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学位論文の内容の要旨

Irrigation, an artificial application of water to agricultural fields, has been mainly practiced in arid and semiarid areas where natural rainfall is either inadequate or erratic to fulfil the water demand of the crops. Within this broad objective of irrigation development, it has been required to resolve food shortage or famine occurrences in many parts of the world and indeed it has significantly contributed to poverty alleviation, food security, and improving the quality of life of mainly rural populations. That is why some of the biggest countries in the world (India, China, and USA) highly depend on irrigated agriculture in order to self-secure the food demand of their people and for export purposes, too. Despite this fact, there are countries depending on unreliable rainfed agriculture while having enough surface water resources for development of irrigated agriculture and yet unable to utilize it due mainly to lack of enough capital, expertise, and other preconditions. The problem could have been addressed through basic support of the international community to enable such countries solve their problem through irrigation development instead of supplying food aid.

In the course of irrigation development, experiences have been gained that irrigation development has also negative side effects apart to its merits. Among these are salinization and degradation, rise of groundwater table and water logging, erosion and sedimentation, and water born health problems, which occur due to lack of monitoring and proper management of a scheme. Soil salinization is the most common negative side effect of improperly managed

irrigation schemes, which results into abandonment of cultivable lands while there are problems of population pressure and growth of food demand in the globe.

In this thesis the researches conducted in two case studies are mainly presented. The first one discusses about the need of promotion of irrigation development in Ethiopia and the second one discusses about the salinization problems in China, which lead to a common conclusion of harmonizing irrigation development and irrigation management.

With regard to the first case study, interpretations were made on recorded droughts, meteorology, and crop production data in order to relate the drought (food shortage) events, rainfed agriculture and available natural water resources in Ethiopia. Comparisons of effective rainfall (*Erf*) and crop water requirement (ET_o) were done for three cereal crops, one pulse crop and three vegetables in Ilalla, a representative drought prone area located in Tigray, Ethiopia at latitude of 13° 5′ N and longitude of 36° 6′ E. In addition, the possibility of promoting microcatchment water harvesting was assessed in the same area.

It was analyzed that the recurrent droughts in Ethiopia have occurred from 1543 to 2002 with a mean interval of 20.9 years. Moreover, the mean intervals for five consecutive drought years had declined from 62.2 years in 1543 through 1876 to 4.8 years in 1983 through 2002. High dependence on rainfed crop production has been one of the most attributors for food insecurity and famine in Ethiopia as lesser effective rainfall (*Erf*) was obtained in most of the time as compared to crop water requirement (*ETc*). The annual production of cereals decreased from 0.18 in 1961 to 0.12 metric tons per capita in 2002. Rainfed agriculture is incapable of shouldering the growing food demand of the people and consequently the food shortage in the future will be worse in the absence of appropriate measures. The country has however unutilized (95%) water resources and (95.4%) land resources for irrigation. In addition, encouraging result of *CCR* of 1:1 was obtained for maize, cabbage, bean, and wheat in Ilalla area. Therefore, to solve the shortage of food and famine in Ethiopia on sustainable basis, promotion of well planned irrigation schemes integrated with microcatchement water harvesting technologies is perhaps the only available alternative. The support of international community in terms of capital and technical advisory is highly demanded towards irrigation development instead of awaiting to contribute food aids during famine events.

With regard to the second case study, collection of groundwater and soil salinity parameters were conducted at field in the eastern block of Luohui irrigation scheme located in Tali county, Shaanxi province of China at latitudes of 34° 45′ 23′′ to 34° 56′ 05′′ N and longitudes of 109° 45′ 22′′ to 110° 10′ 23′′ E. The collected field data were analyzed at laboratory in order to identify and classify the salinization processes going on in the study area. The irrigation scheme consists of about 80 groundwater wells, which

serve as measurement points and used for agricultural and nonagricultural purposes. The measured field data at each groundwater well consisted of electrical conductivity of groundwater (EC_w), pore water salinity of surface soil (EC_p), moisture content of surface soil (MC), groundwater depth, surface elevation and geographic coordinates. Water samples from each well and soil samples from topsoil (depth of 0 to 10 cm) were also collected for laboratory analysis. Then, ions of the water and soil samples were measured using an ion analyzer and atomic absorption spectrometry. All results were interrelated and analyzed. Accordingly, the identified main salinization processes in the study area are: 1) salinization due to capillary water rise as higher salinity (up to 21 dS m^{-1}) was investigated within 3 m groundwater depth, as relatively higher correlation coefficients between water salinity and soil salinity were obtained for less than 3 m groundwater depth, as the area is dominantly (63%) covered by loam textured soil and as the area gets little average rainfall (513.6 mm y^{-1}) while having about threefold average potential evaporation (1689.3 mm y^{-1}); 2) due to use of saline ground water for irrigation as agreements between water salinity of some of the irrigation wells and soil salinity were observed. Besides, according to FAO index, significant potential yield reductions were estimated for the case of salt-sensitive crops by considering the use of saline groundwater for irrigation; 3) due to dumping and compacting dug soil of well sinking in the field indicated by higher EC_p and MC at specific spots nearby the groundwater wells and local information; and 4) due to variation in surface topography and drainage as an increasing concentration of salinity was investigated along the downstream direction of the drainage lines and as higher salinity was observed in the areas having poor drainage condition.

The suggestions for preventing salinization processes in this area include lowering the groundwater table by installing effective drainage system, controlling dumped saline soil in the fields and managing the use of saline irrigation water. The central and northern parts of the scheme need prior focus for further investigation, as water salinity and soil salinity were more or less concentrated at these parts of the scheme. Besides, these areas as well as the northeast part of the study area need further follow up and investigations pertinent to sodification problem.

In a nutshell, the research outputs obtained from the case studies of the two countries can be merged into a theme of "Irrigation development and management". The core idea of "Irrigation development and management" is that countries which have already developed as well as in need of developing their potential water and land resources for irrigated agriculture need to give due focus to the management aspect throughout the lifespan of the scheme to attain its objectives and meet sustainability. Otherwise it would be a vicious circle of problems of lack of irrigation development in one hand and abandonment of

cultivable lands due to salinization problem in the other hand, which all lead to the problem of food shortage.

論文審査の結果の要旨

灌漑は，自然降雨が不十分かもしくは偏った降雨パターンにより作物の用水需要量を満たせない乾燥地・半乾燥地において，主に行われてきた．灌漑開発は，世界の多くの地域における食料不足や飢饉の発生問題を解決するという広範囲に及ぶ目標が掲げられてきた．そして，実際に貧困の緩和や食料の安全保障，主に農村の人々の生活水準の向上等に大きく貢献してきた．しかし，灌漑開発に必要な地表水に恵まれながら，資本，専門技術，その他の条件が不十分なため，信頼性の低い天水農業に依存している国は多い．これらの国にとっては，まず灌漑開発を優先的に先行させることが最も重要である．しかしながら，食料問題解決のための最重要施策として実施された灌漑開発が，完成後その管理が不適切なため，「正の効果」以上に「負の効果」を発揮する事例は多くみられる．「負の効果」の具体例として，ウォーターロギング，塩類集積，侵食，堆砂，水が媒介する病気による健康被害などが挙げられるが，これらは事業の監視と管理が不適切なため起こるものである．農地の塩類集積は，不適切な管理が行われている灌漑地区にみられる最も一般的な「負の効果」であり，地球上で人口圧と食料需要の増大に伴いますます灌漑開発が推進される一方で，灌漑農地の耕作放棄が進行しつつある原因のひとつである．本研究では，この問題に着目し灌漑開発と灌漑管理の必要性と両者の調和について論究した．前者の事例として，水資源に恵まれながら灌漑開発が進まず，食料不足に悩むエチオピアを，後者の事例として，灌漑農業は展開されているものの塩類集積に悩む中国内陸部の灌漑地区をそれぞれ取り上げた．

最初のエチオピアにおける事例研究は，同国の最重要課題である人口増加に見合う食料自給の早期達成に必要な要件について論じた．まず，世界的に注目されている干ばつの発生傾向について分析した．干ばつは周期的に起こっており，５年以上連続して起こる大干ばつの発生間隔は，19世紀以前では平均62年であったが，最近20年間では4.8年に大幅に短縮していることが判明した．このことから，適切な対策をとらなければ，その被害はますます甚大になることが予想される．次に，天水条件下での，主要作物の水需給環境について検証した．その結果，ほとんどの作物はその生育時期において，作物用水量（ET_c）が有効雨量（Erf）を上回っており，天水に大きく依存した作物栽培こそが同国における食料不安と飢饉の最大の原因のひとつであることを解明した．国民１人当たりの年間穀物生産量は，最近40年間に60 kgも減少しており，天水農業では増加する食料需要を賄うことは不可能であり，適切な対策をとらない限り食料不足は将来的にさらに悪化することとなる．この事例研究の主な提案は，食料援助に依らないで食料自給を達成し，国民の栄養状態を改善するために，利用可能な土地資源と水資源（各未利用分95%）を，例えばその30%，50%，75%と中長期目標を設定して開発し，灌漑農業を推進することである．加えて，マイクロキャッチメント型ウォーターハーベスティングは降雨量が作物用水量に比べて不十分な場合は，作物生産の改善に有効であることから，その普及を適切に進める必要がある．飢饉のたび

ごとに食料援助を待つのではなく，灌漑開発を進めるための資金と技術援助に対する国際社会の支援が強く望まれる．

次に，開発後「負の効果」に悩む事例研究については，中国陝西省大荔県に位置する洛恵渠灌漑地区の洛東区 3.2 万 ha を研究対象地区とし，約 80 観測点の地下水および土壌データを定期的に観測・収集し分析を行った．分析結果から対象地区で進行している塩類集積過程と原因の究明を行った．各観測井で観測した現地データは，地形的位置データ，地下水位，地下水の電気伝導度（EC_w），井戸周辺土壌（表土）間隙水の EC (EC_p)，表土の体積含水率（MC)等である．この結果，研究対象地区における主な塩類集積過程は，1) 地下水の毛管上昇による塩類集積，2) 塩分濃度の高い地下水を継続して灌漑利用したことにより生じた塩類集積，3) 井戸の掘削残土（高塩分濃度）を圃場面に締固め盛土したことによる塩類集積，4) 地区内の地形特性および排水特性に起因して起こる排水不良部の塩類集積，に分類できることが提案された．以上のことから，この地区における塩類集積過程を防ぐ対策として，効率の良い排水システムの構築による適正な地下水位の制御，塩類濃度の高い地下水利用の制限，塩類濃度の高い掘削土の圃場への無秩序な投棄の防止，地表排水阻害箇所の修復・整備などが挙げられる．対象地区の中央部と北部は EC_w と EC_p ともに高いことから，より詳細な追跡調査が必要である．さらに，中央部と北部に北東部を加えた地域では，今後ナトリウム化に対するさらなる継続調査が必要と考えられる．

これら２箇国における事例研究で得た成果は，「灌漑の開発と管理」というテーマで統合することができる．「灌漑の開発と管理」の中核的使命は，その利用可能な水資源，土地資源を灌漑農業のために開発することを必要としている国と先進国が，事業のライフスパンを通して，管理面にしっかりと照準を合わせることにより，はじめてその目的を達成し，持続可能性を満たすことができる．さもなければ，一方では劣悪な灌漑開発と，もう一方では塩類集積問題に伴う可耕地の耕作放棄そして最終的には食料不足問題を誘発するという悪循環が形成されることになる．

本研究で得られた包括的な成果は，半乾燥・食料不足地域における灌漑開発と灌漑管理技術の発展に大いに寄与するものと期待される貴重な知見であり，学位論文として十分な価値を有するものと判定した．