amendments (Eaton and Hilhorst, 2003; Graefe et al., 2008). Lacking collection and disposal infrastructure lead to 70% of Kabul's total solid waste being accumulated at the roadsides and in backyards, drains, rivers and open spaces where it represents a significant environmental hazard and to which the effluents of the virtually non-existent sewage system have to be added (Afghanistan online, 2010; UN HABITAT, 2010).

Owing to the short cultivation cycle of vegetables and the fact that cause-effect relationships between produce contamination and human health problems are often ignored, UA-produced leafy vegetables are frequently polluted with pathogens from livestock dung and excrement-loaded wastewater used for irrigation as well as with pesticides (Drechsel et al., 2000; Sonou, 2001). The same is true for heavy metals that are of growing concern in UPA produce of many developing countries (Qadir et al., 2000; Abdu et al., 2010) as their accumulation via the atmosphere-soil-plant chain in the human body can lead to a variety of health disorders, including cancer (Voutsa et al., 1996; Anikwe and Nwobodo, 2002; Türkdogan et al., 2002; Liu et al., 2006; Khan et al., 2008).

1.1.5. Economic analyses of UPA

Economic analyses of UPA concentrated on its effect on urban food supply, income security and finally poverty reduction (Egziabher et al., 1994; Rabinovitch and Schmetzer, 1996; Binns and Lynch, 1998; Bryld, 2003). Thereby, the poverty-reducing effect of UPA was of particular interest given the continuous migration of rural people into the cities (Schnitzler et al., 1998). In developing countries, the poorest urban households spend 50–90% of their income on food (Rabinovitch and Schmetzer, 1996; de Haen, 2002). For these groups, UPA offers the possibility to improve food supply and save money for education and health care (Egziabher et al., 1994). Maxwell (1995) and Maxwell et al. (1998) reported a positive relationship between the involvement of households in UPA and the nutritional status of their children. Given the above mentioned rapid growth of urban populations, the group of poor urban citizens who are substantially depending on UPA for food and income security will rise further. An economic evaluation of UPA is therefore of crucial importance to asses its sustainability.

1.2. Research purposes

This study aimed at an analysis of UPA activities in the capital city of Kabul, Afghanistan and the quantification of its nutrient flows and resource use efficiencies.

The ultimate aims of this research were to:

(i) Quantify nutrient inputs N, P, K and C fluxes, routes, sources, intensity, and leaching to reduce losses by closing nutrient cycles and increase nutrient use efficiency;

(ii) Determine the level and routes of heavy metals and pathogen contaminants in irrigation water, soils, leafy vegetables, and explore options for reduced contamination;

(iii) Assess the most profitable cropping approach in UPA of Kabul where rapid city development and economic growth strongly determine the market potential and spatial limitation of UPA.

It was hypothesized that UPA in Kabul operates under economically viable but ecologically critical conditions, leading to substantial gaseous nutrient emissions and contamination risks for ground water and UPA-derived produce.

1.3. References

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Chapter 2.

Horizontal matter fluxes and leaching losses in urban and peri-urban agriculture of Kabul, Afghanistan

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Abstract

Little is known about nutrient fluxes and nutrient use efficiencies in urban and peri-urban agriculture of Kabul. Therefore horizontal flows of carbon (C), nitrogen (N), phosphorus (P) and potassium (K) and leaching losses of mineral N and P were measured over two years in three representative agricultural production systems. These comprised 21 gardens and 18 fields dedicated to vegetable farming, cereal farming and table grape production (vineyards). Across sites (fields and gardens) biennial inputs averaged 375 kg N ha^{-1}, 155 kg P ha^{-1}, 145 kg K ha^{-1}, and 15,255 kg C ha^{-1} while with harvests 305 kg N ha^{-1}, 40 kg P ha^{-1}, 330 kg K ha^{-1} and 7,125 kg C ha^{-1} were removed. In vegetable gardens biennial net balances were 80 kg N ha^{-1}, 75 kg P ha^{-1}, -205 kg K ha^{-1}, and 3,927 kg C ha^{-1}, whereas in cereal farming biennial horizontal balances amounted to -155 kg N ha^{-1}, 20 kg P ha^{-1}, -355 kg K ha^{-1}, and 4,900 kg C ha^{-1}. In vineyards corresponding values were 295 kg N ha^{-1}, 235 kg P ha^{-1}, 5 kg K ha^{-1}, and 3,362 kg C ha^{-1}. Annual leaching losses in two selected vegetable gardens varied from 70 - 205 kg N ha^{-1} and 5-10 kg P ha^{-1}. Manure and irrigation water were the major sources among the applied nutrient inputs in all studied farming systems, contributing on average 12% and 25% to total N, 22% and 12% to total P, 41% and 53% to total K, and 79 and 10% to total C, respectively.

Key words: Ion-exchange resins; partial nutrient balance; urban farming; vegetable production

2.1. Introduction

Like in many developing countries, Kabul, the capital city of Afghanistan, rapidly expands as people migrate from rural to urban areas in search for better income, infrastructure, education and security. This led to a growth rate of approximately 15% per year since 1999; the projected rate for the next years is 5% (2% migrants and 3% natural growth) which is substantially higher than the country's 3.5% overall population growth (UNICEF, 2000-2008) leading to a prospective total city population of 5.1 million by 2015 (World Bank, 2005). Such development poses an ever increasing challenge for city planners given problems of sprawling construction, under-employment, transportation, food supply and environmental pollution.

In this context urban and peri-urban agriculture (UPA) has received particular interest in many cities of poor countries as the associated highly intensive production systems provide farmers with substantial opportunities for employment and income, and consumers with access to fresh produce (Niang et al., 2002; Drechsel et al., 2006 and 2007; Nguni and Mwila, 2007; van Veenhuizen et al., 2007; Thornton, 2008). There is growing evidence that the biophysically and structurally disadvantaged rural areas of many developing countries dominated by low external input agricultural systems will alone most likely not allow to cope with the increase in food production needed to meet the demand of the growing population (Emadi, 2007). Intensive UPA production systems, which are estimated to contribute presently about 10% to the worldwide food demand (Schnitzler et al., 1998), may therefore be regarded as models for development of productive small-scale modes of agricultural production, for which, however, problem-based regulatory frameworks are urgently needed to minimize negative environmental effects and to secure produce quality.

Characteristic for most UPA production systems are their direct market access and the recycling of organic municipal waste, sewage and market refuse in crop production, which might have negative consequences for the quality of the agricultural products and human health, and cause environmental pollution, particularly of aquatic systems (Mander et al., 2000; Keraita and Drechsel, 2002; Amoah et al., 2005; Huang et al., 2006; Akegbejo-Samsons, 2008). To quantify apparent nutrient use efficiencies in UPA systems and make informed decisions about the potential of management measures to reduce nutrient losses by leaching and volatilization, the establishment of nutrient balances at the field and farm level has been often advocated (Watson et al., 2002; Öborn et al., 2003; Oenema et al., 2003).

Given the scarcity of data on nutrient use and productivity of UPA systems in Kabul, severely affected by several decades of war, the objectives of this study were (i) to determine horizontal matter fluxes by measuring agricultural inputs and outputs of N, P, K, and C for three representative production systems over a two-year period, (ii) to calculate matter balances in these farming systems, and (iii) to identify approaches to increase resource use efficiency, thereby minimizing the potential negative impact of UPA on the environment.

2.2. Materials and methods

2.2.1. Study area and site selection

With its current population of 3.6 million (CSO, 2009) Greater Kabul is located in a valley at about 1,800 m a.s.l. bordered by high mountain ranges. The average annual precipitation of 300-330 mm occurs mainly from November to May and the surrounding natural semi-desert steppe vegetation provides vast grazing grounds for small and large ruminants during three summer months. Average annual temperature varies between 10°C to 13°C with a relative humidity of 54% (1957-1977; Grieser et al., 2006; Houben and Tunnermeier, 2005). During the present study (April 2008 - March 2010) the climatic conditions were with an average annual rainfall of 176 mm and 346 mm, a relative humidity of 45.3% and an average temperature of 14.8°C drier and hotter than normal.

In the study area rainfed wheat (*Triticum aestivum* L.) is grown on 6% of the cultivated land and harvested between July and August, while irrigated wheat, potato (*Solanum tuberosum* L.) and fresh vegetables occupying 94% of the land are harvested between May and October. Irrigation systems are fed by diverted rivers and the traditional underground ‘Karez’ channel systems. Average cultivated land of a farm household is 0.2 ha, but a few large households have irrigated farms >1 ha. The livestock sector in the Kabul region is dominated by cattle (including dairy cows) and sheep, but also comprises goats, donkeys, horses and poultry.

Basic socio-economic data on Kabul’s UPA systems were collected by semi-structured interviews of 100 households in April-May 2008. To select research sites, the Kabul city area was divided into three sub-sections representing the following prevailing farming systems (Figure 2.1):

1. The vegetable farming system in the highly populated areas along the Kabul River (34°29’59.76” N, 69°09’22.06“ E; 1,765 m a.s.l.) where plot sizes range from 54-1,000 m^2 and the most important species are radish (*Raphanus sativus* L), coriander, (*Coriandrum*

sativum L), leek (*Allium ampeloprasum* var. *porrum* L), onion (*Allium cepa* L), carrot (*Daucus carota* L.), turnip (*Brassica compestris* var. *rapa* L.), eggplant (*Solanum melongena* L.), spinach (*Spinacia oleracea* L.), pepper (*Capsicum annuum* L.), lettuce (*Lactuca sativa* L.), mint (*Mentha arvensis* L.), garlic (*Allium sativum* L.), cabbage (*Brassica oleracea* L.), pumpkin (*Cucurbita moschata* L.), tomato (*Lycopersicon esculentum* L.), and forages. Farm work, product sales, and input acquisition keep farmers busy throughout the year.

2. The cereal production area (34°28'45.96"N, 69°12'54.94"E; 1,767 m a.s.l.) in the southern part of the city. It obtains its irrigation water from the Char Asyab district in the spring season, but during summer the amount of available water is insufficient for irrigation. This area has no proper drainage and in spring occasional rainfall events may lead to flash floods that rush through the low laying areas. At plot sizes of 100 - 2,000 m^2 the local cropping system is dominated by wheat, followed by potato, onion, turnip, corn (*Zea mays* L.), and forages. This system is largely subsistence-oriented whereby open land is used by pastoralists whose animals are freely grazing in the city surroundings.

3. The vineyards for table grape production (34°34'12.27"N, 69°14'13.15"E; 1,758 m a.s.l.) with plot sizes of 200-6,497 m^2 have a well established irrigation infrastructure. For these access to the city's solid organic waste inputs is hampered by Kabul's international airport separating this area from the city center. In the spring, irrigation water for this area comes from the Kabul River and during the remainder of the year from sewage water of residential areas complemented by sewage sludge compost.

For the analysis of horizontal fluxes of N, P, K, and C in 2008 and 2009, five households were selected from each of the three farming systems leading to a total of 15 households. Overall 39 sites, consisting of 12 vegetable plots, 15 cereal fields and 12 vineyards were used for flux measurements.

2.2.2. Measurements of nutrient inputs, outputs and leaching losses

Irrigation water was sampled at each site three times per month during irrigation events. In 2009, rainwater was sampled (100 ml) from April to October during each significant precipitation event (measurable amount of rain) at the beginning, in-between, and at the end of the growing season, and pooled across sites. To avoid bio-chemical degradation after sampling and checking for pH, one drop of concentrated (32%) HCl was added to each water sample before storage in PE bottles at < 4°C until analysis of total N, P, K, and C.

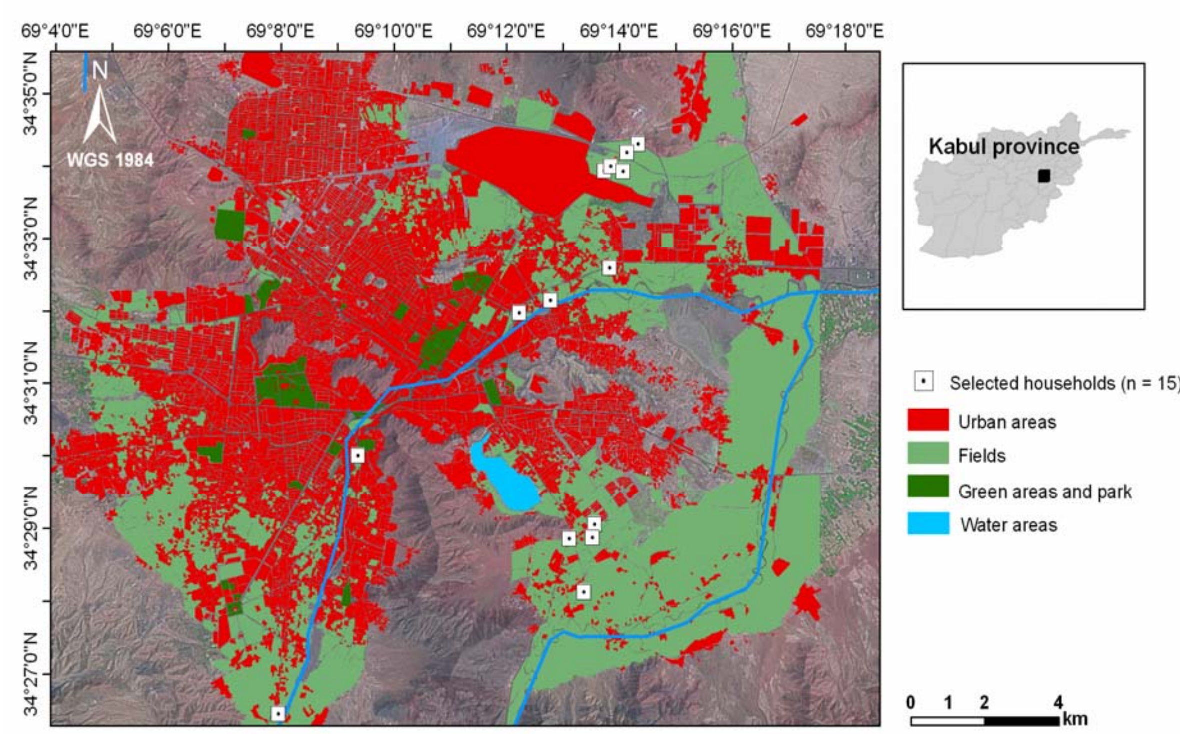

Figure 2.1. Map of Greater Kabul in Afghanistan showing the location of the selected vegetable, cereal and grape research sites.

During farmers' crop and fruit harvests, samples of about 300 g fresh weight of all extracted (marketed and dedicated to auto-consumption) plant parts and residues of vegetables, cereals, and grapes were taken from five points in the field, pooled, weighed, dried to constant weight at 60°C for 48 hours, and weighed again for moisture content correction. Subsamples of dried yield components (Safi et al., 2011) were ground with a mill (T-Tecator Cyclotec 1093, Höganäs, Sweden) to a size of 0.5 mm, and stored in sealed polyethylene bags until analysis of N, P, K, and organic carbon (C_{org}).

To measure inputs from manure application, at each site five sub-samples from the manure heap used were taken with a 5 x 20 cm soil sampler to about 0.5 m depth, pooled, air-dried at room temperature for 48 h, and ground with a Retsch mill (Model MM 301, Retsch GmbH, Haan, Germany). These samples were stored in PE bottles until analysis for dry matter (DM), N, P, K, and C_{org}.

To determine surface soil properties (0-0.2 m), five sub-samples were pooled in April and October of each experimental year from each site, spread out on paper, and air-dried at room temperature. Prior to storage in PE bottles for chemical analysis, roots and other residues were removed by passing the samples through a 2-mm mesh sieve. To determine soil moisture content and bulk density of the surface soil, additional samples were taken with a 7 x 7 cm auger below the surface soil, weighed, dried at 105°C, and reweighed (Grossman and Reinsch, 2002).

2.2.3. Chemical analyses

Dissolved organic carbon (DOC) and total N in irrigation water samples were analyzed using a Dimatec 100 automatic analyzer (Dimatec GmbH, Essen, Germany). Concentration of P and K were analyzed by spectrophotometry (Hitachi U-2000, Tokyo, Japan). Plant available soil P and K were determined using the CAL method (Hoffmann, 1991) at 460 nm and by flame photometry (Auto Cal 743, Instrumentation Laboratory, Milan, Italy), respectively. Soil pH was measured with a glass electrode in a 1:2.5 soil/water suspension and total soil N and total soil C were determined by a Vario MAX CN/CHN/CNS analyzer (Elementar Analysensysteme GmbH, Hanau, Germany). $CaCO_3$-C was subtracted from total soil carbon to determine C_{org}.

In crops total N was determined using a LECO FP-328 (Leco Corp., St. Joseph, MI, USA) and organic matter (OM) according to the method described by Close and Menke (1986). A conversion factor of 1.724 from OM to C_{org} was used based on the assumption that OM contains 58% of organic C (Nelson and Sommers, 1996). Samples were dry-ashed at 550°C, dissolved in HCl and analyzed for P by spectrophotometry and K by flame photometry. In manure samples, adherent sand particles determined according to the method (HCl insoluble ash) described by Naumann and Bassler (1988). Total C derived from photosynthesis was estimated by multiplying total DM harvested by a factor of 1.4 assuming that root dry matter and net exudation constituted on average about 30% of total assimilated C. Such average values were reported for cereals and most pasture grasses in a review paper by Kuzyakov and Domanski (2000) even if some authors reported root transports of up to 80% of total fixed C (Sims and Singh, 1971; Dormaar and Sauerbeck, 1983, Bolinder et al., 2007).

2.2.4. Estimation of mineral N and P leaching in vegetable gardens

Given the high intensity of vegetable production, two out of the five farms producing vegetables throughout the season (April to October) were selected for leaching studies. Both farms used high amounts of composted night soil from residential toilets and a mixture of well, stream, and sewage water for irrigation. At both sites leaching losses were estimated using seven PVC cartridges per site with a surface area of 83 cm^2 closed by a nylon net at the bottom. The PVC cartridges were filled with an ion-exchange resin-sand mixture following the procedure described by Lang and Kaupenjohann (2004) and Predotova et al. (2010a) prior to installation according to the guidelines of TerrAquat Consultancy (Stuttgart, Germany), the patent holder of this method. Cartridges remained below the rooting layer of vegetables at 0.55 m soil depth from April-September 2008 and again from September 2008-April 2009. After removal of the cartridges from the soil, the resin-sand mixture was separated into five layers (L_1-L_5) of about 15-20 mm each, which were stored in a refrigerator until analysis. For ion extraction, 30 ± 0.5 g of each layer were placed into a 250 ml plastic bottle, mixed with 100 ml of an extractant and shaken horizontally for one hour. Each sample was extracted eight times after which extracts 1-4, 5-6 and 7-8 were pooled and a 50 ml sub-samples frozen until analysis for NO_3-N, NH_4–N, and PO_4–P using an Inductively Coupled Plasma Spectrometer (ICP; Model Spectro-Flame, Spectro Analytica Instruments GmbH & Co. KG, Kleve, Germany). Duplicate samples of the sand used (18 g each) were extracted similarly as the samples of the resin-sand mixture and used as blanks. Only data from cartridges that had a near zero central layer for NO_3-N (indicating absence of contamination such as by stagnant water from below; (Predotova et al., 2010a) were used and nutrients contained converted to kg $ha^{-1}yr^{-1}$.

2.2.5. Calculations of nutrient fluxes and apparent nutrient use efficiencies

For each plot, partial (horizontal) nutrient balances were calculated based on the quantity of nutrient inputs and outputs (inorganic and organic fertilizers and irrigation water applied *versus* crop biomass harvested) per hectare. Wherever applicable, crop residues were returned to the plot and therefore not considered for calculation of nutrient outputs. Matter fluxes were estimated by multiplying the mass of material by their element concentrations (Equation 1; Kahi et al., 2007),

$$F = \sum_{\mathbf{i}=1}^{\mathbf{n}} \mathbf{Q}i\mathbf{C}i \qquad (1)$$

where F is the total element flow (input or output) over the period of measurement, n is the number of events (application of fertilizer, irrigation water, rain, or harvest of crop product), Q**i** is the quantity of plant dry matter at event I, and C**i** is the element concentration in the plant dry matter at event i.

The element balance equation for any system was expressed as:

$$\Delta \mathbf{PE} = \boldsymbol{I}_{\mathbf{E}} - \boldsymbol{O}_{\mathbf{E}} \qquad (2)$$

where ΔP_{E}, I_{E} and O_{E} stand for each change in the pool, the input and the output of element E (Khai et al., 2007).

Applying equation (2) the input flows for N, P, K, and C were estimated for seeds at sowing (S_E, though often negligible), irrigation water (IW_E), rainwater (RW_E), Assimilated C from photosynthesis (P_C) and for fertilizer (F_E), Similarly assessed were the output flows from harvested crops (H_E) and leaching (L_E). If ΔP_E is the net change in soil storage of element E ($\Delta soil_E$), equation (2) can be written as:

$$\Delta \textbf{Soil}_E = S_E + IW_E + RW_E + P_C + F_E - H_E \quad (3)$$

This approach neglected atmospheric deposition as it was likely small in Kabul that lacks a sizeable industry, as well as runoff on the well-leveled fields, N_2-fixation in non-symbiotic crops that typically ranges from 2-5 kg N ha^{-1} $year^{-1}$ (Roy et al. 2003), and the likely large volatilization of C and N, which unfortunately could not be measured under the local conditions. Owing to vast variation in management systems of farms, we refrained from using leaching losses obtained in the selected vegetable gardens for estimates of leaching in the other two cropping systems. Calculations included all crops in the rotation from planting to harvest over 24 months.

Apparent use efficiencies for N, P, and K were calculated according to Wang et al. (2007) as:

$$UE = \frac{\sum O}{\sum I} \times 100 \quad (4)$$

where UE denotes apparent nutrient use efficiency, O stands for the nutrient output, and I is the nutrient input.

2.2.6. Statistical analyses

Repeated measurement and multivariate analyses of variance (MANOVA) were performed using SPSS (Version 18.0, SPSS Inc., Chicago, IL, USA) to determine the significance of differences between the three farming systems for nutrient inputs, outputs, horizontal fluxes, UE and soil chemical properties (soil pH, C_{org}, total N, plant available P and K).

2.3. Results

2.3.1. Soil chemical properties

Across locations the soils of all three farming systems were of alluvial origin with on average 66% sand, 22% silt, and 11% clay. Concentrations of $CaCO_3$ were 8%, 11%, and 9% for vegetable production, cereal production, and vineyards, respectively (Table 2.1).

Throughout the experimental period all soils were alkaline with little pH changes throughout the experimental period. Total N levels were higher in vegetable gardens and cereal fields than in vineyards while plant available P was significantly higher in vegetable gardens than in the other two farming systems (Table 2.2). Differences in C_{org} concentrations between the three farming systems were also significant ($P < 0.03$; Table 2.2). In soils of the vegetable cropping system, C_{org} varied across seasons from 21-25% reaching minima in fall 2008 and maxima in spring 2009 (Table 2.2). These changes were likely due to rainfall-related differences in carbonate content. In soils of the cereal system, C_{org} concentrations throughout the four experimental seasons increased from 14% spring 2008 to 25% in fall 2009 ($P < 0.001$). Similar trends were also found in vineyards (10% in spring 2008 to 19% in fall 2009).

2.3.2. Inputs of N, P, K and C

UPA farming in Kabul is characterized by very high inputs of biowaste, irrigation water and inorganic fertilizers, leading to an average annual application of 19 t ha^{-1} (17.1-23.4 t ha^{-1} yr^{-1}) night soil, 4,820 m^3 ha^{-1} yr^{-1} (3.6-5.6 m^3 ha^{-1} yr^{-1}) sewage irrigation water, 130 kg N ha^{-1} (95-205 kg N ha^{-1}) as urea and di-ammonium-phosphate (DAP) averaging 40 kg N ha^{-1} and 45 kg N ha^{-1}. The application of nutrient inputs varied widely across the three farming systems (Table 2.3). Night soil application to vegetables was 18.2 t ha^{-1} and contributed 17% N, 43% P, 41% K, and 75% C to total N, P, K, and C inputs, while the 17.1 t night soil ha^{-1} applied to cereals accounted only for 13% N, 29% P, 57% K, and 69% C. In vineyards the 23.4 t ha^{-1} of night soil applied represented 6% N, 8% P, 32% K, and 90% C.

Table 2.1. Characteristics of the three farming systems studied in urban and peri-urban agriculture of Kabul, Afghanistan.

Characteristics	Farming system		
	Vegetables	Cereals	Vineyards
Socio-economics			
Household orientation	Commercial	Commercial & subsistence	Commercial
Number of studied households	5	5	5
Agriculture area under study (m^2)	25401	76600	24381
Irrigation type	Flood	Flood	Furrow & flood
Main crops	Vegetables, lettuce	Cereal & cash crops	Table grapes
Other crops grown	Forages	Corn, millet, cow pea	Forages
Fertilizers applied	DAP, urea, night soil, city wastewater	DAP, urea, night soil	DAP, urea, night soil, stream sludge
Soil properties			
Soil type	Alluvial	Alluvial	Alluvial
Bulk density (0.07 m depth)	1.4	1.5	1.4
pH	7.8	8.3	8.3
Carbonates (%)	8	11	9
Organic matter (%)	6	5.9	4.8

Table 2.2. Soil chemical properties of 12 vegetable gardens, 15 cereal fields and 12 vineyards in urban and peri-urban agriculture of Kabul, Afghanistan. Total nitrogen (N), plant available phosphorus (P) and potassium (K), and organic carbon (C_{org}) are expressed in g kg^{-1}. Data show means ± one standard error measured over a 24 months period from 2008-2009.

Soil properties / Farming system	Spring 2008	Fall 2008	Spring 2009	Fall 2009
Vegetable gardens				
pH	8.3^{a+} (±0.06)	8.2^{a} (±0.10)	8.4^{a} (±0.08)	8.5^{a} (±0.08)
Total N*	1.6^{a} (±0.07)	1.9^{a} (±0.21)	1.6^{a} (±0.07)	1.4^{a} (±0.10)
Plant available P*	0.4^{a} (±0.08)	0.6^{a} (±0.19)	0.6^{a} (±0.14)	0.5^{a} (±0.10)
Plant available K*	0.3^{a} (±0.05)	0.3^{a} (±0.03)	0.3^{a} (±0.03)	0.3^{a} (±0.03)
C_{org}	22.4^{a} (±4.35)	19.4^{a} (±2.63)	24.8^{a} (±1.54)	21.7^{a} (±1.35)
Cereal fields				
pH	8.3^{a} (±0.09)	8.4^{a} (±0.10)	8.7a (±0.11)	8.6a (±0.02)
Total N	1.6^{a} (±0.06)	1.6^{a} (±0.07)	1.6^{a} (±0.06)	1.4^{a} (±0.06)
Plant available P	0.2^{b} (±0.02)	0.3^{ab} (±0.03)	0.2^{ab} (±0.03)	0.2^{ab} (±0.02)
Plant available K	0.3^{a} (±0.08)	0.4^{a} (±0.05)	0.3^{a} (±0.02)	0.2^{a} (±0.02)
C_{org}	13.8^{a} (±0.29)	16.7^{a} (±0.71)	25.3^{a} (±1.42)	25.1^{a} (±2.28)
Vineyards				
pH	8.3^{a} (±0.11)	8.2^{a} (±0.06)	8.6^{a} (±0.03)	8.5^{a} (±0.02)
Total N	1.2^{b} (±0.10)	1.1^{b} (±0.11)	1.0^{b} (±0.09)	1.0^{b} (±0.08)
Plant available P	0.1^{b} (±0.01)	0.1^{b} (±0.01)	0.1^{b} (±0.00)	0.1^{b} (±0.00)
Plant available K	0.4^{b} (±0.03)	0.4^{b} (±0.04)	0.3^{b} (±0.02)	0.3^{b} (±0.02)
C_{org}	10.1^{b} (±1.04)	10.2^{b} (±0.72)	18.2^{b} (±1.13)	18.6^{b} (±1.87)

[+] Different letters within a column indicate significant differences ($P<0.05$) between the three farming systems.

Over the two years of our study N application with urea averaged 34%, 56%, and 47% of total N in vegetable production, cereal production and table grape production, respectively. The N and P input via DAP varied significantly ($P<0.001$) across farming systems and supplied 6%, 9%, and 18% of N as well as 43%, 69%, and 78% of P in vegetables, cereals, and grapes, respectively (Table 2.3).

Average biennial inputs of N, P, and K from irrigation water were 37% of total N, 14% of P, and 55% of K in vegetable production, 5% of N, 1% of P, and 31% of K in cereals, 21% of N, 14% of P, and 62% of K in grapes. Carbon application with irrigation water contributed 19%, 5%, and 4% of total C inputs for vegetable production, cereal production, and vineyards, respectively (Table 2.3). These variation were largely due to differences in waste water quality from diverse origions.

2.3.3. Outputs

Average biennial N outputs (removal) in the three farming systems were highest ($P<0.001$) in vegetables (46%), followed by cereals (40%), and grapes (14%; Figure 2.2a). Similar differences were observed for P and K outputs. Biennial average C removal from cereal fields was with 49% of total C applied significantly higher ($P<0.001$) than from vineyards (19%), while from vegetable production systems 31% of the estimated C inputs were exported (Figure 2.2b).

Table 2.3. Average inputs of nitrogen (N), phosphorus (P), potassium (K) and carbon (C) in kg ha^{-1} 2 $years^{-1}$ ± one standard error in the three urban and peri-urban farming systems of Kabul, Afghanistan.

Farming system	Source	N	P	K	C
Vegetable gardens (n=8)	Manure	86.6[a] (±23.6)	57.8[a] (±16.7)	98.6[a] (±24.7)	943.7[a] (±245.7)
	Seed	0.4[a] (±0.26	0.1[a] (±0.0)	0.2[a] (±0.1)	11.3[ab] (±7.7)
	Urea	172.0[a] (±16.1)	n.a.	n.a.	n.a.
	DAP	28.4[a] (±5.4)	57.7[a] (±8.4)	n.a.	n.a.
	Irrigation water	189.4[a] (±70.5)	18.5[ab] (±9.6)	132.9[a] (±34.2)	235.5[a] (±105.9)
	Rainfall	34.2[a] (±4.2)	0.34[a] (±0.0)	7.8[a] (±1.0)	73.9[a] (±9.1)
	Photosynthesis C*				9,321[a] (±1,503)
Cereal fields (n=10)	Manure	28.0[b] (±6."9	20.1[b] (±4.3)	46.42[b] (±11.1)	481.8[a] (±187.6)
	Seed	3.5[a] (±1.79	0.5[a] (±0.2)	2.07[a] (±1.3)	105.4[a] (±47.1)
	Urea	121.0[b] (±9.79	n.a.	n.a.	n.a.
	DAP	18.6[a] (±1.69	47.5[a] (±4.1)	n.a.	n.a.
	Irrigation water	11.7[b] (±2.0)	0.5[a] (±0.2)	25.41[b] (±5.2)	38.4[b] (±10.9)
	Rainfall	34.2[a] (±3.7)	0.3[a] (±0.0)	7.8[a] (±0.9)	73.9[a] (±8.0)
	Photosynthesis C				14,703[b] (±2,138)
Vineyards (n=10)	Manure	24.7[b] (±8.0)	19.8[b] (±6.2)	42.8[b] (±13.6)	974.2[a] (±662.9)
	Seed	n.a.	n.a.	n.a.	n.a.
	Urea	204.3[a] (±10.8)	n.a.	n.a.	n.a.
	DAP	76.9[b] (±6.0)	196.6[b] (±15.2)	n.a.	n.a.
	Irrigation water	90.8[ab] (±27.6)	34.3[b] (±13.8)	84.1[ab] (±25.4)	39.8[b] (±12.0)
	Rainfall	34.2[a] (±3.7)	0.3[a] (±0.0)	7.8[a] (±0.9)	73.9[a] (±8.0)
	Photosynthesis C				6,392[ab] (±1,403)

+ Different letters within a column indicate significant differences ($P<0.05$) between the three farming systems.

* Assuming that C in roots + net root exudates = 30% of total photosynthetic C (total C = shoot C x 1.4; Kuzyakov and Domanski, 2000).

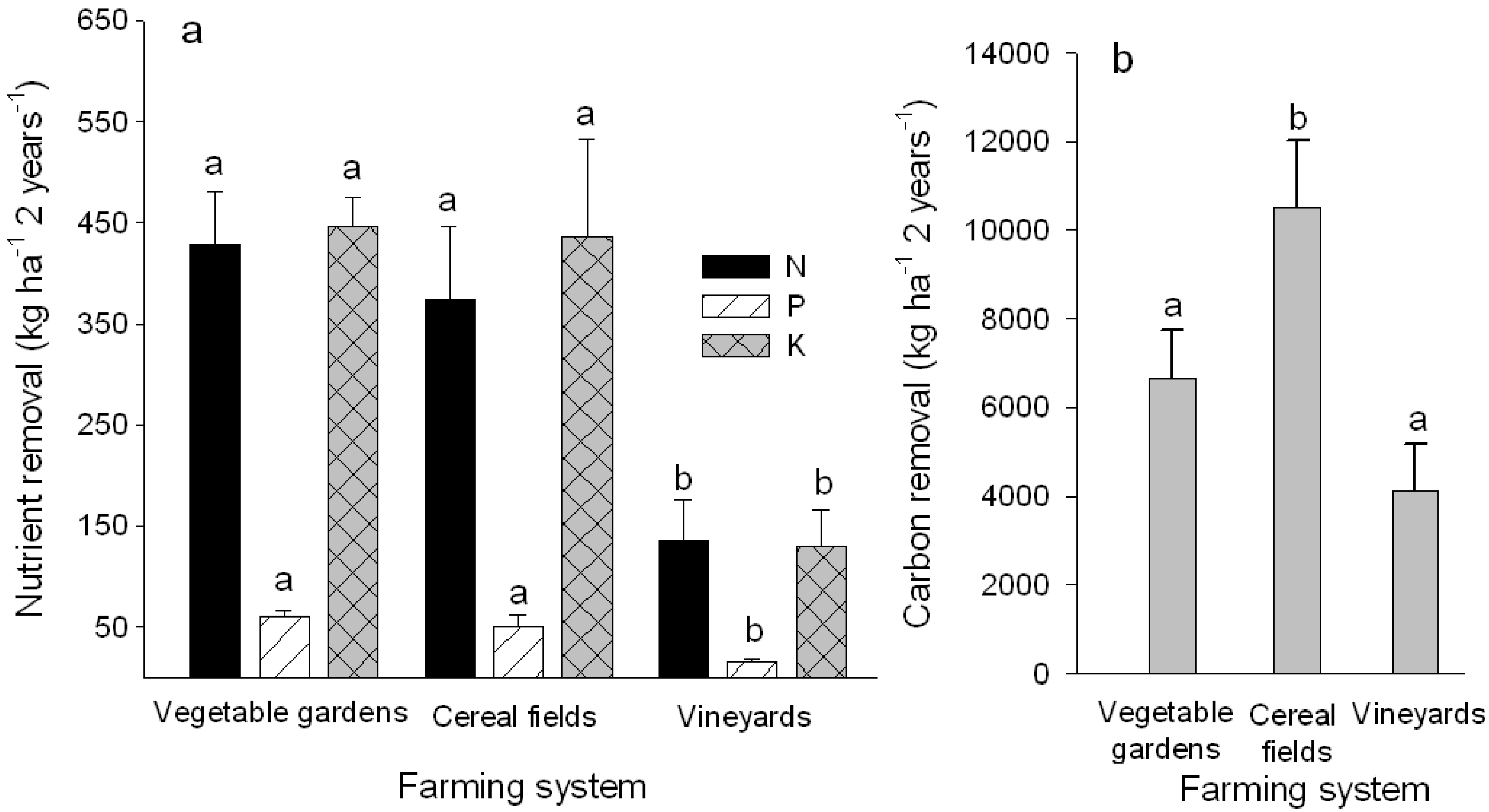

Figure 2.2. Biennial amounts of nitrogen (N), phosphorus (P), potassium (K), and carbon (C) removed from urban and peri-urban vegetable (n= 8), cereal (n=10), and grape (n=10) farming systems of Kabul, Afghanistan in 2008-2009. Bars show one standard error of the mean and different letters indicate significant differences (P<0.05) between farming systems.

2.3.4. Leaching losses

Resin-based nitrate nitrogen (NO_3-N) leaching averaged 138 kg ha^{-1} yr^{-1} in both gardens studied while NH_4-N leaching was only 1.9 kg ha^{-1} yr^{-1} (Table 2.4). Nitrate leaching losses from April to September 2008 were more than five times higher in garden 2 than in garden 1. Cumulative mineral P losses averaged 6.5 kg ha^{-1} (Table 2.4). In contrast to mineral P losses, garden-specific differences in mineral N leaching were highly significant ($P<0.001$).

Table 2.4. Leaching of NO_3-N, NH_4-N, and PO_4-P in two urban vegetable gardens of Kabul, Afghanistan in 2008. Data show means (kg ha^{-1} yr^{-1}) ± one standard error.

Nutrient	Garden 1	Garden 2
NO_3-N	69.0 (±12.4)	207.0 (±16.8)
NH_4-N	3.4 (± 0.6)	0.5 (± 0.2)
PO_4-P	4.0 (± 1.1)	9.0 (± 2.8)

2.3.5. Horizontal N, P, K, and C balances

Over the two years of our study, horizontal (partial) balances of N and P and C in vegetables were with 80 kg N ha^{-1}, 75 kg P ha^{-1} and 3,927 kg C ha^{-1} positive compared to negative balance of -205 kg K ha^{-1} (Figure 2.3a). On an annual basis these partial balances strongly changed with an N surplus of 215 kg ha^{-1} in 2008 and a deficit of -70 kg N ha^{-1} in 2009. Similarly, in cereals, the positive biennial balance of 20 kg P ha^{-1} and C 4,900 kg K ha^{-1} compared to -155 kg N ha^{-1} and -355 kg K ha^{-1} (Figure 2.3b). For grapes in contrast, partial balances were with 295 kg N ha^{-1}, 235 kg P ha^{-1}, 5 kg K ha^{-1} and 3,360 kg C ha^{-1} highly positive (Figure 2.3a).

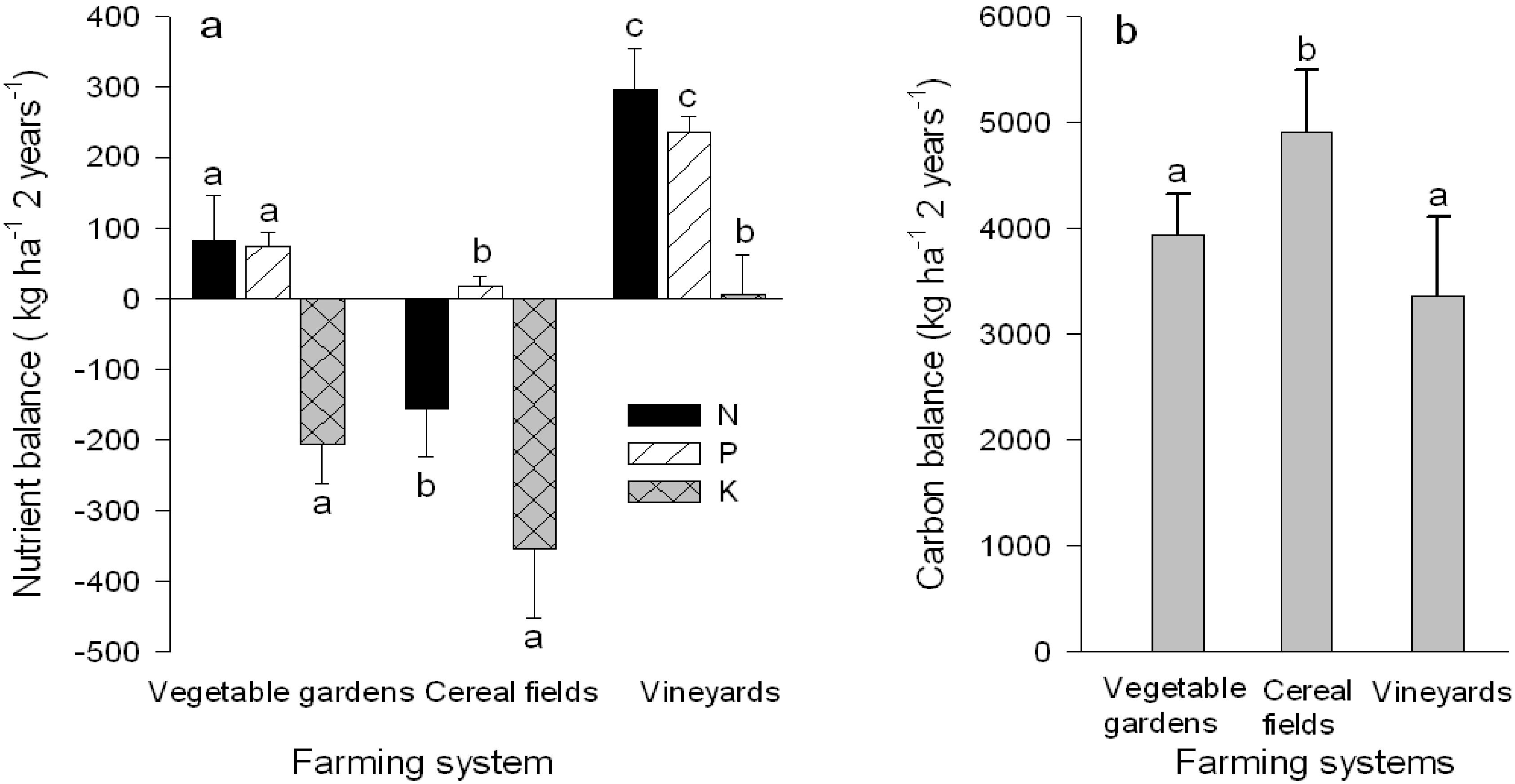

Figure 2.3. Biennial horizontal (partial) balances of nitrogen (N), phosphorus (P), potassium (K), and carbon (C) in urban and peri-urban vegetable (n= 8), cereal (n=10), and grape (n=10) farming systems of Kabul, Afghanistan in 2008-2009. Bars show one standard error (SE) of the mean and different letters indicate significant differences ($P<0.05$) between farming systems.

2.3.6. Apparent nutrient use efficiency

Largely reflecting changes in annual application rates, apparent nutrient use efficiencies ranged from 35%-170% during the two year study period. Efficiencies were highest in cereal followed by vegetables and grapes. Average NUE was in 2008 with 62% lower than in 2009 with 136%. Both, annual and biennial differences in use efficiencies between farming systems were highly significant (P<0.001). Apparent PUE ranged from 7-82% across the three farming systems with a maximum in cereals, followed by vegetables and grapes (Figure 2.4) whereby average annual efficiency tended to be higher in 2009 (69%) than in 2008 (24%). Yearly and biennial differences were statistically (P<0.001) highly significant. Apparent KUE ranged from 216%-708% in the three farming systems with a maximum in cereals where animal dung and night soil was applied, followed by vegetable production while values were lowest for vineyards. Apparent annual KUE was 138% in 2008 compared to 651% in 2009 (system effect P<0.001 and year effect P<0.001).

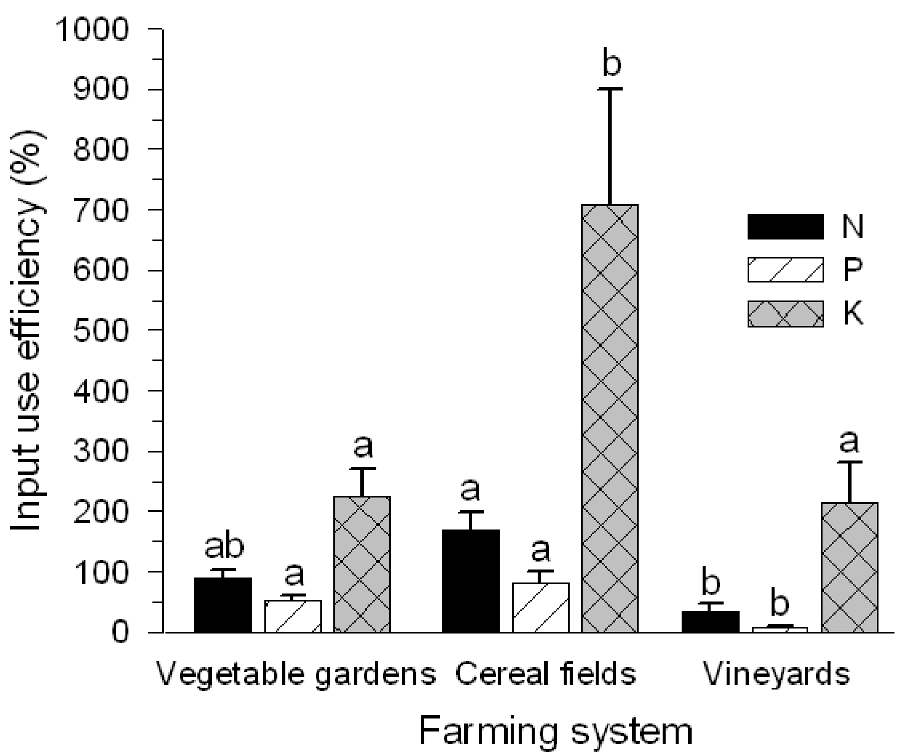

Figure 2.4. Apparent input use efficiency of nitrogen (N), phosphorus (P), and potassium (K) in vegetable (n=8), cereal (n=10), and grape (n=10) farming systems of Kabul, Afghanistan. Bars show one standard error of the mean and different letters indicate significant differences (P<0.05) between farming systems.

2.4. Discussion

High carbonate levels in UPA soils of Kabul were probably responsible for their pH values above 7. A decline of pH with prolonged intensive vegetable production was previously reported by Wang et al. (2007), Kwak et al. (2003), and Eneje et al. (2007) who examined the effects of different amounts of fertilizer and manure application on soil chemical properties.

The measured changes in total soil N may be only of transitory nature given the time-dependency of a soil's N status reflecting the effects of changes between phases of large nutrient uptake by crops, inputs from easily available sewage sludges, and from unquantified volatilization losses. If for Kabul with its rather low winter temperatures we assume cumulative N and C-emissions (consisting of NH_3-N, NO_2-N, CH_4-C and CO_2-C) to amount only 30-50% of the values determined for UPA vegetable gardens in Niamey (Predotova et al., 2010b), those would reach annually 27-46 kg N ha^{-1} and 6-10 t C ha^{-1}.

The soils' K status slightly varied between the different systems which may reflect site-specific differences in the application of animal manure compared to city sewage wastes and inorganic fertilizers. Seasonal variation of K was not significant but variation of K between farming systems was ($P< 0.05$). Similar results have been reported by Wang et al. (2007) in his study of small-scale vegetable-farming in two contrasting peri-urban areas of the Yangtze river delta region of China.

Levels of soil C_{org} varied across farming systems with higher levels in cereal fields than in vegetable gardens and vineyards. Given that C volatilization losses were not quantified in this study, further research should examine how much lower such losses are given the comparatively harsh winters than those reported by Predotova et al. (2010b).

2.4.1. Leaching of mineral N and P

Estimated leaching losses in the two UPA gardens investigated varied but were on average surprisingly high which may reflect the sandy soil texture and the frequency of irrigation with nutrient-rich sewage water. During the growing season farmers irrigated their fields in 3-day intervals with average application rates of 4,820 m^3 ha^{-1} per year. The values in this study by far exceeded the 5.9 kg N ha^{-1} and 0.7 kg P ha^{-1} reported by Predotova et al. (2010a) and the 32 kg ha^{-1} NO_3-N and 7 kg HPO_4-P reported for sub-surface drip irrigation in raised-bed tomato production in northern Victoria, Australia (Stork et al., 2003). The very high leaching values in our study raise serious concerns about possible groundwater contamination with wastewater used for irrigation, which has already been reported by Houben et al. (2009).

2.4.2. Nutrient outputs and partial balances

The biennial average outputs of N, P, K and C reflect differences in cropping system-specific management. Vegetables with their short growing period (35 - 45 days) extract much larger amounts of N, P and K than cereals and grapes.

High nutrient inputs of N, P and K through biowastes and wastewater were reported in several studies from West African cities. Diogo et al. (2010) showed large N surpluses as a result of N-rich wastewater irrigation in Niamey, Niger. Similarly, Khai et al. (2007) reported large N and P inputs into vegetable gardens of Hanoi, Vietnam, through wastewater irrigation. The net surpluses of 215 kg N $ha^{-1}yr^{-1}$ and 150 kg P $ha^{-1}yr^{-1}$ with a corresponding negative balance for K across the studied farming systems in 2008 (Figure 2.3) by far exceeded the averages reported by Watson et al. (2002) for organic farms (83 kg N ha^{-1} yr^{-1}, 4 kg P ha^{-1} yr^{-1}, and 14 kg K ha^{-1} yr^{-1}), particularly those planted to vegetables, and the 131 kg N ha^{-1}, 37 kg P ha^{-1}, and 84 kg K ha^{-1} measured in intensive irrigated subtropical farming systems in Oman by Buerkert et al. (2004). Our values are, however, still lower than the 882 kg N ha^{-1} yr^{-1}, 196 kg P ha^{-1} yr^{-1} and 306 K kg ha^{-1} yr^{-1} reported by Khai et al. (2007) from Hanoi, Vietnam. Possible reasons for these large surpluses may be the vast amount of manure and condensed sewage water applied.

Overall, the established partial nutrient balances seem to be useful indicators for the sustainability of urban agricultural systems in Kabul (Bekunda et al., 2003). Such balances have been used for the last two decades to improve the natural resources management and/or to define policy recommendations (Smaling and Braum, 1996; Defoer et al., 1998; De Jager, 2005). The results, however, should be interpreted with care as this approach has several methodological shortcomings (Bationo et al., 1998; Fraege and Magid, 2004; Öborn et al., 2003).

2.5. Conclusions

The collected data provide evidence of the role that sewage water and night soil play for nutrient supply in UPA systems of Kabul. Improved nutrient management should aim at a better synchronization of nutrient availability and plant nutrient demand. The intensive use of sewage wastes in the studied urban and peri-urban farming systems can potentially contribute to groundwater contamination.

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Chapter 3.

Heavy metal and pathogen loads in sewage irrigated vegetables of Kabul, Afghanistan

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Abstract

Little is known about the heavy metal and microbial (pathogens) contamination of vegetables produced in urban and peri-urban agriculture (UPA) of southern Central Asian cities. To contribute in filling this gap, we measured the concentration of cadmium (Cd), lead (Pb), copper (Cu) and zinc (Zn) and of faecal pathogens (Coliform bacteria, *Salmonella sp*., *Shigella sp*., *Ascaris lubricoides.*, *Entamoeba sp.* and pinworms [*Oxyuris vermicularis*; *Enterobius vermicularis*]) in soil, irrigation water, and marketed vegetables of Kabul City, Afghanistan.

Leaf Pb and Zn concentrations of leafy vegetables with 1-5 and 33-160 mg kg^{-1} dry weight (DW) several-fold above respective international thresholds of 0.3 mg Pb kg^{-1} and 50 mg Zn kg^{-1}. The tissue concentration of Cu was below threshold limits in all samples except for spinach in one farm. Above-threshold loads of microbes and parasites on vegetables were found in five out of six gardens with coliforms ranging from 0.5-2 x 10^7 cells 100 g^{-1} fresh weight (FW), but no salmonella and shigella were found. Contamination with 0.2 x 10^7 eggs 100 g^{-1} FW of ascaris was detected on produce (radish, coriander and salad onion) of three farms and critical concentrations of entamoeba were encountered once, while *Oxyuris vermicularis* and *Enterobius vermicularis* were found in three and four farms, respectively. Irrigation water had ascaris, coliforms, salmonella, shigella, entamoeba, *Oxyuris vermicularis*, and *Enterobius vermicularis* ranging from 0.35 x 10^7 – 2 x 10^7 cells l^{-1}. The high concentrations of heavy metal and pathogens in fresh UPA vegetables are likely the result of contamination from increasing traffic (Pb), residues of the past decades of war (bullets and blasted bomb's particles) and lacking treatment of sewage pathogens which call for solutions to protect consumers and producers health.

***Key words*:** Faecal contamination; Food safety; Urban agriculture

3.1. Introduction

As an important subsistence and income generating activity urban and peri-urban agriculture (UPA) is of particular importance in Kabul city which is rapidly growing as a consequence of the continuing arrival of war-refugees and infrastructural constraints in the countryside where the majority of the country's population lives (CSO, 2010-11). Lacking collection and disposal infrastructure lead to 70% of Kabul's total solid waste (at least 300 t day^{-1}) being accumulated at the roadsides and in backyards, drains, rivers and open places where it represents a significant environmental hazard and to which the effluents of the virtually non-existent sewage system have to be added (Afghanistan online, 2010; UN HABITAT, 2010). At present most sewage is disposed of in domestic drainage pits and shallow open sewage channels along the streets, threatening the largely shallow aquifers with microbial contamination, which adds to the already existing loads of borate and nitrate (Houben et al., 2009). A recent US geological survey reported 70% of all wells in the Kabul basin being contaminated by faecal bacteria (Akbari et al., 2007). This likely contributes to the high infant mortality as a consequence of water-borne diseases (UNICEF, 2008) even if possible cause-effect relationships between sewage water-related contamination of leafy vegetables (Drechsel et al., 2000; Sonou, 2001) and human health problems are largely ignored by consumers and policy makers alike. The same is true for heavy metals that are of growing concern in UPA produce of many developing countries (Qadir et al., 2000; Abdu et al., 2010) as their accumulation via the atmosphere-soil-plant chain in the human body can lead to a variety of health disorders, including cancer (Voutsa et al., 1996; Anikwe and Nwobodo, 2002; Türkdogan et al., 2002; Liu et al., 2006; Khan et al., 2008).

Given lacking quantitative data on UPA produce contamination with pathogens and heavy metals, this study aimed at determining the concentrations of both types of contaminants in irrigation water, UPA soils, and leafy vegetables studying five representative gardens in the center of Kabul city.

3.2. Methodology

3.2.1. Agro-ecological setting and physical structure of the area

The monitored gardens (N 34°29'59.76"; E 69°09'22.06"; 1,765 m a.s.l.) were distributed along a 10 km transect crossing one of the most densely inhabited parts of Kabul city from Bagh-e-Rayees to Hootkhail in an E-W direction (Figure 3.1). This area has an old irrigation infrastructure with temporary water courses along the Kabul River and sewage channels.

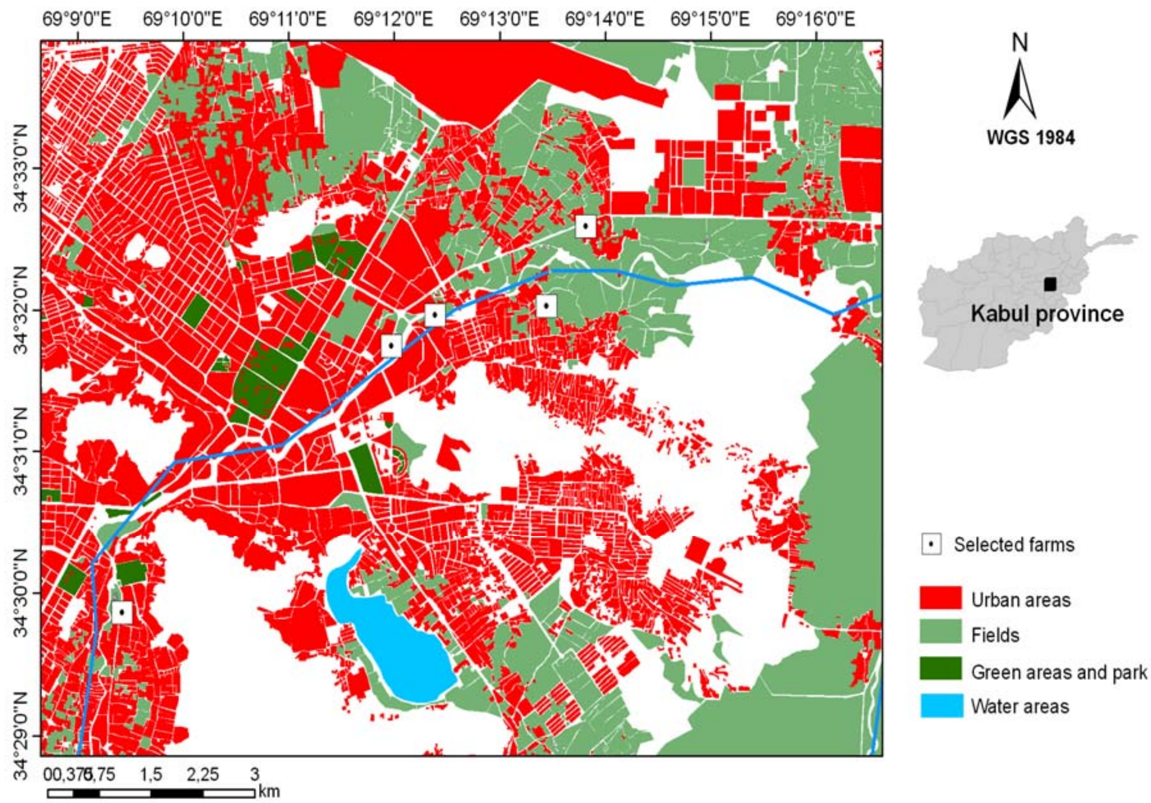
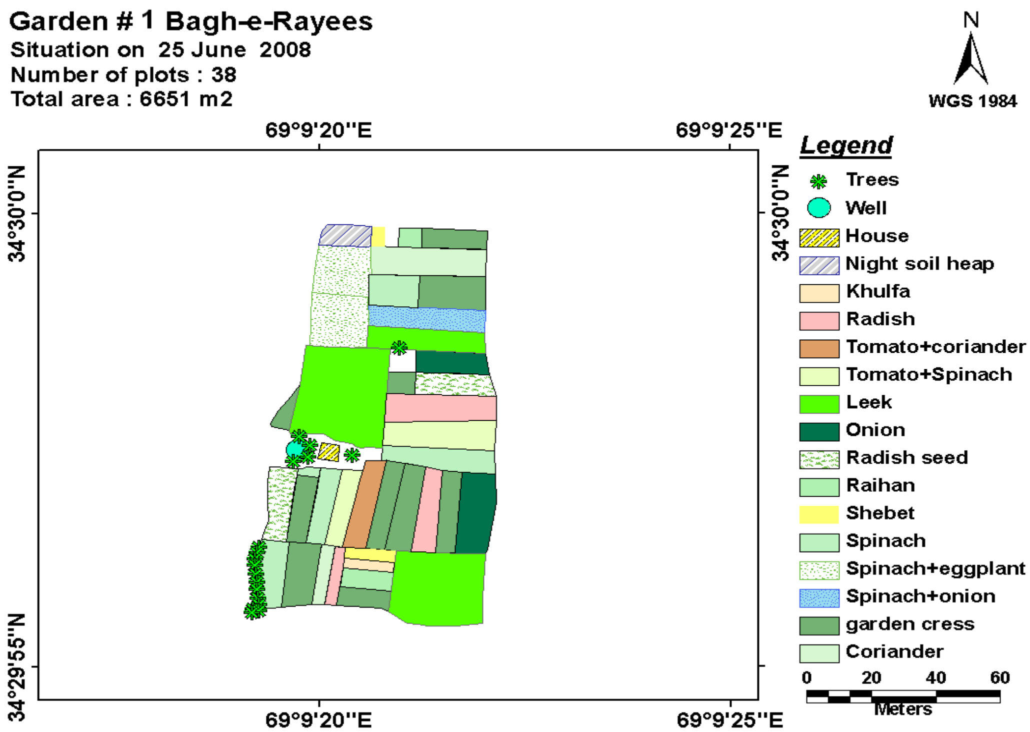
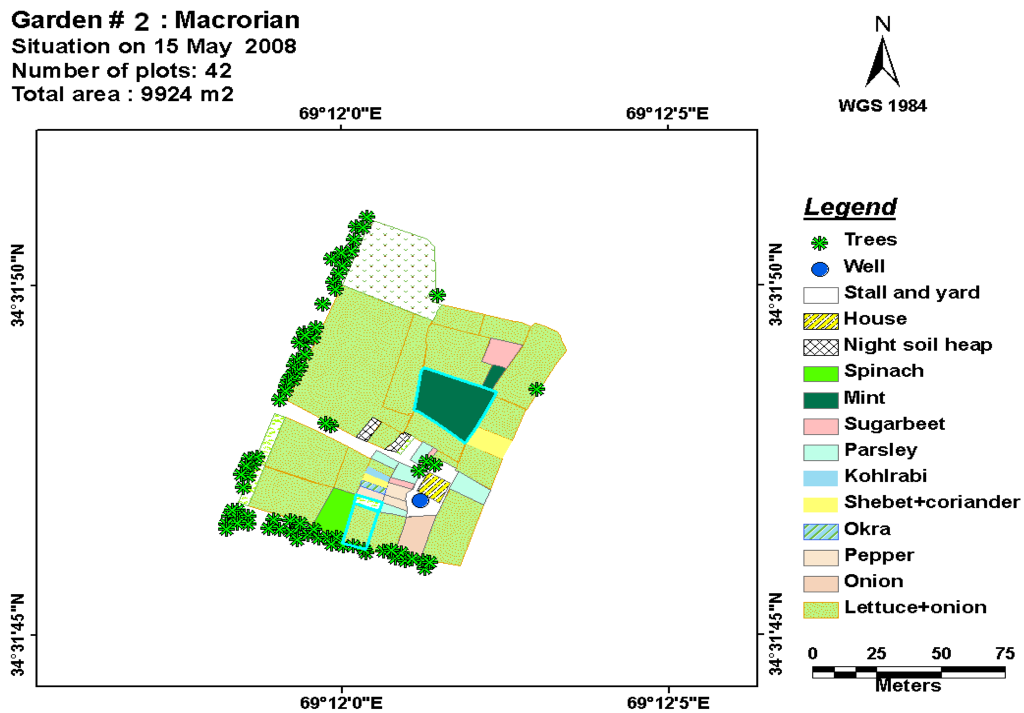


Figure 3.1. Map of Kabul city indicating the location of the five vegetable gardens monitored in 2008 and 2009.

During April 2008 a baseline survey of 100 farms was conducted for which farms were selected to represent the major agricultural land use systems (Safi et al., 2010). Household selection followed a cluster analysis of production systems and socio-economic status (family composition, household members, on-farm income, off-farm income, education). Based on the survey results five farm households were selected, their garden areas mapped with a handheld GPS and the cropping system recorded (Figure 3.2). This was followed by a sampling of the irrigation water, soil, and agricultural produce as described below.

Figure **3.2.** GIS-based maps showing the plot structure and species grown in five studied urban vegetable gardens in Kabul, Afghanistan.





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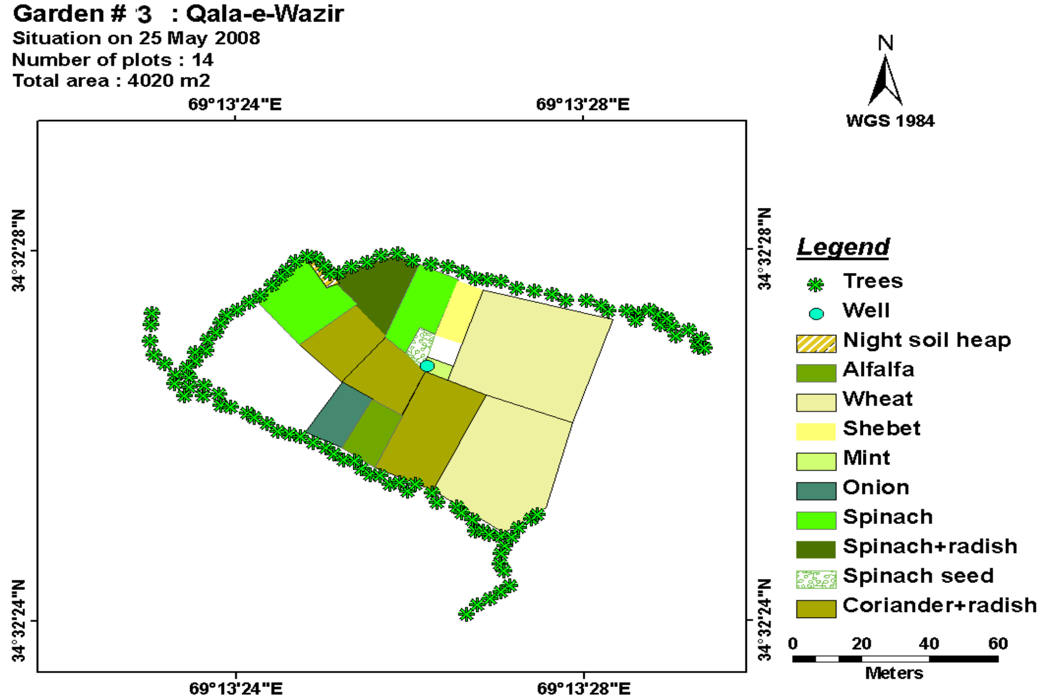

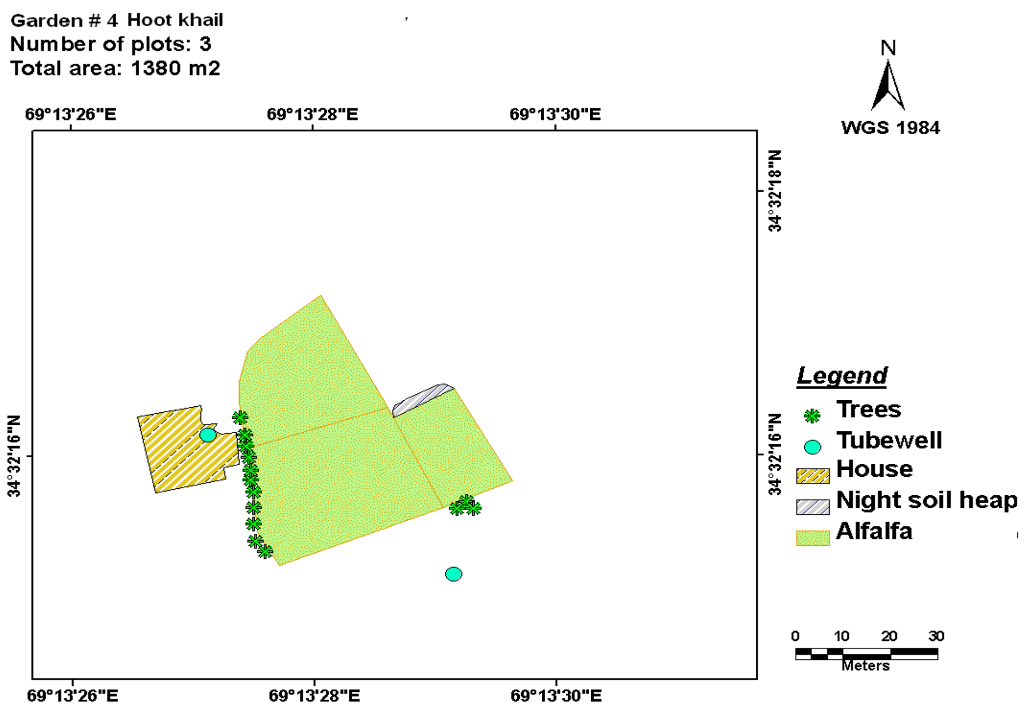

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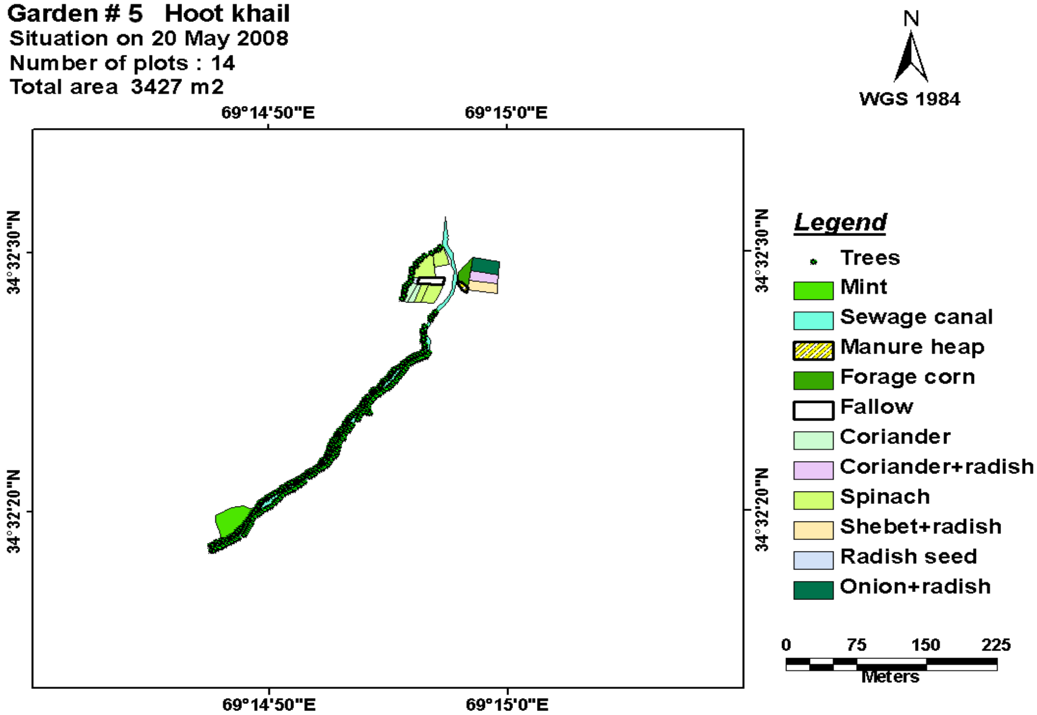

3.2.2. Measurements of heavy metal and pathogen contamination

3.2.2.1. Vegetables

For heavy metal analysis five sub-samples per plot of edible parts of the economically relevant vegetables lettuce (*Lactuca sativa* L.), radish (*Raphanus sativus* L.), coriander (*Coriandrum sativum* L.), mint (*Mentha arvensis* L.), onion (*Allium cepa*), leek (*Allium ampeloprasum* var. *porrum* L., spinach (*Spinacia oleracea* L.), garden cress (*Lepidium sativum* L.), turnip (*Brassica rapa* var. *rapa* L.), and the forage crop alfalfa (*Medicago sativa* L.) were randomly collected from each garden over a period of seven months (April-October 2009). The samples were washed with distilled water, sliced, pre-dried on a sheet of paper and subsequently oven-dried to constant weight at 65^{o}C for 48 hours, ground with a ceramic-coated grinder (Liu et al., 2006) and stored in 100 ml PE bottles. For the same species and management system samples were pooled across sampling periods. Heavy metal concentrations (Cd, Pb, Cu, and Zn) were determined according to Liu et al. (2006) and Schumacher et al. (1993) using a microwave assisted digestion procedure. To this end 0.2 ± 05 g of a homogenized sample was digested under pressure in Teflon vessels with 3 ml of HNO_3 (65%) and 1 ml of H_2O_2 (30%). After completion of the digestion, the solutions were filtered and brought to 50 ml with distilled water. Concentrations of Cd, Pb, Cu, and Zn were determined in duplicates by a GBC 906 atomic absorption spectrophotometer (AAS; GBC Scientific Equipment LLC, Hampshire, IL, USA).

For pathogen analysis in 2008 a composite sample of freshly eaten vegetable (garden cress, lettuce, coriander, radish, and salad onion) consisting of 5 - 10 individual plants was harvested and stored at <10°C until parasitological analysis (Anh et al., 2007). Protozoan parasite cysts and eggs in vegetables were counted after washing 10 g plant sample with 100 ml of sterile distilled water. Subsequently, the samples were pulsified (Pulsifier®, Filtaflex, Almonte, ON, Canada), and concentrated by centrifugation for 10 minutes to a final volume of 2 ml. The samples were then processed according to the modified Bailenger method (Ayres and Mara, 1996).

3.2.2.2. Irrigation water

To determine annual changes in microbial loads on 15th June and 15th August 2008 1l composite sample of irrigation water from five points in each of the five gardens was collected between 8-11 am and immediately transferred to the laboratory for analysis of coliform bacteria, salmonella, shigella, *Ascaris lubricoides*, entamoeba, *Oxyuris vermicularis,* and *Enterobius vermicularis* according to the WHO method (Ayres and Mara, 1996). The samples were sedimented for 2 hrs and 90% of the supernatant removed. Subsequently, the sediments were centrifuged for 15 min. Again the supernatant was removed and the sample re-centrifuged before the pellet was suspended in an volume equal to that of the pellet of $CH_3C(O)CH_2CO_2H$ buffer amended by two volumes of $CH_3COOCH_2CH_3$ and vigorously shaken in a vortex. Thereafter the mixture was centrifuged again for 15 min, re-suspended in five volumes of $ZnSO_4$ solution and an aliquot transferred to a McMaster counting slide (Chalex Corp., Wallowa, OR, USA). The number of eggs was calculated as:

$$N = AX / PV \qquad \text{Eq. (1)}$$

where N = number of eggs per liter of sample

A = number of eggs

X = volume of final product (ml)

P = volume of the McMaster slide (0.3 ml)

V = original sample volume (liters)

The number of faecal coliform bacteria was determined using the most probable number (MPN) method based on test tubes with medium A-1 (Hach Co., Loveland, Co, USA; Powell et al., 1979) incubated at 44°C over night. The number and distribution of positive tubes (acidification or gas production or both) were used to obtain the populations of coliform bacteria from MPN tables (Ayres and Mara, 1996; Amoah et al. 2005).

In each of the five gardens, surface soil (0-0.20 m depth) was collected twice per year (spring and fall of 2008 and 2009), air dried at room temperature, and passed through a 2 mm nylon sieve mesh in order to remove sand, larger particles and debris. Of each pooled sample per year (spring+fall, 2008 and spring+fall, 2009) 0.3 ± 0.5 g was digested under pressure in Teflon vessels with 2 ml of HNO_3 (65%) and 6 ml of HCl (37%). After completion of the digestion, the solutions were filtered and brought to 50 ml with distilled water. Concentrations of Cd, Pb, Cu, and Zn were determined on duplicate samples as described above.

3.3. Results

3.3.1. Heavy metals

Regardless of the season wastewater concentrations of the heavy metals analysed were in all gardens orders of magnitude below the threshold levels given by Drechsel et al. (2010; Table 3.1).

Table 3.1. Concentration (mg l^{-1}) of the heavy metals cadmium (Cd), lead (Pb), copper (Cu) and zinc (Zn) in irrigation water used for urban vegetable production in Kabul, Afghanistan.

No. of garden	Season[a]	Cd	Pb	Cu	Zn
1	Spring	<0.15	<2.5	<1.0	<20
1	Fall	<0.15	<2.5	<1.0	<20
2	Spring	<0.15	<2.5	<1.0	<20
2	Fall	<0.15	<2.5	<1.0	<20
3	Spring	<0.15	<2.5	<1.0	<20
3	Fall	<0.15	<2.5	11.3	<20
4	Spring	nd	nd	nd	nd
4	Fall	nd	nd	nd	nd
5	Spring	<0.15	<2.5	<1.0	<20
5	Fall	<0.15	<2.5	<1.0	<20
Safety Threshold (µg l^{-1})[b]		10	5000	200	2000

[a]Seasons of sampling
[b]Source: Drechsel et al. (2010).
nd: not detected

Prolonged use of this irrigation water led to heavy metal concentrations in the surface soil of the five gardens that were also uncritical (Table 3.2). Heavy metal concentrations in the edible plant parts of the harvested vegetables, however, were consistently below the safety threshold only for Cd (Table 3.3). According to WHO standards all samples were heavily contaminated with Pb, whereby spinach in garden 1 and cress in garden 2 exceeded the WHO safety threshold 11- and 15-fold, respectively and where also above the less strict Indian standards (Awashthi, 2000).

Table 3.2. Physical properties, pH, organic carbon (C_{org}) and heavy metals cadmium (Cd), lead (Pb), copper (Cu) and zinc (Zn) concentrations in the surface soil (0-0.20 m depth) of five urban vegetable gardens in Kabul, Afghanistan.

No. of garden	Texture	pH*	C_{org}	Cd	Pb	Cu	Zn
			$g\ kg^{-1}$	$mg\ kg^{-1}$			
1	silt loam	8.37	30	0.19	26	66	184
2	sandy loam	8.44	18	0.18	25	52	154
3	silt loam	8.38	22	0.18	33	62	140
4	sandy loam	8.60	20	0.20	30	50	113
5	sandy loam	8.21	18	0.15	26	53	129
Thresholds							
Indian*				3-6	250-500	135-270	300
EU**				3	300	140	300-600
UK**				3	300	80-200	200-300
USA**				20	150	170	1400

Sources: Awashthi (2000)* and CCME (2001)**

* Measured in a 1:2.5 soil:water suspension

For Cu only spinach from garden 1 exceeded both the WHO and the Indian standards, but for Zn 50% of all samples across gardens were above the safety thresholds; highest concentrations were found in spinach of garden 1 and cress of garden 2 (Table 3.3).

3.3.2. Parasites and microbes

Concentration of microbes and parasites in irrigation water were several times higher than the WHO safety thresholds. Coliform loads were four-fold higher in garden 3 and 5 than in garden 2 and 6. Salmonella were detected only in the irrigation water of garden 3 and 5, while Shigella was higher in garden 2 and 6 than in gardens 3 and 5. Ascaris eggs were, except for garden 2, in all gardens above the threshold. There was also considerable difference between irrigation waters for entamoeba and *Oxyuris vermincularis* (Table 3.4).

In all gardens coliforms from the irrigation water (with considerable numbers per liter of irrigation water) were transferred to the agricultural produce. Irrigation water induced produce contamination also occurred for *Enterobius vermicularis* in four gardens, for *Oxyuris vermicularis* and *Ascaris lubricoides* in three gardens and for entamoeba in one garden, while *Salmonella sp*. and *Shigella sp*. were not found on the crops (Table 3.5).

Table 3.3. Concentration of the heavy metals cadmium (Cd), lead (Pb), copper (Cu) and zinc (Zn; all in mg kg^{-1} dry weight) in vegetables grown in waste-water irrigated gardens in Kabul, Afghanistan.

No. of garden	Crop name	Botanical name	Cd	Pb	Cu	Zn
1	Coriander	*Coriandrum sativum* L.	n.d.*	1.4	8.8	45.5
1	Radish	*Raphanus sativus* L	n.d.	1.5	5.2	55.1
1	Spinach	*Spinacia oleracea* L.	0.14	3.4	53.7	86.9
1	Leek	*Allium porrum* L.	n.d.	1.7	10.6	43.1
2	Spinach	*Spinacia oleracea* L.	n.d.	1.3	8.5	75.4
2	Lettuce	*Lactuca sativa* L.	n.d.	1.5	8.2	45.0
2	Onion	*Allium cepa* L.	n.d.	1.3	5.7	62.5
2	Radish	*Raphanus sativus* L	n.d.	1.9	5.9	62.9
2	Garden cress	*Lepidium sativum* L.	0.14	4.6	7.0	160.1
2	Mint	*Mentha arvensis* L.	0.05	2.5	13.7	38.5
3	Turnip	*Brassica rapa* var. *rapa*	n.d.	2.0	3.0	35.3
3	Spinach	*Spinacia oleracea* L.	n.d.	2.1	10.2	64.9
3	Onion	*Allium cepa* L.	n.d.	0.9	7.1	39.3
4	Alfalfa	*Medicago sativa* L.	n.d.	0.8	6.6	34.2
4	Spinach	*Mentha arvensis* L.	n.d.	2.0	9.6	72.1
5	Spinach	*Spinacia oleracea* L.	n.d.	1.6	6.2	42.9
5	Radish	*Raphanus sativus* L.	n.d.	0.9	4.5	53.6
5	Mint	*Mentha arvensis* L.	n.d.	0.8	10.0	32.7
Safety threshold						
[a]WHO			0.2	0.3	40	50
[b]India			1.5	2.5	30	50

[a] FAO/WHO, 2001, Joint Codex Alimentarius Commission. [b]Indian limit, Awashthi, 2000.

* < 10 µg kg^{-1} or not detectable

Table 3.4. Most probable number data (10^7)of faecal pathogens in sewage water used for irrigation of urban vegetables in Kabul, Afghanistan.

No. of garden	Water source	Coliform bacteria	Salmonella	Shigella	*Ascaris lubricoides*	Entamoeba	*Oxyuris vermicularis*	*Enterobius vermicularis*
1	Well+sewage*	-	-	-	1.0	-	-	-
2	Sewage+river	0.5	-	2.5	-	-	0.5	-
3	Sewage+river	2.0	2.0	1.0	2.0	0.5	0.35	1.0
4	well	nd	nd	nd	nd	nd	nd	nd
5	Sewage+river	2.0	1.0	1.5	1.75	0.9	0.53	1.25
6	Sewage+river	0.5	-	2.5	1.0	1.5	-	0.5
Safety limit[a]		1000	1000	1000	1.0	1.0	1.0	1.0

[a]Source: WHO (1989)

*Well water in this household was dominated by sewage water

nd. Not detected

Table 3.5. Most probable numbers (10^7) of faecal pathogens in wastewater irrigated urban vegetables in Kabul, Afghanistan.

No. of garden	Crop	Coli form bacteria	Salmonella	Shigella	*Ascaris lubricoides*	Entamoeba	*Oxyuris vermicularis*	*Enterobius vermicularis*
1	Garden cress	1.0	-	-	-	-	-	-
2	Lettuce	0.5	-	-	-	-	-	0.4
3	Coriander+radish	1.0	-	-	0.2	-	0.3	0.7
5	Radish+coriander	2.0	-	-	0.2	0.5	0.3	0.4
6*	Onion+radish	1.5	-	-	0.2	-	0.3	0.4

*Note: garden 4 due to inappropriate crop for analyses replaced by grden-6

3.4. Discussion

3.4.1. Heavy metal loads

The low heavy metal concentrations in irrigation water were surprising and may in view of the still important contamination of agricultural produce reflect the effects of recent (post-war) reductions in water-related contamination sources as well as the contribution of unquantified amounts of dust to the overall loads. The generally low levels of Cd in the vegetable samples may reflect the effect of the high pH of Kabul's garden soils which reduces the availability of Cd for crops (Kuo et al., 1985; He and Singh, 1994). Another reason may be the absence of significant Cd sources such as factory of battery making, paint manufacturing, mining and metal processing. The soil and produce contamination with Pb may be the result of fuel combustion from the rapid increase in traffic and city waste (Maleki et al., 2008). Nabulo et al. (2006) reported atmospheric deposition to be the dominant pathway for Pb to leafy vegetables. The overall low levels of Cu may again be the results of lacking Cu-using industries in the Kabul area. The high Zn loads in the studied vegetables may partly come from war-related junk that caused rivers, streams, and ditches to be filled with broken tanks, military vehicles and bullet cartridges.

3.4.2. Contamination with parasites and microbes

The high levels of bio-contaminants in the irrigation water sources may be due to septic wastes from the city's hospitals, and sewage from schools, and residential areas. An elevated contamination of vegetables with parasite eggs excreted by human and animals was also reported by Uga et al. (2009) from Hanoi, Vietnam, and by Abougrain et al. (2010) from Tripoli, Libya. Significant contamination of vegetables with *Amoeba sp*., *Ascaris lubricoides* and *Enterobius vermicularis* were also found in neighbouring Iran by Gharavi et al. (2002), but thier values were lower than ours. In Kabul many farmers accept the direct unloading of sewage tanks into their gardens given the free input of plant nutrients contained therein.

3.5. Conclusions

Though the data of this study only indicate excessive Pb and Zn loads as well as pathogen contaminations for UPA vegetables (garden cress, lettuce, coriander, radish, and salad onion) and other produce to exceed international thresholds levels, the high incidence of intestinal diseases and diarrhea in Kabul's population calls for further surveys to confirm our results. Improvements in Kabul's sewage infrastructure are nevertheless urgently needed to eliminate potential health risks and decrease the widespread odour nuisance.

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Chapter 4.

Economic analysis of cereal, vegetable, and grape production systems in urban and peri-urban agriculture of Kabul, Afghanistan

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Summary

Little is known about the economics of urban and peri-urban agriculture (UPA) in Kabul, Afghanistan. This study therefore aimed at investigating the profitability of 15 mixed cropping farms with together 42 farm plots that were selected from a survey of 100 households (HHs). The sample represented the three dominating farm types: cereal producers (15 plots), vegetable farmers (15 plots), and grape producers (12 plots). A cost-revenue analysis of all inputs and outputs (costs of tillage, seed where applicable, weeding, harvesting, casual labour, machinery use, pruning, pesticides, and of revenue form produce sold) over two years showed major differences in net HH income. Differences were largely due to production type and crops grown and reflected differences in market prices for produce. Cereal production yielded a total bi-annual revenue of 9,630 US$ ha^{-1}, and a gross margin and a net profit of 8,770 US$ ha^{-1}. Returns from vegetable farming were with an average bi-annual revenue of 27,900 US$ ha^{-1}, a gross margin of 26,330 US$ ha^{-1}, and a net profit of 25,530 US$ ha^{-1} much higher. Surprisingly, vineyards generated the lowest returns with a revenue of 5,400 US$ ha^{-1}, and a gross margin and a net profit of 4,480 US$ ha^{-1}. The results suggest that among the production systems studied vegetable cultivation was most profitable given its direct linkage to city market demands, rather stable prices, and much shorter growing season than for cereals and grapes. In addition, the inflow of wheat and grapes from rural areas into the city negatively affects local producer revenues. If vineyards are to be maintained in the city surroundings, incentives such as subsidized credit may need to be made available to producers in the near future.

Key words: Land use systems; partial revenue analysis; gross margin, net profit

4.1. Introduction

In recent years urban and peri-urban agriculture (UPA) has been widely recognized as a means to contribute to the livelihoods of local livestock and vegetable producers, small traders, and consumers in many cities of the developing world. While UPA is part of the legal economy, its existence is often rather tolerated than supported given that most UPA producers operate on land to which they have no legal entitlement (Gerstl et al., 2002). As poor urban households can spend 60-80% of their income on food, UPA may also significantly contribute to their subsistence needs and thus to poverty alleviation (Avila and van Veenhuizen, 2002; Nguni and Mwila, 2007; van Veenhuizen and Danso, 2007). On the other hand the often intensive use of sewage water for irrigation and urban waste as a soil amendment in UPA has been reported to cause microbial and heavy metal contamination of agricultural soils and produce (Keraita and Drechsel, 2002; Amoah et al., 2005; Keraita et al., 2007; Abdu et al., 2010). In view of such pros and cons of UPA, urban planners and policy makers increasingly seek effective solutions to integrate these activities into inner city areas (FAO, no date; Rachel and Nugent, 2010).

Given the scarcity of data on the profitability of different types of UPA production systems and the role that such activities play for the income of its practitioners, the objective of this study was to compare costs and benefits of UPA for the Afghan city of Kabul where rapid city development and economic growth strongly determine its spatial extension and income potential.

4.2. Materials and methods

4.2.1. Site conditions and UPA activities

Kabul, the capital city of Afghanistan, is located at 1,750-1,770 m asl. It is characterized by an average annual precipitation of 300-330 mm, distributed between November and May, and a long-term annual average temperature of 10-13°C with a relative humidity of 54% (Grieser et al., 2006). Kabul province comprises 14 rural and 22 urban districts, and about 81% of its population live in the city. The average farm size in the province is about 0.4 ha whereby even large landowners rarely have more than 1 ha. Sharecropping, whereby the landlord rents out his land in return of typically 50% of the harvest, is common practice among small farmers. While in the countryside cereals such as wheat (*Triticum aestivum* L.), maize (*Zea mays* L.), and barley (*Hordeum vulgare* L.) dominate, in the city the majority of crops grown are vegetables rotated with some cereals and grapes.

The cereal farming area under study situated in the southern part of the city (34°28’45.96“ N, 69°12’54.94“ E;1,767 m a.s.l Figure 4.1) and obtains for a few months each year irrigation water from the Char Asyab district to complement precipitation for a single crop. A few vegetables such as potato (*Solanum tuberosum* L.), onion (*Allium cepa* L.), turnip (*Brassica rapa* var. *rapa*) and forages such as alfalfa (*Medicago sativa* L.) and clover (*Trifolium* spp.) are also occasionally grown. In this area, no regular runoff exists but occasional rainfall in spring and sometimes in summer can lead to flash floods that rush through the low laying areas. Total area under cultivation per household ranged 6,025 – 39,490 m^2 and Plot sizes from 100 – 2,000 m^2. While vegetable production is largely for sale, cereals are for subsistence and cash earning. Major constraints of this landuse system are the timely availability of water and mineral fertilizers.

The vegetable farming area is located in the center of the city (34°29’59.76” N, 69°09’22.06“E; 1,765 m a.s.l.; Figure 4.1) stretching from East to West along the Kabul River. This area has an old irrigation infrastructure including sewage channels from local residential areas. Total area under cultivation per household ranged from 4,020 – 9,925 m^2. Plots sizes ranged from 54 – 1,000 m^2 and are typically cropped from April to November with an intensive rotation of vegetables such as radish (*Raphanus sativus* L.), coriander, (*Coriandrum sativum* L.), leek (*Allium ampeloprasum* var. *porrum* L.), onion, carrot (*Daucus carota* L.), turnip (*Brassica compestris* var. *rapa* L.), eggplant (*Solanum melongena* L.), spinach (*Spinacia oleracea* L.), pepper (*Capsicum annuum* L.), lettuce (*Lactuca sativa* L.), mint (*Mentha arvensis* L.), garlic (*Allium sativum* L.), cabbage (*Brassica oleracea* L.), pumpkin (*Cucurbita moschata* L.), tomato (*Lycopersicon esculentum* L.), and wheat. Forages such as alfalfa and clover are also sporadically grown. Major opportunities of this system are the easy market access for produce while water availability, the amount of arable land and competition from other parts of Afghanistan with cheaper labour cost are important constraints.

Vineyards for table grape production are located at the northern corner of the city (34°34’12.27“ N, 69°14’13.15“ E; 1758 m a.s.l; Figure 4.1) and are at least 40 years old. The moderately fertile vineyards are situated in a large flat area with a poor drainage system. During spring the area’s major water source is the Kabul River which is increasingly complemented by sewage water from residential areas as the year progresses. Total area under cultivation per household ranged from 1,720 – 9,586 m^2 with and plot sizes from 200 – 6,500 m^2. Some of the farmers also grow wheat, vegetables and forages in association with grapes or in separate plots, but grapes are always dominant. Apricot

(*Prunus armeniaca* L.), mulberry (*Morus sp.*), and other deciduous fruit trees grown for non-commercial purposes, are also present as garden borders. The major constraints to this system are water availability, poor drainage conditions and seasonal sensitivity of the grape to frost events.

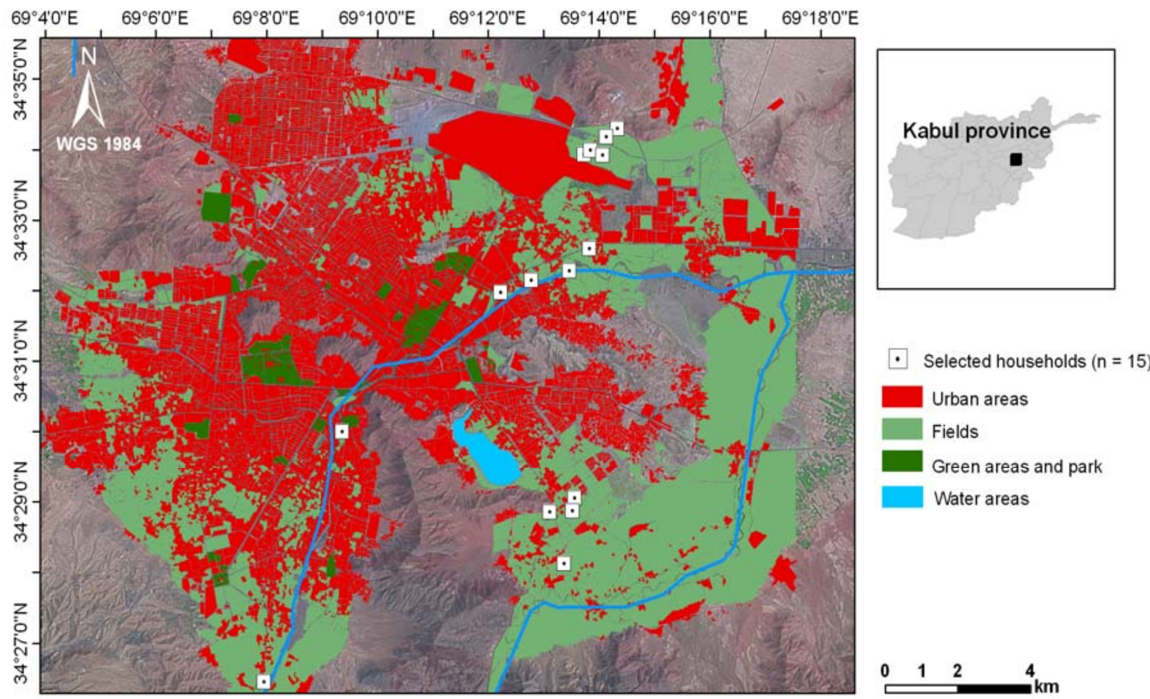

Figure 4.1. Map indicating the location of the studied urban and peri-urban farming households in Kabul, Afghanistan.

4.2.2. Data collection and calculations

For this study we used data obtained from a detailed farm and household (HH) survey conducted from 14th April 2008 to 25th October 2009 (Safi et al., 2011). The data included quantitative and monetary values of all crop inputs, such as seeds, organic and inorganic fertilizers, pesticides, irrigation water, land leasing, hired labour charges, fuel, machinery needed for all field operations, and harvested crop yields from all fields of each of the 15 representatively selected farm HHs. All of these were full-time farmers who may, however, still have had some secondary, yet unquantified income from Afghanistan's sprawling informal economy or from small ruminants kept at home (Table 4.1). Each of the three existing UPA production types was represented by five HHs and a total of 42 plots were used for this study. All input prices and the farm gate price of each produce sold were recorded at each transact event for whole growing season in 2008 and 2009. Costs of manure and irrigation water were calculated based on current prices at the farm gate. All expenses and revenues were computed at a hectare basis and converted from the local currency Afghani to US$ at a rate of 50:1. Depreciation of irrigation equipment as well as interest on capital for the variable expenses incurred by the farmers during the crop season was not taken into account in our calculations of production costs. Furthermore the establishment costs of the vineyard plantations were considered amortized over their past 40 years life span. Therefore, no further amortization costs were considered.

Based 0n crop yields, product prices and costs, we evaluated relative farm profitability using the average gross margin and average net profit per hectare and year. The gross margin was computed by subtracting variable costs from the value of total production as follows:

$$TGM = \sum (Yi * Pi) - \sum (VCi) \qquad \text{Eq. (1)}$$

where, Yi = is the quantitative yield of crop i; Pi = the farm gate price for crop i; VCi = the total variable costs for crop i.

Net profit (NP) was calculated by subtracting the total production costs from the gross margin.

$$NP = TGMi - TFCi \qquad \text{Eq. (2)}$$

where, NP is the net profit, TGMi is total gross margin of crop i,TFCi is the total fixed cost for crop i.

4.2.3. Statistical analysis

A multivariate analysis of variance (MANOVA) using the GLM procedure of SPSS version 18 (SPSS Inc. Chicago, IL, USA) was performed to assess differences between HH farms and between production systems (Sites).

4.3. Results

4.3.1. Cereal production

Cereal farms were mainly subsistence- and only partly market-oriented. At the end of growing season some of the farm land was used by landless families to graze their flocks. Most farmers had pre-paid contracts with retailers which allowed the latter to purchase the produce at less than half the market price fetched at harvest. Given the distance to the city manure costs were 0.44 US$ per wheelbarrow (including handling). Malathion (organophosphate parasympathomimetic) was applied to control aphids and leaf hoppers. Across farms machinery (e.g. a tractor) was often used for land preparation.

4.3.2. Vegetable production

Despite the availability of snow-melt water in the spring season and year-round availability of sewage water for irrigation, two out of the five vegetable farms had invested in a water pump to convey river and sewage water onto the plots which carried a wide variety of species (Annex VII). Manure price per wheelbarrow was 0.08 US$ plus additional handling costs of 0.08 US$. Manure had 97% dry matter and contained 70% sand and 30% of organic and non-organic municipal solid wastes. Night soil was sometimes collected for free from local toilets and applied to the field after a few months of composting. Mineral fertilizers such as urea and di-ammoniumphosphate (DAP) were also used. The produce market was very close to the production area, but most clients and retailers came to the farm to make their purchases. Rent paid in kind for leased land was 350 kg wheat for 0.2 ha yr^{-1}. Like in cereal farms, malathion was used to control aphids and leaf hoppers in the gardens.

4.3.3. Grape production in vineyards

Grape producers in the city had only infrequent access to municipal solid wastes as Kabul International Airport cuts the grape growing area off the city, but sewage water and stream sediments were abundantly used. Most farmers used sulfur to control powdery mildew, but during our study no such disease outbreak occurred. Farmers pruned their vines and vine sprouts in early and late spring, respectively. Weeding and soil slacken was done once in the spring season by spading of the furrows. While the latter operation was traditionally performed under the traditional Afghan “Ashar” labour sharing system, this practice was not observed during the time of our study. This likely is a consequence of the recent war history and the still insecure current political situation. Most grapes were sold at the farm to retailers who transported them to the market. Surpluses of products are traditionally dried under the open sun or in a well aerated shed to produce ‘Sayagee’ (sun-dried raisins) and ‘ Aftabee’ (shed-dried raisins).

4.3.4. Price fluctuations during the study period

During the two year study period labour wage rates were constant at 4 US$ / 8 hrs day for an unskilled labourer while input costs fluctuated widely. In 2008, the first year of study, prices of urea and DAP (18:46:0) were 24 US$ 50 kg^{-1} and 44 US$ 50 kg^{-1}, respectively, while in 2009 they were 16 US$ 50 kg^{-1} and 24 US$ 50 kg^{-1}. Fuel prices were 1.3 US$ l^{-1} in the first year and declined to 0.9 US$ l^{-1} in the second year. The wheat price was 0.52 US$ kg^{-1} in 2008 and 0.36 US$ kg^{-1} in 2009. Vegetables prices remained fairly constant, although they are affected by imports from other parts of Afghanistan and neighboring Pakistan, China, and Iran (MAAHF, 2005).

4.3.5. Farm-based analyses of key economic parameters

4.3.5.1. Total cost of production

Total production cost varied from 640 - 1,100 US$ $ha^{-1}yr^{-1}$ in cereal farms (Table 4.4), whereas in the five vegetable farms it ranged from 1,460 - 3,110 US$ with a maximum in one farm growing forage along with the vegetables. Production costs in vineyards ranged from 700 - 1,130 US$ $ha^{-1}yr^{-1}$ and were twofold higher in farms growing grape only compared to those growing grape in association with vegetables and forages (clover and alfalfa). Differences in production costs between farms of the three production systems were highly significant ($P < 0.001$).

4.3.5.2. Revenues, gross margins, and net profits

Total revenues from crop cultivation ranged from 5,690 - 13,790 US$ ha^{-1} yr^{-1} in cereal production, from 15,340 - 51,790 US$ ha^{-1} yr^{-1} in vegetable production, and from 4,580 - 5,890 US$ ha^{-1} yr^{-1} in vineyards. These differences of revenues between farm types were highly significant ($P < 0.001$). Similarly, gross margins were significantly different between farm types ($P<0.00$, Table 4.4). They ranged from 4,900 - 12,690 ha^{-1} US$ yr^{-1} in cereal production, from 14,670 - 49,470 US$ ha^{-1} yr^{-1} in vegetable production, and from 3,450 - 5,200 US$ $ha^{-1}yr^{-1}$ in vineyards.

Net profits were significantly ($P < 0.001$) higher in vegetable farms (13,880 - 48,680 US$ ha^{-1} yr^{-1}) than in cereal farms (4,900 - 12,690 US$ ha^{-1} yr^{-1}), and in vineyards (3,450 - 5,200 US$ ha^{-1} y^{-1}, Table 4.4).

4.3.6. Site-based key economic parameters

4.3.6.1. Costs of production

Cumulative costs of operation (total expenses) were with 860 US$ ha^{-1} for cereal, 2,365 US$ ha^{-1} for vegetable and 920 US$ ha^{-1} for grape production significantly ($P < 0.001$) different from each other.

4.3.6.2. Revenue, gross margin, and net profit

Revenue in the three production systems varied from 5,400 - 27,900 US$ ha^{-1} yr^{-1} and were 2.8- and 5-fold higher in vegetable gardens than for cereals and grape production, respectively ($P < 0.001$, Table 4.4).

Table 1. Basic household (HH) characteristics in the three management systems of urban peri-urban agriculture (UPA) in Kabul, Afghanistan (2008 -2009). Labour payment rates for agricultural labour are 4 $ per day (10 hours) regardless of whether the labour was skilled or unskilled.

HH	Total cultivated land area (m^2)	Land use mode	Indigenous/ immigrant	Cropping history (years)	Income from cropping (%)[a]	Labour availability: Full time (family)	Labour availability: Casual (hired)	Fertilizer application: Organic (%)	Fertilizer application: Inorganic (%)
1	10,685	Open	Indigenous	> 40	50	1	1	58	42
2	9,600	Open	Indigenous	> 40	50	2	3	38	62
3	39,490	Open	Indigenous	> 40	100	1	1	23	37
4	6,025	Open	Indigenous	> 40	80[a]	1	2	51	49
5	10,800	Open	Indigenous	> 40	80	1	1	58	42
6	6,651	Open	Indigenous	40	100	2	1	80	20
7	9,924	Open	Migrant	5	100	2	1	84	16
8	4,020	Open	Indigenous	40	50	2	-	70	30
9	1,380	Open	Indigenous	5	80[a]	1	1	65	35
10	3,427	Open	Indigenous	> 40	100	2	-	49	51
11	2220	Wall fenced	Indigenous	> 40	30[a]	1	2	0	100
12	1,720	Wall fenced	indigenous	> 40	50	1	1	46	54
13	9,586	Wall fenced	Indigenous	> 40	20	-	2	82	18
14	6,326	Wall fenced	Indigenous	> 40	80	1	1	79	21
15	4,530	Wall fenced	Indigenous	> 40	80[a]	2	2	65	35

[a] Household in which animal husbandry contributed to total income

Table 2. Crop rotation and marketable yields in 15 urban and peri-urban farming systems in Kabul from April, 2008 to October, 2009

Household Type / No.	Marketable yield (t ha^{-1})	Farming type	Cropping sequence*
Cereals			
1	[4.8-14], [5.4]	Commercial & subsistence	Wheat [grain-straw +residues], onion [bulb]
	[4.9], [2.5-22.5]		Onion, wheat
	[2.9-8.7], [2.5-22.5]		Wheat, wheat
2	[4.1-10.0], [4.5, 4,5, 5.6]	Commercial & subsistence	Wheat, clover, clover, clover
	[3.7, 4.5, 5.5], [5.5-20.6]		Alfalfa, alfalfa, alfalfa, wheat
	[3.9], [4.8-21.4]		Onion, wheat
3	[2.4, 5.0, 5.0, 10.0, 6.8, 12.0, 4.6]	Commercial & subsistence	Alfalfa, alfalfa, alfalfa, alfalfa, alfalfa, alfalfa, alfalfa[1]
	[4.1-10.0], [5.6], [1.9], [0.36-25.4], [4.7]		Wheat [grain-straw], clover, corn, wheat, onion
	[3.8], [4.5-21.2], [14.5]		Onion, wheat, corn
4	[4.9], [5.6-19.9], [7.4]	Commercial & subsistence	Onion, wheat, turnip
	[4.1-10.0], [5.4], [6.5],		Wheat, corn, onion
	[5.9], [3.9], [5.6-19.9], [37.2]		Potato, tomato, wheat, millet
5	[4.9-20.0], [10.7],[5.4)]	Commercial & subsistence	Wheat, barley, onion
	[7.9], [5.4-16.1], [3.2]		Potato, wheat, barley
	[5.7], [5.4-16.1], [3.2]		Onion, wheat, barley

[1] Alfalfa is largely sold and only in some cases partly used as a feed supplement for a few small ruminants destined to home consumption.

Table 2. Continued

Vegetables			
6	[3.4], [3.2], [2.7], [2.2], [3.1], [1.9], [3.0]	Commercial	Garden cress, coriander, spinach, coriander, radish [shoot and bulb], radish, spinach,
	[1.3], [0.54], [1.8], [0.55], [1.3], [1.8], [2.7], [3.4]		Spinach, eggplant, eggplant, radish, spinach, radish, coriander, garden cress
	[1.6, 1.1, 0.93, 0.56, 2.3, 4.2, 5.2, 2.1, 2.6]		Leek, leek, leek, leek, leek, leek, leek, leek, leek
7	[2.0], [4.2], [0.18], [0.66], [1.2], [4.0], [2.09, [3.0]	Commercial	Radish, lettuce, eggplant, eggplant, spinach, lettuce, radish, onion,
	[2.3], [6.4], [2.0], [4.0], [4.0], [5.1], [2.7], [7.3]		Radish, lettuce, radish, onion, onion, lettuce, radish, garden cress
	[5.4, 6.6, 5.1, 1.3, 1.3], [1.9], [1.8], [2.1]		Mint, mint, mint, mint, mint, radish, lettuce, radish
8	[2.0], [2.3], [2.0], [0.94], [2.8], [5.5-31.0], [7.4]	Commercial	Radish, coriander, radish, coriander, spinach, wheat, turnip
	[2.1], [2.2], [2.7], [2.7], [4.1], [4.6-31], (2.0]		Spinach, coriander, radish, radish, coriander, wheat, spinach
	[4.9-24.2], [2.7], [4.2], [1.3], [1.1], [0.59], [1.3]		Wheat, coriander, radish, spinach, onion, radish, spinach
9	[6.0, 5.8, 6.3, 15.9, 13.6, 6.8, 6.8]	Commercial	Alfalfa, alfalfa, alfalfa, alfalfa, alfalfa, alfalfa, alfalfa
	[6.2, 6.2, 7.0, 15.9, 11.4, 6.6, 3.3]		Alfalfa, alfalfa, alfalfa, alfalfa, alfalfa, alfalfa, spinach
	[3.5, 3.3, 4.3, 9.1, 9.8, 6.8, 12.3]		Alfalfa, alfalfa, alfalfa, alfalfa, alfalfa, alfalfa, corn
10	[4.1], [2.3], [3.4], [2.7], [3.4], [2.7], [5.9]	Commercial	Radish, onion, radish, coriander, radish, coriander, spinach
	[4.1], [2.9], [3.4], [2.7], [2.8], [5.9]		Radish, coriander, radish, coriander, spinach, spinach
	[4.6, 7.4, 5.3], [0.79], [3.2, 6.8, 4.1]		Mint, mint, mint, radish, mint, mint, mint

Table 2. Continued

Vineyards			
11	[0.37], [0.37], [0.42], [5.4], [1.5], [0.35], [4.1]	commercial	Grape (fruits, leaves, sprouts), grape (fruit, leaves, sprouts, sticks)
12	[0.36], [0.39], [0.42], [4.7], [1.5], [0.42], [3.8]	Commercial	Grape, grape
	[0.0], [0.39], [0.43], [0.0], [0.87], [0.42], [3.8]		Grape, grape
	[0.37], [0.39], [0.43], [4.7], [1.5], [0.42], [3.8]		Grape, grape
13	[1.8, 2.2, 2.0, 9.9, 16.5, 9.9]	Commercial & subsistence	Alfalfa, alfalfa, alfalfa, alfalfa, alfalfa, alfalfa
	[2.3, 4.0, 5.0], [9.8, 9.9, 14.8]		Clover, clover, clover, alfalfa, alfalfa, alfalfa
	[0.36], [0.38], [0.42], [4.6], [1.3], [0.89], [3.1]		Grape, grape
14	[0.38], [0.389], [0.45], [5.9], [2.2], [0.82], [3.7]	Commercial & subsistence	Grape, grape
	[4.1], [6.1], [0.88], [0.82], [0.81]		Pumpkin, onion, grape (intercropping)
	[5.1], [3.6-19.0]		Tomato, wheat
15	[0.37, [0.39], [0.43], [5.3], [4.6], [0.87], [3.8]	Commercial	Grape, grape
	[0.37], [0.39], [0.43], [5.3], [4.6], [0.87], [3.8]		Grape, grape

* The scientific [and local] names of the listed crops are: Garden cress: *Lepidium sativum*, [taratezak]; Coriander: *Coriandrum sativam*.[Gashneez]; Spinach: *Spinacia oleracea* L., [palak]; Radish: *Raphanus sativus*., [mulisurkhak]; Eggplant: *Solanum melongena*, [badenjan]; Leek: *Allium ampeloprasum*, [gandana]; Onion: *Allium cepa,* [piaz]; Tomato: *Lycopersicum esculentum,* [romibadenjan]; Lettuce: *Lactuca sativa* L., [kaho]; Mint: *Mentha arvensis,* [nana]; Pumkin: *Cucurbita moschata* L., [kadu]; Turnip: *Brassica compestris* var.rapa L., [shalgham]; Wheat: *Triticum aestivum,* [gandum]; Barley: *Hordeum vulgare,* [jau]; Maize: *Zea mays,* [jawari]; Potato: *Solanum tuberosum,* [kachalu); Alfalfa: *Medicago sativa,* [rishqa]; and clover: *Trifolium resupinatum* L. [shabdar]

Table 4.3. Average variable and fixed costs of inputs for cereals, vegetable, and grape production in urban and peri-urban agriculture of Kabul, Afghanistan in 2008 and 2009.

			Costs (US$ ha^{-1} yr^{-1})											
Farming system	Farm No.	Area (ha)	Seed	Manure	Urea	DAP	Pesticides	Land lease	Tractor	Tillage	Pruning	Weeding & harvest	Threshing	Irrigation
Cereals	1	0.03	52	62	100	85	20	-	67	69	-	324	74	62
	2	0.06	37	61	103	75	20	-	53	69	-	208	72	-
	3	0.04	94	61	88	85	20	-	100	69	-	347	73	102
	4	0.05	51	101	100	85	30	-	93	104	-	463	104	135
	5	0.07	78	60	113	85	30	_	93	69	-	324	80	48
Vegetables	6	0.07	93	131	163	102	-	935	-	347	-	625	-	561
	7	0.17	47	115	252	127	60	935	-	255	-	926	-	585
	8	0.07	115	103	180	67	20	935	53	278	-	880	112	-
	9	0.14	43	8	12	-	-	935	40	93	-	255	-	246
	10	0.07	70	53	178	104	120	935	-	208	-	625	-	-
Vineyards	11	0.22	-	-	200	340	-	-	-	-	208	278	-	-
	12	0.06	-	33	200	340	-	-	-	-	208	278	-	-
	13	0.28	-	26	93	340	-	-	40	69	208	231	-	198
	14	0.05	33	-	133	170	20	-	40	104	104	301	47	144
	15	0.23	-	-	200	340	-	-	-	-	208	278	-	-

Farm numbers in the table from 1-15 refered to 2,5,4,3,1 for cereal; 6,7,8,9,10, for vegetable and 11,14,12,13, and 15 for vinveards, respectively, in the annexes.

Table 4.4. Mean (± one standard deviation) of the economic components of cereal, vegetable, and grape production in urban and peri-urban agriculture of Kabul, Afghanistan in 2008 and 2009.

Farming system	Farm No.	Total cost	Revenue	Gross margin	Net profit
Cereals	1	789 (±184)	5,687 (± 2,553)	4,898 (± 2,437)	4,898 (± 2,437)
	2	644 (±334)	7,141 (± 3,670)	6,498 (± 3,858)	6,498 (± 3,858)
	3	902 (±385)	11,615 (± 3,841)	10,713 (± 3,748)	10,713 (± 3,748)
	4	1,103 (±347)	13,790 (± 4,465)	12,687 (± 4,520)	12,687 (± 4,520)
	5	864 (±190)	9,902 (± 5,521)	9,038 (± 5,397)	9,038 (± 5,397)
Vegetables	6	2,669 (±480)	24,025 (±19,227)	22,149 (±19,423)	21,356 (±19,575)
	7	3,108 (±334)	51,787 (±27,031)	49,472 (±27,096)	48,679 (±27,231)
	8	2,539 (±624)	18,564 (± 7,598)	16,818 (± 7,630)	16,025 (± 7,710)
	9	1,462 (±372)	15,343 (± 5,977)	14,673 (± 6,068)	13,880 (± 6,193)
	10	2,048 (±887)	29,770 (±13,375)	28,514 (±13,948)	27,721 (±14,090)
Vineyards	11	no data	no data	no data	no data
	12	1,129 (±200)	4,582 (± 4,337)	3,454 (± 4,537)	3,454 (± 4,537)
	13	695 (±390)	5,892 (± 2,662)	5,196 (± 2,948)	5,196 (± 2,948)
	14	894 (±228)	5,860 (± 4,054)	4,966 (± 4,111)	4,966 (± 4,111)
	15	1,096 (±162)	4,791 (± 4,550)	3,695 (± 4,712)	3,695 (± 4,712)

Values in the table indicative US$ ha^{-1} yr^{-1}

Cumulative gross margins ranged from 4,480 - 26,330 US$ ha^{-1} yr^{-1}, with highest values in vegetable production followed by cereal and grape farms ($P < 0.001$).

Net profits ranged from 4,480 - 25,530 US$ ha^{-1} yr^{-1}. Similar to gross margins, they were significantly ($P < 0.001$) higher in vegetable gardens than for cereal fields and vineyards.

4.4. Discussion

4.4.1. Farm based key economic parameters

4.4.1.1. Costs of operation

The recorded differences in costs of operation between cereal, vegetable and grape production systems were largely dependent on the inputs costs needed. Growing a commercial potato crop and vegetables such as onion implied much higher costs than the cultivation of cereals with their long growing period. In vegetable gardens, the main costs of operation were due to tillage and weeding, while in vineyards expenses for to purchase and application of urea and DAP dominated (Table 4.3). Differences in variable costs between farmers operating the same system were considerable and seemed to be partly due to differences in farm location. Grape farmers cut off by the airport were unable to access city waste as a cheap organic fertilizer. They had to invest more than the vegetable and cereal farmers in mineral fertilizers such as urea and DAP that were applied at up to 500 kg ha^{-1}. Larger vineyard sizes also allowed the use of machinery and pesticides which reduced labour costs (Table 4.3).

4.4.1.2. Revenues

Similar scale effects in revenue from cereal farming as in our study were shown for wheat production in Pakistan (Hassan et al., 2005). The low revenue from grape production may be due to effects of an unexpected frost in late 2007. Several years of dry and hot conditions left the farmers neglecting traditional frost protection techniques such as coverage of vine twigs and roots with soil and organic material. In any case the sensitivity of vineyards to climatic hazards makes grape production much more risky than vegetable and cereal farming.

4.4.1.3. Gross margins and net profits

The three cereal farmers with a particularly high revenue intensively grew cash crops in a well irrigated double-cropping system that was closely connected to wholesalers and retailers who were able to provide cash advances to producers. Market-oriented vegetable farms yielded highest net profits. Net profits in vineyards were highest in those farms that were able to well access local markets or sell secondary farm products such as groundwater to water dealers or fresh fodder from parts of their land.

4.4.2. Site specific differences in key economic factors

The poor economic performance of vineyards was likely due to the residual effects of a severe frost event in late 2007. The high profitability of subtropical vegetable production as compared to perennial tree crop cultivation was also shown by Al Said et al. (2007) for the Batinah coastal plain in Oman. Similar data were also reported by Maiangwa and Okpukpara (2007) from a study in Nigeria, where gross margins per hectare were higher for double-cropping than for single- or triple-cropping systems. These findings contradict, however, reports by ICARDA (2003) which claimed that average gross incomes from vineyards are much higher than from cereal and vegetable production. This certainly does not hold for grape production in the surroundings of Kabul.

4.5. Conclusions

The 15 farms investigated showed a high variation in their costs of production, revenues, gross margins, and net profits. Economic gains were highest in vegetable farms despite their high variable and fixed costs. Cereal cropping and grape production was much less profitable, particularly the latter that was hampered by high variable costs. While these data may need verification they provide evidence for the pivotal role of vegetable farming for income generation of farming households in the city of Kabul. Improved market access for small UPA farmers, enhanced access to credit and certification schemes specifying quality standards for produce may foster the existing opportunity for UPA farmers to escape poverty while contributing to food security in Afghanistan.

Acknowledgements

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Chapter 5.

General discussion, conclusions and recommendations

5.1. Evaluation of nutrient fluxes in UPA of Kabul

The results of flux measurements of N, P, K and C in UPA production systems of Kabul (21 gardens and 18 fields) comprising inputs in manure, irrigation water, and inorganic fertilizers and outputs such as crop removal and leaching indicated that, in the studied vegetable gardens bi-annual net balances were positive for N, P and C negative for K. In cereal farming bi-annual balances were negative for N and K and positive for P and C. In vineyards, in contrast, the corresponding values were positive for inputs of N, P, K and C. These results were consistent with those reported by Diogo et al. (2010), Khai et al. (2007), Buerkert et al. (2005), De Jager et al. (1998), and Wang et al. (2008). The observed K deficit was in line with the result of a study conducted in the Yangtze River Delta, China by Wang et al. (2008) who claimed that the negative K balance in soil may hamper soil productivity.

The data suggest that the most important contributor to N, P, K and C fluxes in vegetable production were sewage water and night soil in association with partial application of urea and DAP for N and P. In cereal production night soil and inorganic fertilizers (urea and DAP) were most important, while in vineyards sewage water and inorganic fertilizers were major sources of nutrients.

The different management practices of farmers and crop requirements made it difficult to calculate matter balances. Leaching losses of mineral N and P were only determined in two representative vegetable gardens and may not be representative for others productions systems.

Data collection problems may have led to an underestimation of inputs and outputs due to the unquantified occasional use of night soil in winter. Furthermore, biological N_2 fixation by legume crops grown in rotation or in alternative plots in the mixed cropping systems studied might have affected the N balance calculations.

5.2. Leaching losses of mineral N and P

For the assessment of vertical nutrient fluxes, we investigated the mineral N, P, and K leaching below the rooting zone using self integrating resin cartridges. The leaching losses of mineral N and P were with 70 - 205 kg N ha^{-1} and 5 – 10 kg P ha^{-1} yr^{-1} much higher than from UPA gardens in Niamey, Niger. (Predotova et al., 2010). Further investigations are necessary to substantiate these results as a function of management and soil type.

5.3. Heavy metal and pathogen contaminations of vegetables and sewage irrigation water: implication for safety of UPA production systems

This study showed that some heavy metal concentrations in the vegetables of UPA in Kabul were above the safety threshold recommended by (FAO/WHO, 2001). The degree of contamination with Cd, Pb, Cu and Zn was elevated for spinach, radish, and mint which are frequently consumed vegetables in the city (Safi et al., 2011). Microbial contamination of vegetables with coliform bacteria was found in four farms; ascaris was detected in three farms with one case of entamoeba in vegetable production. Sewage water used for irrigation of the gardens was the main transport means for ascaris, coliform and salmonella, Shigella, entamoeba, *Oxyuris vermicularis*, and *Enterobius vermicularis.*

These pathogens are well-known as a cause of zoonotic, typhoid, diarrhea and other diseases in the consumers of agriculture produce. The contaminations of UPA produce reflected deficiencies of the municipal sewage management. Efforts are necessary to coordinate stakeholder's activities in this sector.

5.4. Profitability of cereal, vegetable and grape production systems

As an economic activity farming should be profitable, environmentally sound, socially just and culturally acceptable (FAO, 2007). Calculation of key economic components of the farm enterprises studied revealed that, proceeds in cereal production farms were much lower than in vegetable farms. While grape gardens (vineyards) yielded the lowest revenues among all farm types. These findings contradicted those of ICARDA (2003) for the whole country of Afghanistan. Since our approach was based on products and their sales (at the farm gate) onto markets or to small retailers in the city, uncertainties may be introduced. Also a severe frost event in late 2007 had led to major yield losses in grapes which highly has distorted the results for these production system. Long term studies are therefore needed to explore the reliable economic contribution of these production systems for improving the livelihoods of UPA farmers in Kabul.

In our cost–revenue calculations of the three UPA farm types fixed costs such as land tax and depreciation of existing machinery were not accounted Unless for. They were reported as rental costs.

5.5. Clustering of UPA households

Our initial baseline survey of 100 UPA households allowed to classify them into three clusters characterized by (i) low crop diversity, (ii) high off-farm income and mixed agriculture, and (iii) farmers having a high number livestock plus low off-farm income (Table 5.1, Annex I). Representative farmers from each cluster were combined into the three groups subjected to further studies.

Our monitoring exposed few links between socio-economic status and nutrient fluxes in these three areas of study. This was corroborated by socio-economic information reported by Wang et al. 2008 in two peri-urban areas Nanjing and Wuxi, China. Cereal farmers (owned land) with relatively large area for cultivation (76,600 m^2 with plot sizes of 100 to 2000 m^2, Annexes VII-VIII) population density of 50-140 person ha^{-1} (World Bank, 2005).

Table 5.1. Characteristics of household clusters in urban agriculture of Kabul, Afghanistan in spring 2008.

Variables	Cluster 1 (N =47)		Cluster 2 (N =15)		Cluster 3 (N = 36)	
	Mean	SD	Mean	SD	Mean	SD
Area of fields (m^2)	10902	8434	16133	18669	10055	7035
Area of gardens (m^2)	9265	8381	7380	4064	5930	4621
Number of crops (n)	1.3	0.50	2.5	1.40	3.3	1.20
Mineral fertilizers (kg ha^{-1})	141.6	106.90	144.2	73.20	135.3	86.40
Livestock_sum	0.2	0.60	0.2	0.60	1.9	2.00
Number_products (n)	1.3	0.50	2.5	1.40	3.3	1.20
Off farm income (%)	1.3	6.10	37.3	13.40	0.3	1.70

SD: standard deviation of the mean

5.6. Conclusions

Our results of N, P, K and C fluxes in the three studied production systems indicate high surpluses of N, P and C but deficits of K and contamination of UPA produce with heavy metals and in some cases with microbes and pathogens. It is therefore concluded that UPA in Kabul operates under economically largely viable but ecologically critical conditions.

The following recommendations may help to improve the safety, productivity and sustainability of the three investigated UPA production systems in Kabul.

- Collection and treatment of city wastes before ejection to ditches, stream and rivers should be organized.
- The use of untreated wastewater in UPA of Kabul has to be reduced; the construction of dams and reservoirs in suitable valleys of Kabul province would allow to store snow melt water in early spring for subsequent use in vegetable production. It may also be feasible to divert water of the Panjshe River to Kabul as originally planed by the late president Sardar Muhammad Daud Khan.
- Certification schemes and targeted advice may lead to increase awareness among UPA tenants (producers, consumers and processors) about the risk of pathogens and heavy metals on UPA produce watered with untreated sewage effluent.

5.7. References

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Annexes

Annex I. Basic household (HH) characteristics in the three management systems of urban and peri-urban agriculture in Kabul, Afghanistan (2008 -2009)

HH	Area of plot (m^2)	Land use mode	Indigenous/ immigrant	Cropping history (years)	Labour availability *	Cropping income (%) **	Fertilizer application	
							Organic (%) ***	Inorganic (%)
1	1276	Open	Indigenous	> 40	1+ labour P	50	58	42
	126							
	660							
2	600	Open	Indigenous	> 40	2 F+ 3 P (female)	50	38	62
	600							
	1000							
3	1580	Open	Indigenous	> 40	1+ labour P	100	23	37
	1385							
	1199							
4	1000	Open	Indigenous	> 40	1F+ 2P	80a	51	49
	200							
	1000							
5	2000	Open	Indigenous	> 40	1F+ 1P	80	58	42
	2000							
	800							
6	54	Open	Indigenous	40	2+ labour P	100	80	20
	112							
	540							
7	932	Open	Migrant	5	2+ labour P	100	84	16
	500							
	325							
8	185	Open	Indigenous	40	2 F	50	70	30
	551							
	495							
9	348	Open	Indigenous	5	1F+ 1P	80a	65	35
	672							
	360							
10	416	Open	Indigenous	> 40	2 F	100	49	51
	416							
	1000							

a in the column indicates household's income contributing partly via animal husbandry,

* F in the column indicates full time labour and, P, part time labour.

** Contribution of cropping/farming to total income

*** Organic matter

Annex I. continued

HH	Area of plot (m^2)	Land use mode	Indigenous / immigrant	Cropping history (years)	Labour availability **	Cropping income (%)***	Fertilizer application	
							Organic (%)****	Inorganic (%)
11	2220	*surrounded	Indigenous	> 40	1F+ 2P	30b	0.0	100
12	1173	surrounded	Indigenous	> 40	2F	20	82	18
	707							
	6498							
13	400	surrounded	Indigenous	> 40	1F+ 1P	80	79	21
	1040							
	420							
14	1200	surrounded	indigenous	> 40	1F+ 1P	50	46	54
	320							
	200							
15	1650	surrounded	Indigenous	> 40	2F+ 2P	80a	65	35
	2880							

a in the column indicates household's income contributing partly via animal husbandry,

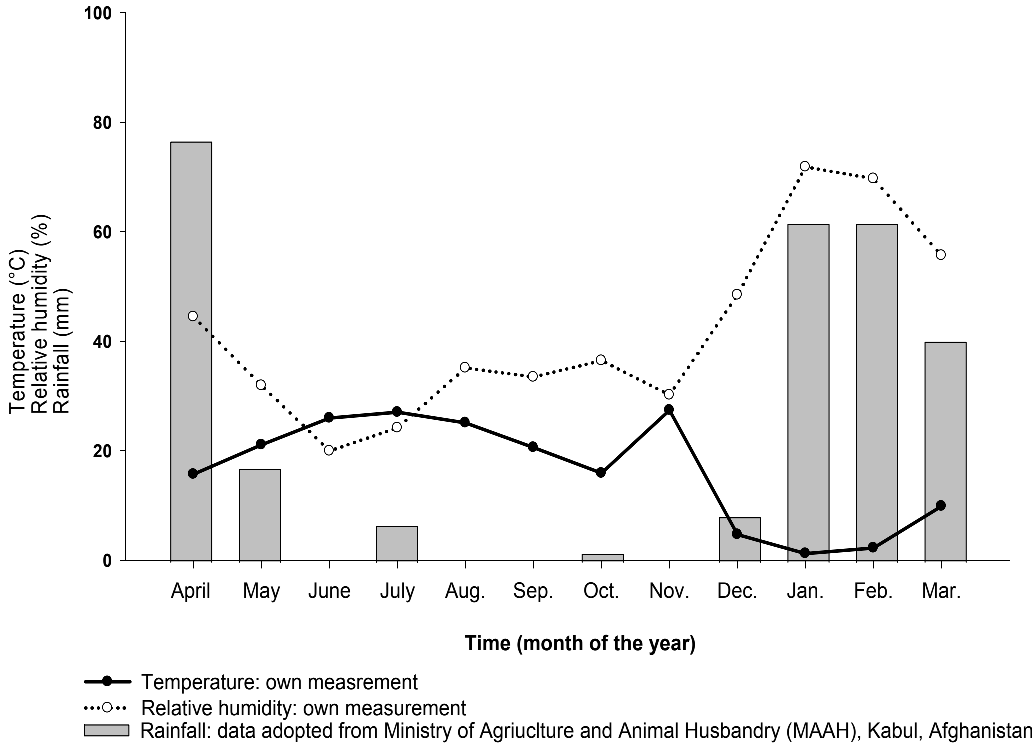
*Vineyards were protected by walls around the gardens.

** F in the column indicates full time labour and P, part time labour.

*** Contribution of cropping/farming to total income

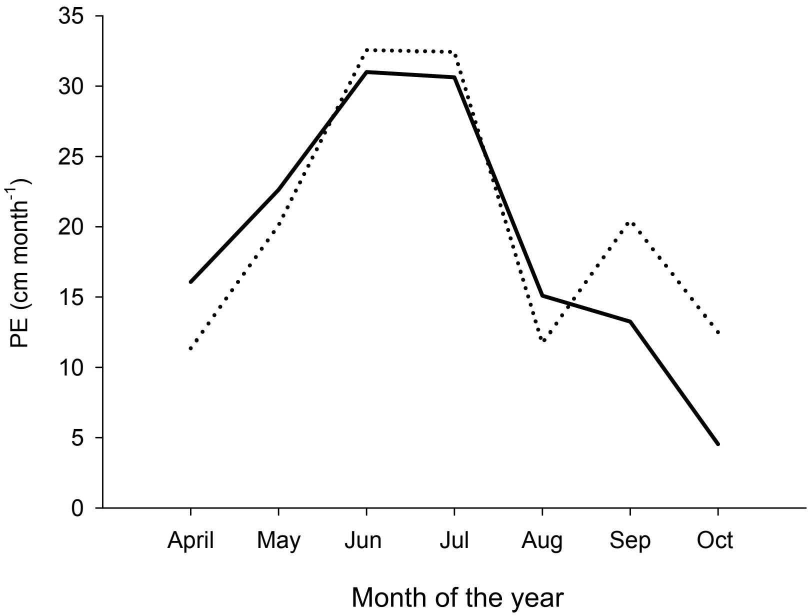
**** Organic matter

Annex II. Average monthly temperatures, relative humidity and precipitation from April 2008 – March 2009 in one garden (34°29’59,76”N, 09°22’06.6”E, 1,781 m a.s.l) in urban and peri-urban agriculture (UPA) of Kabul, Afghanistan.



View of HOBO data logger installation in one of the urban gardens in Kabul, Afghanistan.

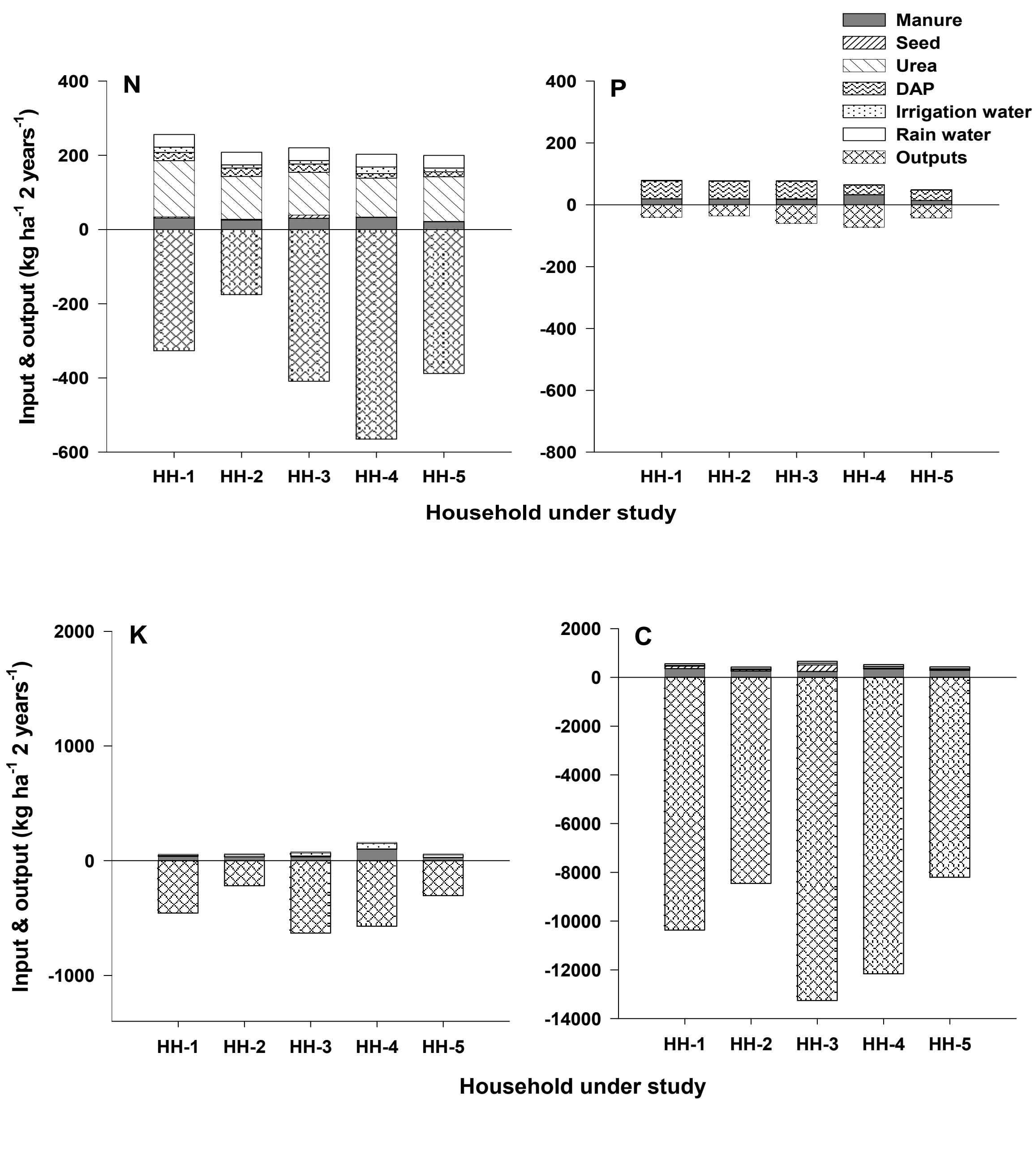
Annex III. Average monthly potential evaporation (PE) for the specific period of 2 years (April-October 2008 & 2009) in two gardens (34°31’45.87”N, 69°12’01.6”E and 34°29’59,76”N, 69°09’22,06E) of Kabul, Afghanistan.



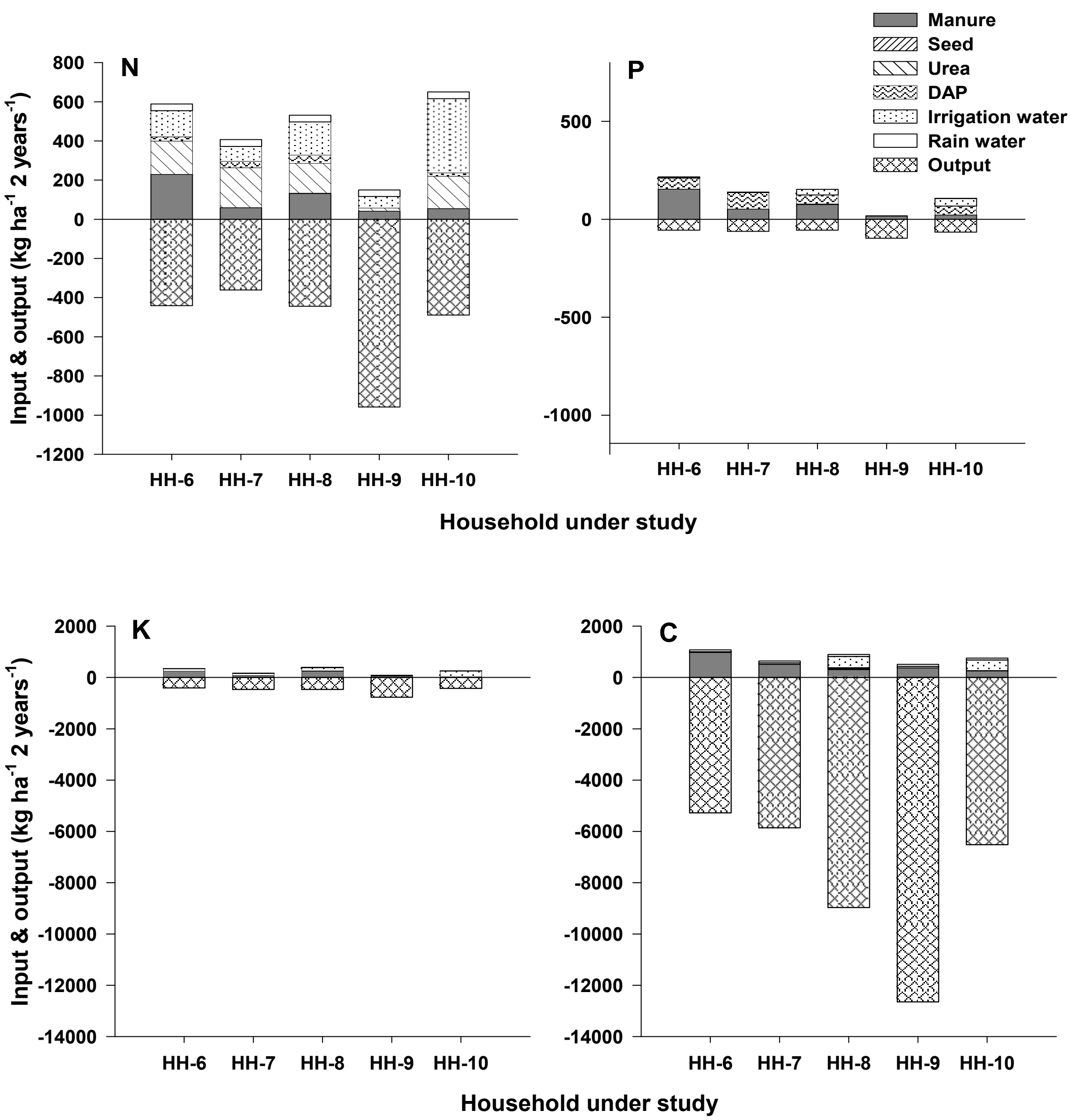
—— PE:Own measurement
······· PE:Adopted from Ministry of Agriculture and Animal Husbandry (MAAH), Kabul, Afghanistan

Self-made American Class A-Pan for measurement of potential evaporation in Kabul city, Afghanistan.

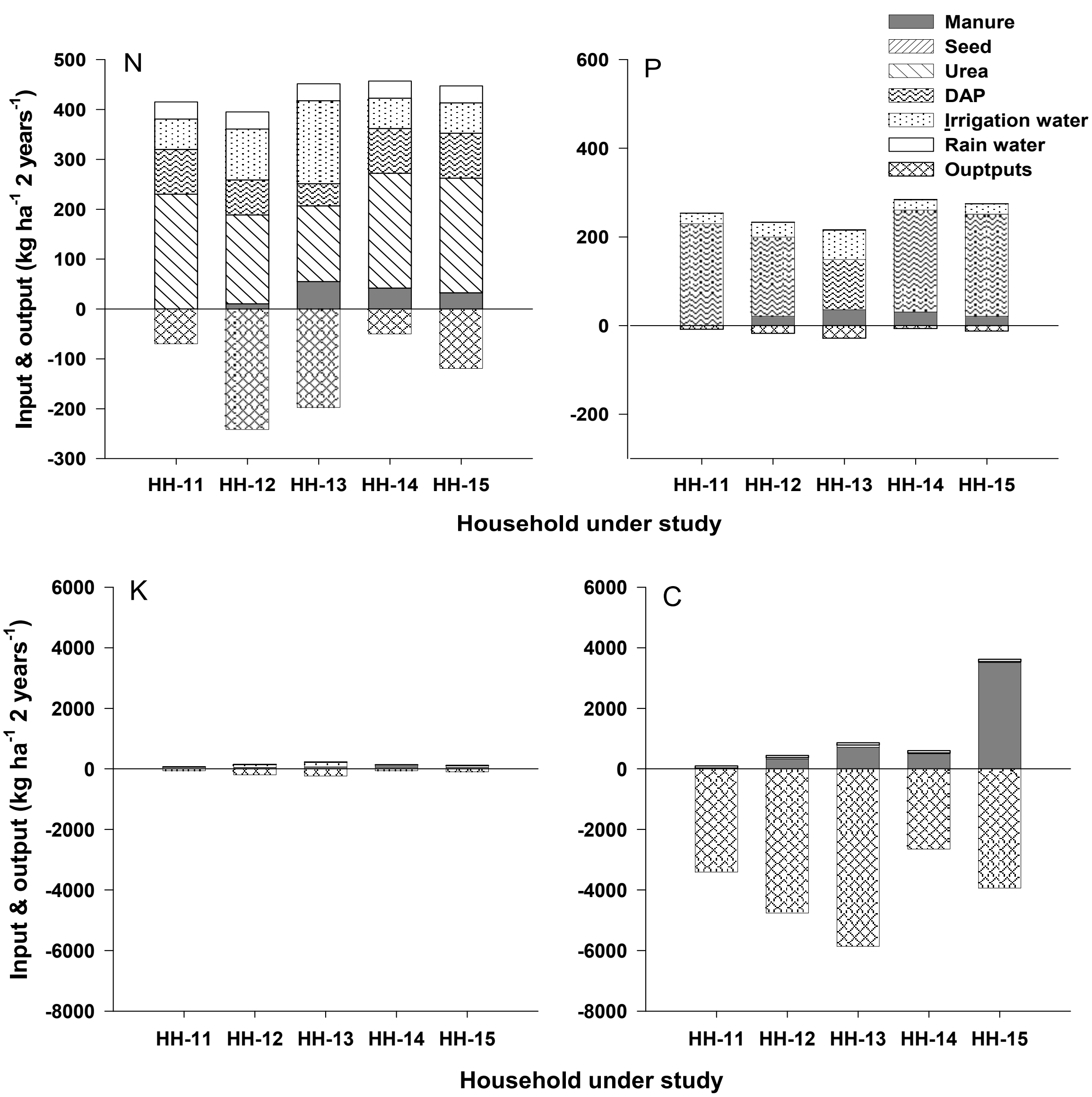
Annex IV. Biennial inputs (positive values) of nitrogen (N), phosphorus (P), potassium (K) and carbon (C) and removal (outputs, negative values) per household (HH) in cereal fields of UPA in Kabul, Afghanistan.



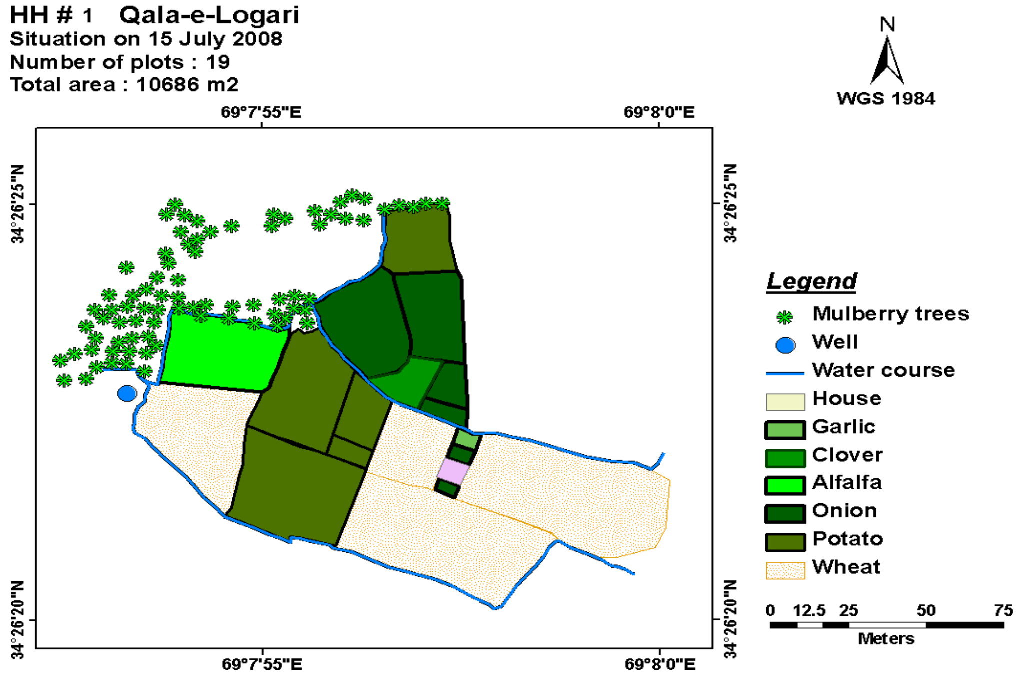
Annex V. Biennial inputs (positive values) of nitrogen (N), phosphorus (P), potassium (K) and carbon (C) and removal (outputs, negative values) per household (HH) in vegetable gardens of UPA in Kabul, Afghanistan.

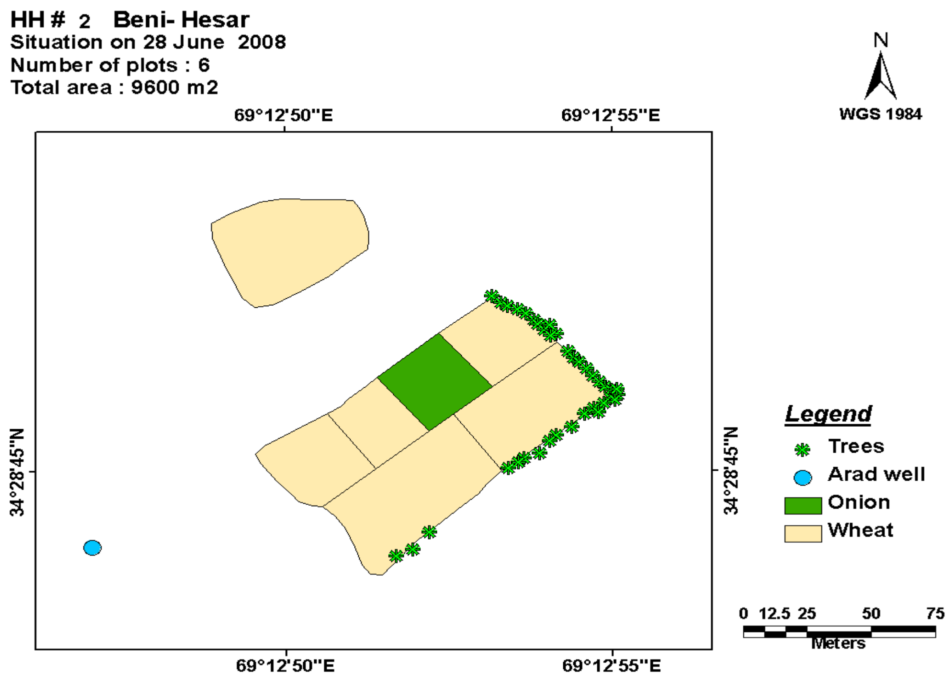


Annex VI. Biennial inputs (positive values) of nitrogen (N), phosphorus (P), potassium (K) and carbon (C) and removal (outputs, negative values) per household (HH) in vineyards of UPA in Kabul, Afghanistan.

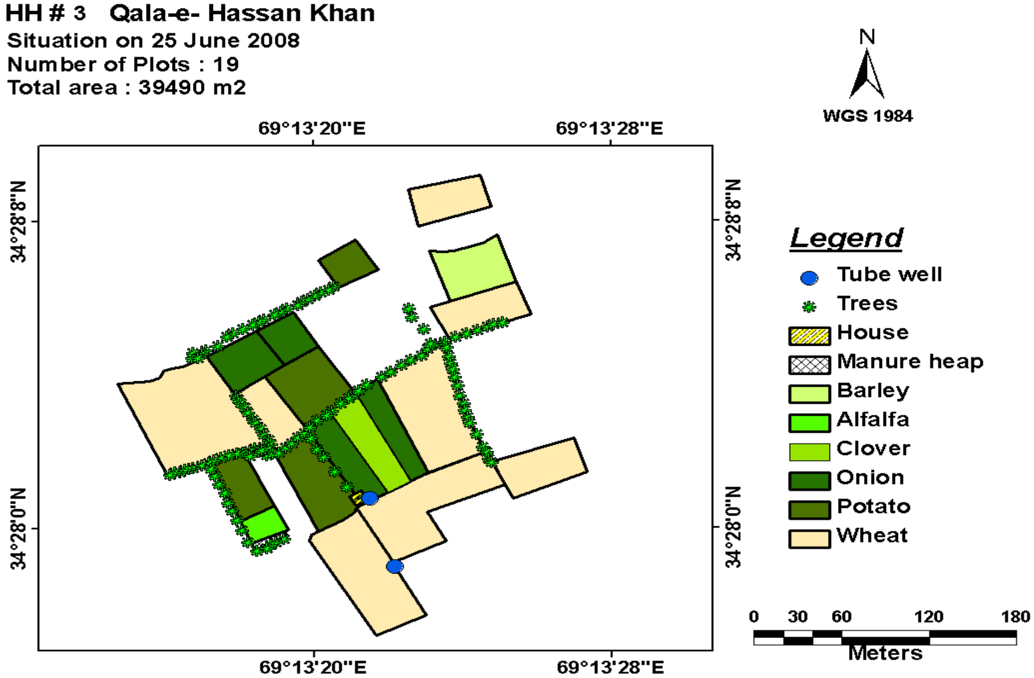


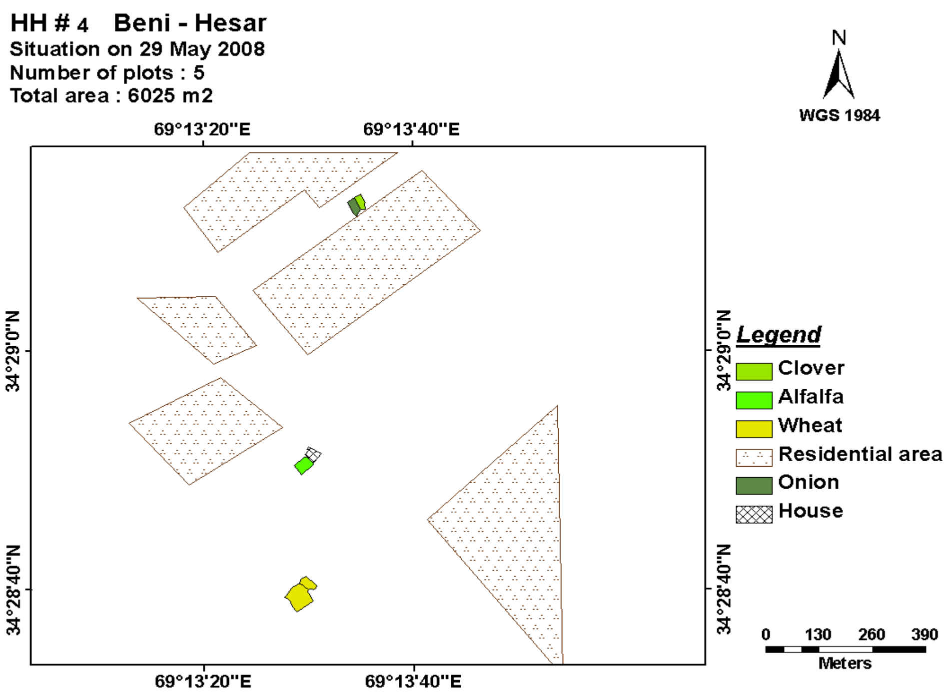
Annex VII. GIS based edited map indicates farm of household 1 (HH-1) Haji Mir Ahamad, (HH-2) Fazal Haq, (HH-3) Bismellah, (HH-4) Husamuddin, and (HH-5) Dr. Muhammad Ishaq in urban and peri-urban agriculture (UPA) of Kabul, Afghanistan.



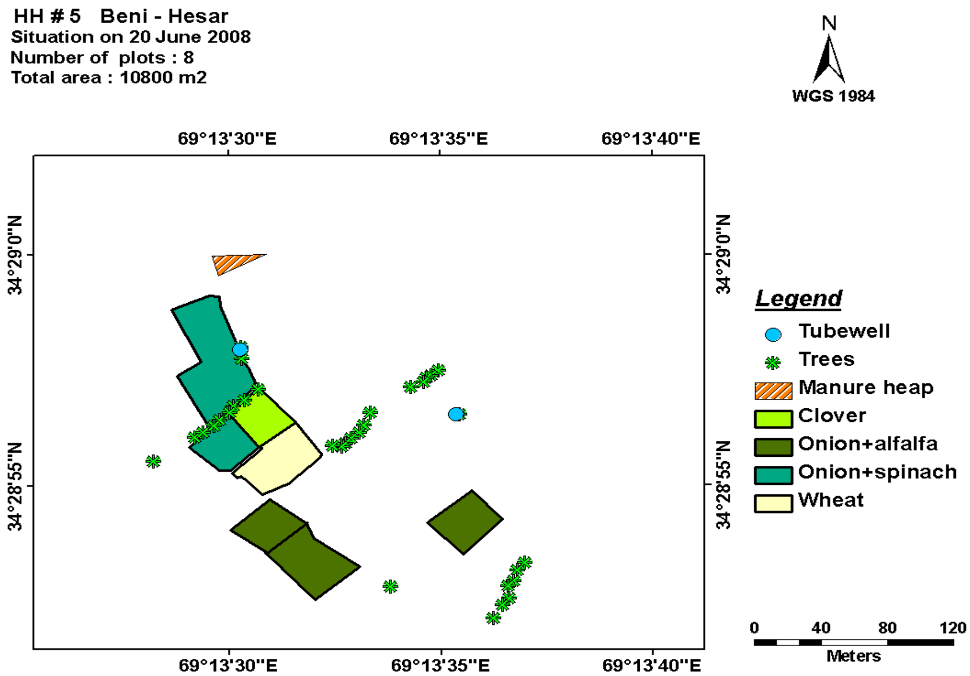


Annex VII. Continued

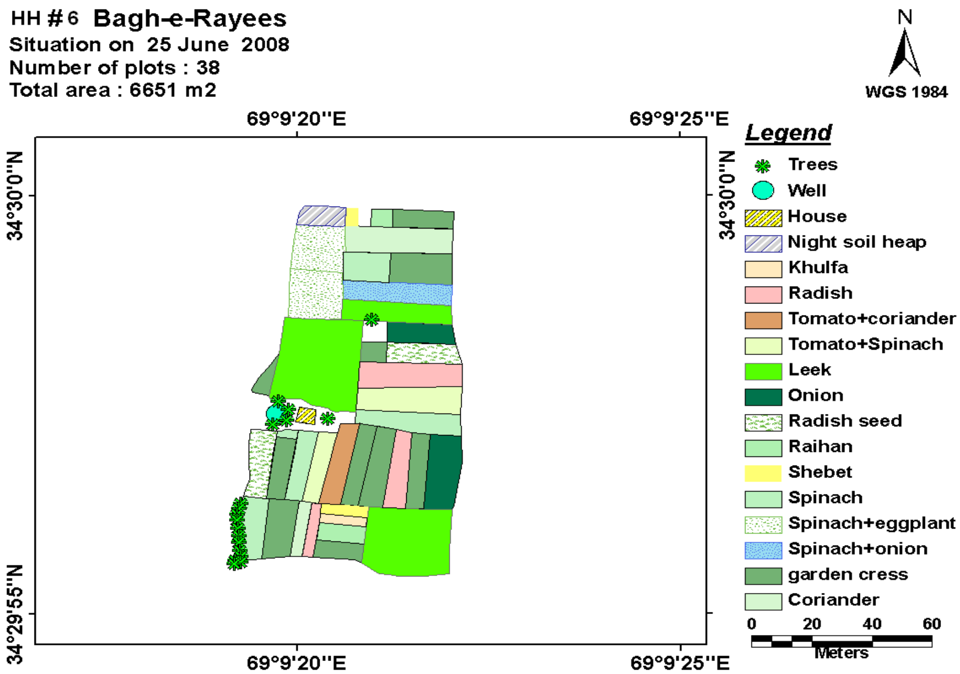


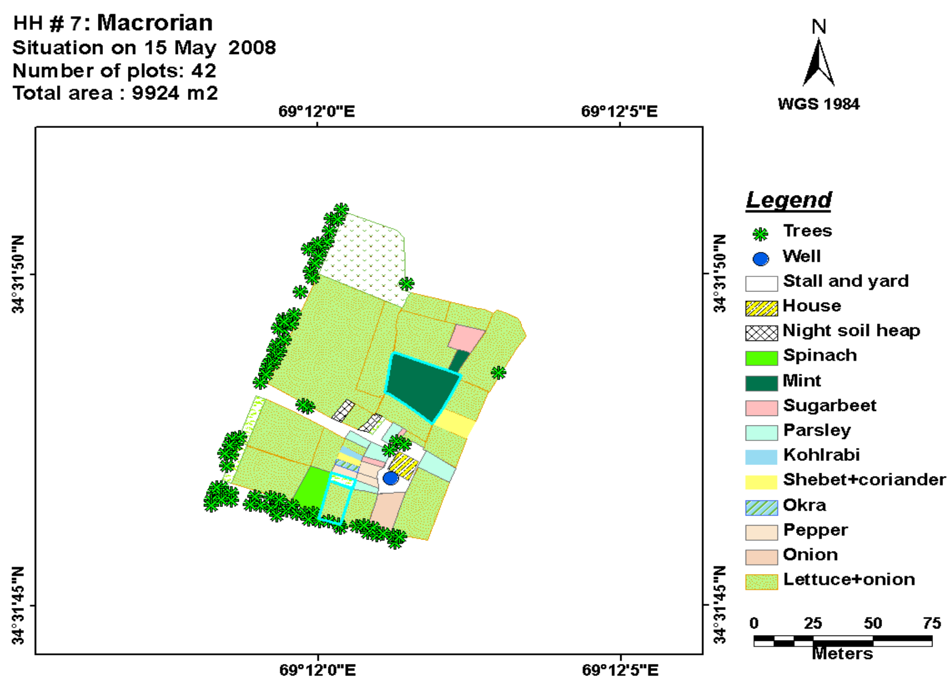


Annex VII. Continued

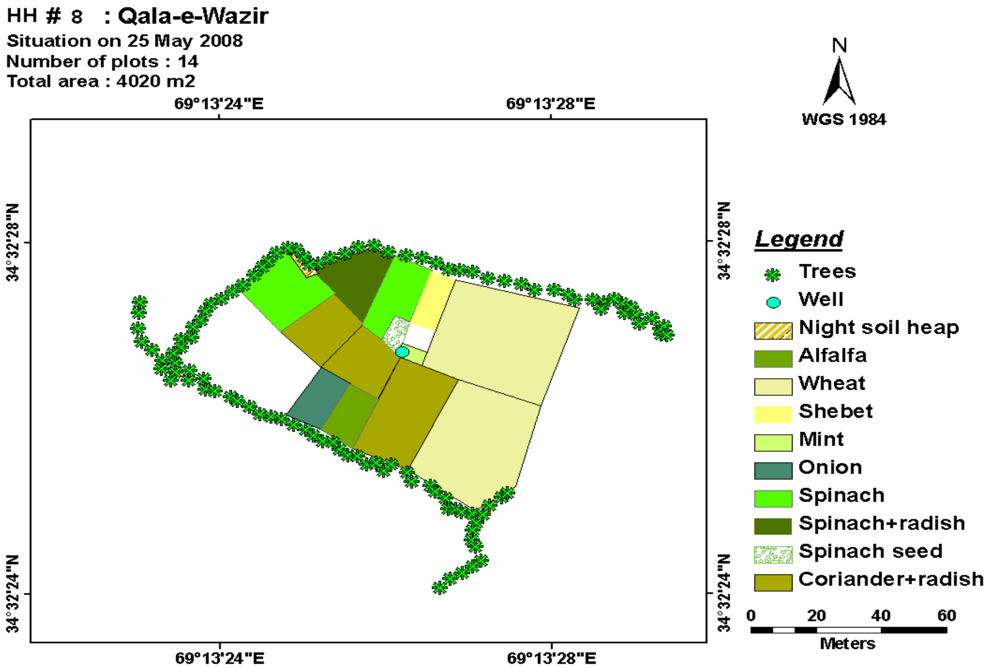


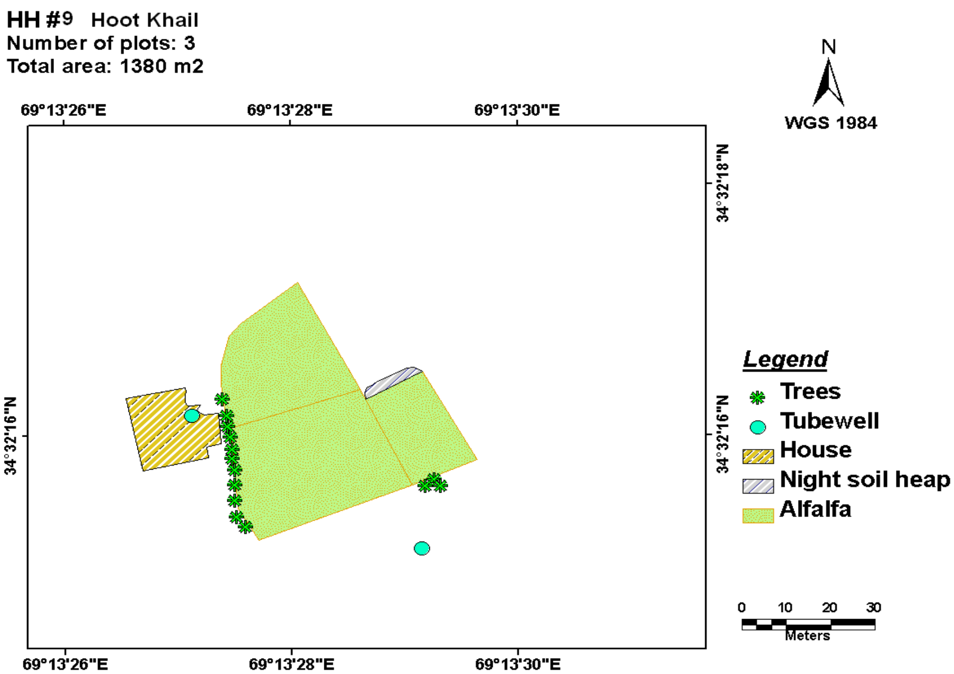
Annex VIII. GIS based edited map indicates farm of household 6 (HH-6) Muhammad Alam (HH-7) Aqa Sherin, (HH-8) Tela Muhammad, (HH-9) Muhammad Tahir, and (HH-10) Muhammad Aqa in urban and peri-urban agriculture (UPA) of Kabul, Afghanistan.



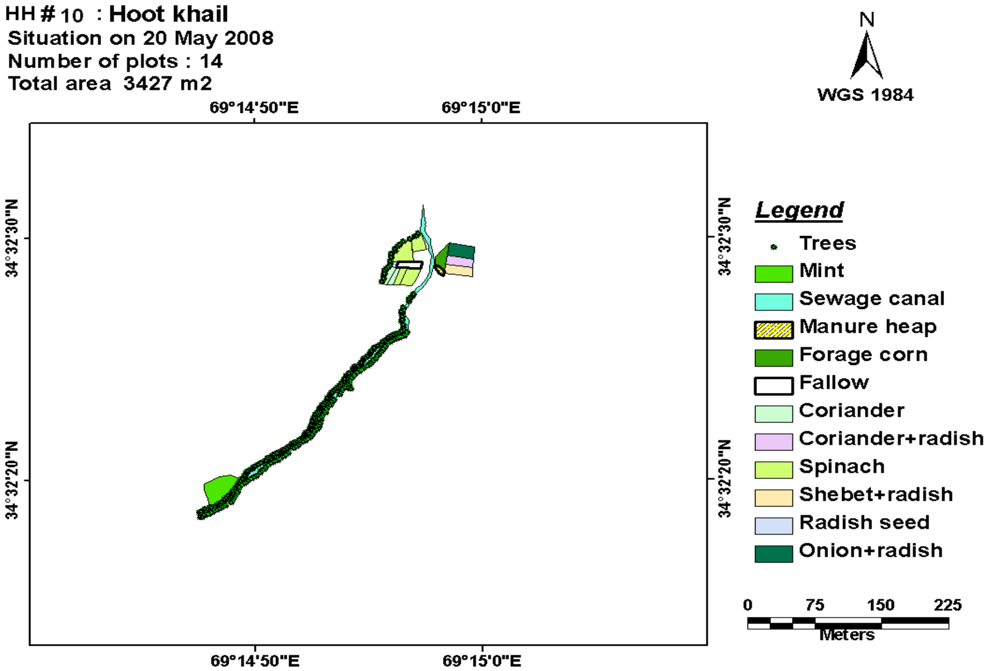


Annex VIII. Continued

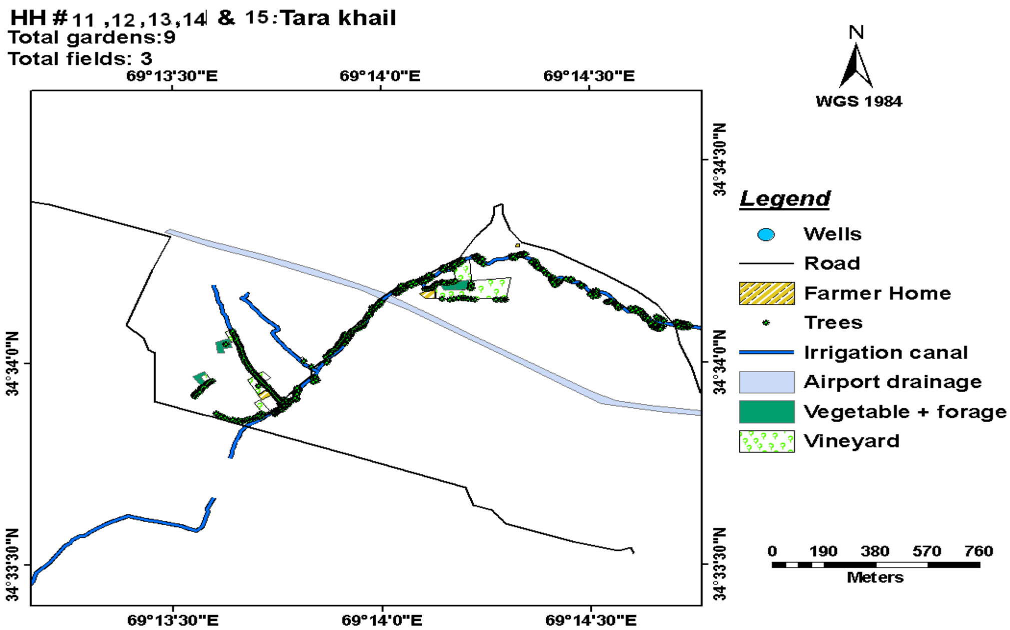




Annex VIII. Continued



Annex IX. GIS based edited map indicates farm of household 11 (HH-11) Abdullah, (HH-12) Muhammad Nasir, (HH-13) Zulfuddin, (HH-14) Abdul Wahab, and (HH-15) Muhammad Asif in urban and peri-urban agriculture (UPA) of Kabul, Afghanistan.



Curriculum vitae

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Scientific educations and activity:

1980-1988 Secondary school (Mujahid High School) at NWFP Peshawar, Pakistan

1990-1994 BSc Nangarhar University, Nanagarhar, Afghanistan

2001-2002 MSc (Hons.) NWFP Agricultural University, Peshawar, Pakistan

2002-2007 Lecturer, College of Agriculture, Kabul University, Kabul, Afghanistan

Award and fellowships:

2001-2002 UNHCR/DAFI. (United Nations High Commissioner for Refugee/Deutsche Akademische Flüchtlingsinitiative Albert Einstein)

2003 DAAD (Deutscher Akademischer Austausch Dienst/ German Academic Exchange Service)

2006 USAID (United States Agency for International Development)

List of publications

Theses

Safi, Z. (2002). Intercropping wheat chick pea and rapeseed under non-irrigated condition. MSc thesis, NWFP Agricultural University, Peshawar, Pakistan.

Safi, Z.. Mohsini, Y. (2006). Effect of three levels of livestock and sheep manures on wheat's yield. College of Agriculture, Kabul University, Kabul, Afghanistan.

Articles published in national journals

Safi, Z., Mohsini, Y. (2005). Role of irrigation in agriculture development in Afghanistan. Ulum-e-Tabyee, Kabul University, Kabul, Afghanistan.

Safi, Z., Hamzakhyl, N. (2006). Making compost from local materials in our own farm. Ulum-e-Tabyee. Kabul University, Kabul, Afghanistan.

Scoyoc, G.V. (2006). How to prepare soil monolith, edits and translated to Dari (Safi, 2007). Ulum-e-Tabyee, Kabul University, Kabul, Afghanistan.

Abstracts and proceedings

Safi, Z., Schlecht, E., Buerkert, A. (2011). Horizontal matter fluxes and leaching losses in urban and peri-urban agriculture of Kabul, Afghanistan. (submitted)

Safi, Z., Buerkert, A. (2011). Heavy metal and microbial loads in sewage irrigated vegetables of Kabul, Afghanistan. (submitted)

Safi, Z., Dossa, H., Buerkert, A. (2011). Economic analysis of cereal, vegetable and grape production systems in urban and peri-urban agriculture of Kabul, Afghanistan. (submitted)

Affidavit

I assure that this dissertation was written independently and without non-permissible help and that I used no sources other than those specified in the dissertation. All quotations that have been extracted from published or unpublished sources have been marked as such. No part of this work has been used in other PhD processes.

Hiermit versichere ich, dass ich die vorliegende Dissertation selbständig und ohne unerlaubte Hilfe angefertigt und keine anderen als die in der Dissertation angegebenen Hilfsmittel benutzt habe. Alle Stellen, die aus veröffentlichten oder unveröffentlichten Schriften entnommen sind, habe ich als solche kenntlich gemacht. Kein Teil dieser Arbeit ist in einem anderen Promotionsverfahren verwendet worden.

Witzenhausen, 3rd March 2011 Zikrullah Safi