Lowland Soils for Rice Cultivation in Ghana

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1. Introduction

In Ghana lowlands mostly comprising floodplains and inland valleys occur throughout the whole country. These lowlands have been characterized to be heterogeneous in morphology, soil type, vegetation and hydrology. Lowland soils therefore occur across all the agro-ecological zones of the country. These agro-ecological zones include the drier Savannahs (Sudan, Guinea and Coastal) which cover the northern and coastal parts and the Forest which covers the western, central and eastern corridors of the country. According to estimates, the country has over one million hectors of lowlands (Wakatsuki et al, 2004a, b) which can be developed for effective and sustainable rice cultivation, beside the pockets of areas used for dry season vegetable production.

In the Savannah agro-ecological zones rice cultivation is common due to the presence of abundant poorly drained lowlands. These soils are deep sandy loams to clay loams and abundant water resources from the major rivers, comprising the Volta, Oti, Nasia, Daka, Kulda and their numerous tributaries that could be tapped for irrigation. The soils are developed over shale / mudstone, sandstone, granites and phyllites (Adu, 1995a, 1995b, 1969; Dedzoe et al, 2001a & b). They include *Kupela* (Vertisol) and *Brenyase* (Fluvisol) series occurring over granite, *Pale* series (Gleysol) occurring over Birimian schist, *Lapliki, Siare* and *Pani* series found on floodplains of major rivers and *Lima* and *Volta* series developed over shale and mudstone. The most commonly used soils for rain-fed rice production in the Savannah agro-ecological zone include the inland valley soils occurring within the shale / mudstone areas of the Voltaian Basin. Under irrigation, soils found on the old levees of the Volta and Nasia rivers, *Lapliki* series, are highly suitable.

The Savannah agro-ecological zones experience the lowest rainfall (< 1000mm) amounts for the year. There is only one growing season, commonly referred too as the rainy season. The rainy season starts when the rains commence from May/June and ends in September/October. A long dry period is experienced from November to April. Temperatures are normally high and quite uniform throughout the year. Average monthly temperatures range from 25^{o} to 35^{o} C.

The Forest agro-ecological zones on the other hand, experience relatively higher rainfall amounts (> 15000mm per annum) with a bimodal pattern. The major season rains occur between March and mid-July with a peak in May/June. There is a short dry spell from mid-July to mid-August. The minor rainy season starts from mid-August to about the end of

October with a peak in September. A long dry period is experienced from November to February with possibilities of occasional rains. The rains appear to be nearly well distributed throughout the year, with amounts considered adequate for crop production occurring in the two peaks. Temperatures are normally high throughout the year with very little variations. The mean monthly temperatures range from 25^{o} C in July/August to 29^{o} C in March/April.

Agriculture is the dominant land use for these lowlands. Across the country, the lowlands are commonly cultivated to rice and sometimes to vegetables. Within the forest ecology, maize, cocoa, oil palm, plantain and citrus are also cultivated in these areas, while maize, sorghum and millet are also cultivated within these lowlands in the Savannah agro-ecological zones. With increasing intensity in use, there is the need for the development of technologies that will ensure the sustainable use of these lowlands, particularly for rice production. This chapter is therefore describing the nature of lowland soils in Ghana, their suitability for rice production and possible effective measures that need to be put in place for their sustainable use. Possible areas for further research are also provided.

2. Soil types

2.1 Soils of Savannah agro-ecological zones

The most extensive lowland soils in the Savanna agro-ecological zones are *Lima* and *Volta* series, which originate from shale and mudstone. *Lima* series is the most extensive, followed by *Volta* and *Changnalili* series respectively (Dedzoe et al, 2001a & b; Senayah et al, 2001). These soils occupy a generally flat (0-3% slope), broad and very extensive lowland plains that are generally suitable for mechanization. In a catena, the fringes of the valley adjoining the upland is occupied by *Changnalili* series (Stagnic Plinthosol), followed by *Lima series* (*Endogleyi–Ferric Planosol*) and with the *Volta* series (*Dystric or Eutric Gleysol*) occurring closest to the stream bed. A general description (Senayah et al,) of some of these soil series are as given below.

2.1.1 Lima series (Endogleyi – Ferric Planosol)

The profile description of *Lima series* is presented in Table 1. *Lima* soils are deep (>140 cm) and imperfectly to poorly drained. At the peak of the wet season, they are flooded intermittently, depending on the duration or breaks in the rainfall. Topsoil textures are loam, silt loam or sandy loam and the underlying subsoil textures range from sandy clay loams to clays.

2.1.2 Volta series (Dystric or Eutric Gleysol)

Table 2 shows a typical profile description of the *Volta series*. *Volta soils* are also very deep (>150 cm) and poorly drained. They occur close to streams or in depressions as compared to Lima. Textures are heavier and they are flooded for much longer periods than Lima soils. Topsoil textures are mainly silt loams and silt clay loams and in the underlying subsoil, silt clays and clays. The limitation of this soil is the difficulty of working when it is wet or dry. When wet, it is very sticky and easily gets stuck to implements and very hard when dry.

2.1.3 Lapliki series (Abrupti-Stagnic Lixisol)

Lapliki series is developed from mixed alluvial deposits and occur above flood plains. Unlike the *Volta* and *Lima* series, it is seldom flooded. It could be used under irrigation. The soil is moderately well to imperfectly drained and occurs on middle to lower slopes. *Lapliki* series has a topsoil of grayish brown to light grey sandy loam, which is usually less than 30 cm thick. This grades into brownish yellow compact sandy clay loam below 30 cm and in turn overlies several meters of yellowish brown, mottled red sandy clay loam or sandy clay.

Horizon	Depth (cm)	Description
Ap	0- 23	Dark grayish brown (10YR 4.5/2) to light brown (7.5YR 6/3); few brownish yellow mottles; sandy loam; weak fine and medium granular; loose
Eg	23 - 36	blocky; friable. yellowish brown (10YR 5/4); many (15%) distinct brownish yellow mottles; sandy clay loam; weak fine and medium sub-angular
Btg c	36 – 68	Light yellowish brown (10YR 6/4); many (20%) distinct brownish yellow and yellowish red mottles; clay loam to clay; weak to moderate fine, medium and coarse sub-angular blocky; slightly firm to firm; many (20%) iron and manganese dioxide concretions.
Btg	68 – 140	Light brownish grey (10YR 6/2); common (10%) distinct dark red mottles; clay; strong medium prismatic; very firm; common (10%) iron nodules

Table 1. Profile description of a typical *Lima* soil series (FAO/WRB: *Endogleyi-Ferric Planosol*)

Fig. 1.a. Typical profile of *Lima* soil series (FAO/WRB: *Endogleyi-Ferric Planosol*)

Horizon	Depth (cm)	*Description*
Apg	0 – 35	Dark grayish brown (10YR 4/2); few distinct brownish yellow mottles; silt clay loam; moderate fine and medium sub-angular blocky; friable to slightly firm; very few (<3%) iron concretions
Bwg 1	35 – 60	Grayish brown (10YR 5/2); common distinct brown mottles; silt clay; moderate fine and medium sub-angular blocky; slightly firm; few (3%) hard iron and manganese dioxide concretions
Bwg2	60 – 116	Grayish brown (10YR 5/2; common (10%) distinct dark red and yellowish brown mottles; clay; moderate fine and medium sub-angular blocky firm; common (10%) iron and manganese dioxide concretions

Table 2. Profile description of a typical *Volta* soil series (FAO/WRB: *Eutric Gleysol*)

Fig. 2.a. Typical profile of *Volta* soil series (FAO/WRB: *Eutric Gleysol*)

2.2 Soil of forest agro-ecological zones

Soils within the forest agro-ecology, on the other hand, are developed from the Lower Birimian rocks. The soils fall under the Akumadan – Bekwai / Oda Complex and Bekwai – Zongo / Oda Complex associations (Adu, 1992). The lower slope is occupied by imperfectly drained gravel–free yellow brown silty clay loams, *Kokofu series,* which are developed from colluvium from upslope, *Temang series* which are gray, poorly drained alluvial loamy sands and *Oda series* which are clays occupy the valley bottoms. Most of the major streams are flanked by low, almost flat (0 – 2%) alluvial terrace consisting of deep, yellowish brown, moderately well to imperfectly drained silty clay loams, *Kakum series.* The Bekwai – Zongo / Oda complex association also consists of Bekwai, Nzima, Kokofu, Temang, Oda and Kakum series but in addition has a large tract of seepage iron pan soils called *Zongo series*. *Zongo* soils consist of sandy loam topsoil overlying yellow brown, imperfectly drained, clay loams containing ironstone concretions and iron pan boulders in the subsoil. On the other hand, *Nzima* soils are characterized by a high content of stones and gravel in some places resulting from the break up during weathering of veins and stringers of quartz injected into the phyllite. This results in the formation of the *Mim series.* A brief but general description of these soils includes:

2.2.1 Mim series (Ferric Acrisol)

Mim series is a moderately well to well drained soil found on middle slopes of 5-8%. The topsoil is dark reddish brown sandy loam. This overlies many to abundant (40-80%) quartz and stones in a reddish brown clay loam soil. This soil differs from the *Nzima series* by the higher gravel and stone content in the subsoil. Its effective depth is determined by the amount of quartz gravel and stones, where it becomes so abundant that there is only little soil material which varies between 30 and 60cm depth.

2.2.2 Zongo series (Plinthosol)

Zongo series is a moderately well to imperfectly drained soil, found on middle to lower slopes. The topsoil is dark grey sandy loam. The underlying subsoil is pale brown sandy clay loam containing ironstone gravel from 40cm, which increases with depth from many (15-40%) to abundant (40-80%).

2.2.3 Kakum series (Gleyic Lixisol)

Kakum soils are very deep (> 150cm), imperfectly to moderately well drained, occurring on the slightly raised old alluvial flats along the banks of major rivers/streams. The profile consists of dark brown, weak granular friable sandy loam at the topsoil. The subsoil is yellowish brown and faintly mottled, strong brown friable clay loam and a structure that is weak to moderate fine and medium sub-angular blocky granular. Below 100cm, the mottles become prominently reddish yellow.

2.2.4 Kokofu series (Gleyic Lixisol)

Kokofu series is found below *Nzima series* and occupies lower slope sites with slope gradients of 1-3%. It is developed from colluvial material from upslope. The soil is deep, non gravelly and moderately well or imperfectly drained. The topsoil consists of dark brown friable silt loam. The underlying subsoil consists of yellowish brown silt clay loam, faintly mottled yellow

2.2.5 Temang series (Haplic Gleysol)

This soil is developed from alluvial material and occupies the valley bottoms of 0-1% slope and depressions that are subjected to water-logging during the rainy season. The soil is deep and poorly drained. The topsoil consists of brown, faintly mottled dark yellowish brown friable loam. The underlying subsoil is pale brown to light brownish grey friable sandy loam with dark yellowish brown mottles.

Fig. 3. Typical *profile of Nta* soil series (FAO/WRB: *Eutric-Gleysol*)

Horizon	Depth (cm)	Description
Apg	0-6	Dark grayish brown (10 YR 4/2) with clear smooth rusty mottles, moderate sub-angular blocky with a sandy loam texture
Bacg	6-17	Dark grayish (10 YR 3/2) with clear waxy yellow mottles, moderate granular and sandy loam in texture
Bcg	17-34	Grayish (10 YR 6/2) with clear smooth yellow mottles, moderate crumbly and sandy loam in texture
Bcg2	34-75	Grayish (10 YR6/1) with clear smooth rusty mottles, fine granular with a sandy clay loam texture
Cg1	75-89	Grayish (10 YR 6/2) with clear smooth rusty mottles, moderate crumbly and sandy clay loam
Cg2	89-140	Grayish (10 YR7/1) clear smooth rusty mottles, fine granular and a sandy clay loam texture

Table 3. Profile description of typical *Oda* soil series (FAO/WRB: *Eutric-Gleysol*)

Fig. 4. Typical profile of *Oda* soil series (FAO/WRB: *Eutric-Gleysol*)

3. Some research findings

3.1 General fertility status of lowland soils in West Africa

Across the sub-region, various studies (Issaka et al, 1999a, b, 1997, Buri et al, 1996, 1998, 2000, 2006) have shown that lowlands are generally low in soil fertility with wide variations in fertility levels across the different and varied agro-ecological zones. Soil fertility levels as compared to other regions of the world showed the sub region to be quite deficient in available phosphorus and relatively lower in the basic cations particularly calcium and potassium, thus reflecting lower levels of eCEC. Thus soils of West African lowlands in general are characteristically low in basic plant nutrients.

3.2 General fertility status of lowland soils in Ghana

3.2.1 Soil reaction

In Ghana, soil pH within the drier Savannah agro-ecological zones, particularly both the *Volta* and Lima series are strongly acid (mostly < 5.0). Topsoil pH ranges from strongly acid to neutral for *Lapliki* series. However, pH of lowlands within the Forest agro-ecological zones is relatively uniform. Soil pH is slightly higher and generally greater than 5.5. Even though some of the soils within this zone are relatively acid, this is on a limited scale. Exchangeable acidity is also relatively higher within the savannah agro-ecology (mean = 1.0 cmol (+) kg^{-1}) which can adversely affect basic cation balances particularly Ca and Mg leading to adverse effect on rice growth. However, generally and under reduced conditions, pH levels may not pose any serious problem for rice production, since hydromorphic or reduced conditions under rice cultivation tend to favour and enhance pH increases.

3.2.2 Total carbon and nitrogen

Within the forest agro-ecological zones, lowland soils have low to moderate levels of organic carbon. Organic Carbon levels could be as low as 4 g kg^{-1} at some sites and rising to 37g kg^{-1} at some locations. Mean levels are around 12.0 g kg^{-1}. However, within the savannah agro-ecology, organic carbon levels are comparatively lower with general mean levels around 6.0 g kg^{-1} with a 50% coefficient of variability across locations. *Volta* series shows relatively higher organic matter content (13-22 g kg^{-1}) than *Lima* series (8-19g kg^{-1}) within the topsoil. In the same vein total Nitrogen levels show a similar trend to that of Carbon, being slightly higher for the forest than the savanna agro-ecological zones. Total Nitrogen has a mean value of 1.1g kg^{-1} within the forest agro-ecology with very little variability. The savannah zones show much lower levels of total Nitrogen with much lower variability compared to the forest ecology. Mean levels across locations is lower than 0.7g kg^{-1}.

3.2.3 Available phosphorus (P)

Available P is generally very low for all the soil types and across all agro-ecological zones (Buri et al, 2008a, b). Available P is the single most limiting nutrient. It varies very greatly across locations within the forest agro-ecological zones. Mean levels within the Forest is about 5 mg kg^{-1} but varied very greatly (CV > 90%). Within the Savanna zones, mean available P levels for lowlands is even lower and also varies significantly (CV > 60%). Mean level is about 1.5 mg kg^{-1}. Under hydromorphic conditions, P utilization and availability is enhanced. This makes current available P levels very inadequate and therefore very limiting to the utilization of these lowlands for rice cultivation due to its significant inlake.

3.2.4 Exchangeable bases

Exchangeable cations (K, Ca, Mg) levels within the forest ecology are generally moderate to medium across most locations, even though they also vary significantly (CV > 60%). Exchangeable Potassium (K) has a mean value of 0.4cmol (+) kg^{-1}. Exchangeable Ca and Mg have mean values of about 7.5 cmol (+) kg^{-1} and 4 cmol (+) kg^{-1} respectively. Exchangeable Na levels are lower {mean = 0.32 cmol (+) kg^{-1}} but show much higher variability (CV > 80%). Effective Cation Exchange Capacity (eCEC) values within the forest agro-ecology are relatively moderate, a reflection of the moderate levels of exchangeable cations. Most lowlands within the forest are therefore relatively adequate in Ca, Mg and Na, but with some areas showing potential K deficiencies.

Exchangeable cation levels within the Savannah agro-ecological zones are, however, generally low when compared to those of the forest agro-ecological zone. Topsoil exchangeable calcium is moderate and relatively higher for *Volta* series {2.2-5.8 cmol (+) kg^{-1}}

than the Lima series {1.76-2.24 cmol (+) kg^{-1}}. Mean levels of exchangeable K {0.22 cmol (+) kg^{-1}}, Mg {0.9 cmol (+) kg^{-1}} and Na {0.11 cmol (+) kg^{-1}} are also quite low with coefficient of variability levels of over 74%, 90%, and 77% respectively. Effective cation exchange capacity levels are therefore relatively low across locations, indicative of the need to consider improving upon the levels of these nutrients under any effective and sustainable cropping program (Table 4).

3.2.5 Soil texture

Within the drier Savannah agro-ecological zones, lowland soils are relatively low in clay content. Most locations show less than 10% clay content but again with higher variability (CV > 60%). The soils, however, show appreciable levels of silt (mean > 60%) and are therefore mostly Silt loam in texture, with isolated areas being sandy loam. They occur abundantly and cover a greater part of the lowlands. The soils are generally deep but water retention capacity may be low due to low clay contents. Typical examples are as described earlier. Within the forest ecology, the soils are also relatively low in clay (mean = 13%). They also contain relatively higher levels of silt (mean > 50%). Some are deep while others are very shallow. Textures vary from sandy loam through silt loam to loam. The water retention capacity of these soils is better when compared to those of the savannah zones.

Parameter	Savannah agro-ecology (Ghana)	Forest agro-ecology (Ghana)	West Africa lowlands	Paddy fields of S. E. Asia
Sample (No.)	90	122	247	410
pH (water)	4.6	5.7	5.3	6.0
Total Carbon (g kg^{-1})	6.1	12.0	12.3	14.1
Total Nitrogen(g kg^{-1})	0.65	1.10	1.08	1.30
Available Phosphorus (mg kg^{-1})	1.5	4.9	8.4	17.6
Exch. Calcium {cmol (+) kg^{-1}}	2.1	7.5	2.8	10.4
Exch. Magnesium {cmol (+) kg^{-1}}	1.0	4.1	1.3	5.5
Exch. Potassium {cmol (+) kg^{-1}}	0.2	0.4	0.3	0.4
Exch. Sodium {cmol (+) kg^{-1}}	0.1	0.3	0.3	-
Effective CEC {cmol (+) kg^{-1}}	4.4	12.7	5.8	17.8
Clay (g kg^{-1})	66	127	230	280

Table 4. Soil nutrient levels of lowlands in Ghana in comparison with West Africa and paddy field of South East Asia

Research further shows that productivity of these soils can be improved and sustained when water and nutrient management structures are put in place. Buri et al, (2004) observed that, soils of lowlands in Ghana respond significantly to the application of soil amendments like farm organic materials and mineral fertilizer. The authors observed that, applying 7.0 t ha^{-1} of poultry droppings gave similar rice grain yields as the full dose of recommended mineral fertilizer of 90kg N, 60kg $P_2O_5$and 60kg K_2O per ha or a 50% dose of recommended mineral fertilizer rate and 3.5t ha^{-1} of poultry droppings combined. Furthermore application of cattle dung or rice husk resulted in significant increases in rice grain yield over the control. In a similar study, Issaka et al, (2008) also reported significant increases in rice grain yield with improvement in water management and land preparation. Rice grain yield increased significantly in the order: farmers practice < bunded only < bunded and puddled < bunded, puddled and leveled. The introduction of improved soil, water and nutrient management, to some selected farmers resulted in significant increases in total rice grain production. Mean rice grain yields among such farmers compared to the national mean is presented in Table 4. There was an increase in yield ranging from 154% to 235% over the period 2003 to 2009. Such significant yield increases in rice grain could lead to improved and sustainable management of these lowlands, as enough revenue will be generated which can be re-invested in effective and proper soil management.

*National mean rice grain yield (t ha^{-1})

Year of Production	Grain yields under "Sawah" system (t ha^{-1})	National mean rice grain yield (t ha^{-1})	% increase as a result of "Sawah" adoption
2003	5.1	2.0	155
2004	5.6	2.0	180
2005	5.0	2.0	150
2006	5.7	2.0	185
2007	5.7	1.7	235
2008	6.0	2.3	161
2009	6.1	2.4	154
Mean	**5.6**	**2.1**	**167**

*source – Ministry of Food and Agriculture, Ghana

Table 5. Mean rice grain yields under the "Sawah" system compared to the national mean in Ghana

4. Conclusions

On the basis of generally observed nutrient levels and heterogeneous nature, lowland soils in Ghana are deficient in most basic nutrient elements which vary considerably from location to location. Site specific nutrient management options are therefore recommended. However, nutrient deficiency limitations can be corrected through improved organic matter management, additions of mineral fertilizers, integrated soil fertility management methods and adoption of sustainable and improved rice production technologies (e.g. "Sawah" system). The "Sawah" system which is intrinsic and conservative can help improve and/or maintain nutrient levels within these environments which will enhance sustainability. Considering the variable nature of lowlands, further research in soil, water and nutrient management (particularly organic matter) may be necessary for the development of specific suitable and sustainable technologies for the various ecologies. This will encourage and promote easy adoption for sustainability and increased productivity.

5. Recommended management practices

Lowland soils in Ghana are deficient in most basic nutrient elements which vary considerably across locations. These are soils with heterogeneous characteristics and therefore require different/varied management options. The major constraints to the use of these sites for rice cultivation include luck of proper land preparation methods, ineffective water management and low soil fertility. Generally, greater emphasis is laid on the development of improved planting material (varieties) to the neglect of the micro-environment in which the improved planting material will grow. Consequently, the high yielding varieties perform poorly because soil fertility cannot be maintained. This has led to farmers not realizing the full potential of improved rice varieties. There is the need for the integration of genetic and natural resource management. Therefore for the effective utilization of these lowlands, the development of technologies that will result in a balance between bio-technology (varietal improvement) and eco-technology (environmental improvement) should be promoted.

The provision of water management structures will greatly improve the utilization and nutrient management options of these lowlands. The development of technologies that will be easy-to-adopt and using affordable materials for water harvesting will make more farmers adopt water harvesting for use on their rice fields. This therefore calls for the development of technologies that will enhance water harvesting from small streams and springs that occur abundantly in these lowlands. Due to farmers inability to use the recommended amounts of mineral fertilizers, integrated nutrient management options are very necessary. The combined use of farm organic materials, mineral fertilizers and effective cropping systems will help improve soil fertility. The recycling of farm organic matter will be very useful. Farm organic materials may be used directly on rice fields or may be treated (composted, ashed, charred). The constant burning off of farm organic matter should be discouraged. Instead, farmers should be educated on how to do partial burning under special conditions.

The adoption of improved rice production technologies such as the "Sawah" systems will significantly lead to improved water and nutrient management. The concept and term

"Sawah" refers to man-made improved rice fields with demarcated, bunded, leveled, and puddle rice fields with water inlets and outlets which can be connected to various irrigation facilities such as canals, ponds, weirs, springs, dug-outs or pumps. Field demarcation based on soil, water and topography need to be considered seriously for the sustainable use of these lowlands. Site specific nutrient management options are therefore recommended. However, while nutrient deficiency limitations can be corrected through improved organic matter management, additions of mineral fertilizers and/or integrated nutrient management options, water management under current traditional systems is very poor. This tends to negatively affect both soil nutrient retention and availability for plant use. As a step towards improving water management, simple and cost effective management structures are necessary for harvesting surface water for temporal storage and use. Land preparation methods for rice cultivation should be improved to include the construction of bunds and leveling in addition to ploughing. The uses of heavy land preparation machinery such as tractors are not suitable for most lowlands due to their sizes, topography, wetness and nature of soils. The use of lighter and affordable land preparation machinery such as the power tiller (two wheel tractor) should be preferred.

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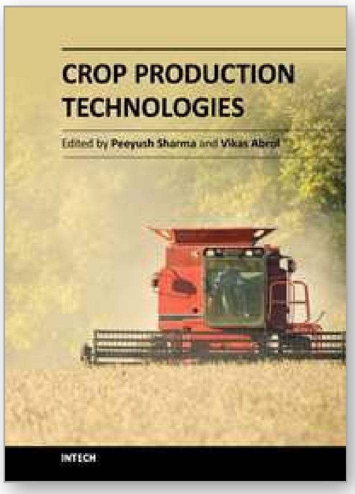

Crop Production Technologies
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Crop production depends on the successful implementation of the soil, water, and nutrient management technologies. Food production by the year 2020 needs to be increased by 50 percent more than the present levels to satisfy the needs of around 8 billion people. Much of the increase would have to come from intensification of agricultural production. Importance of wise usage of water, nutrient management, and tillage in the agricultural sector for sustaining agricultural growth and slowing down environmental degradation calls for urgent attention of researchers, planners, and policy makers. Crop models enable researchers to promptly speculate on the long-term consequences of changes in agricultural practices. In addition, cropping systems, under different conditions, are making it possible to identify the adaptations required to respond to changes. This book adopts an interdisciplinary approach and contributes to this new vision. Leading authors analyze topics related to crop production technologies. The efforts have been made to keep the language as simple as possible, keeping in mind the readers of different language origins. The emphasis has been on general descriptions and principles of each topic, technical details, original research work, and modeling aspects. However, the comprehensive journal references in each area should enable the reader to pursue further studies of special interest. The subject has been presented through fifteen chapters to clearly specify different topics for convenience of the readers.