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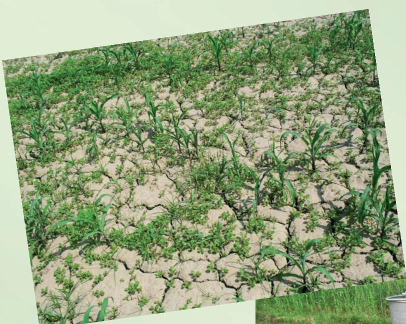
Towards a water and nutrient efficient forage production in semi-arid regions of Pakistan

Sami-Ul-Allah



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This work has been accepted by the Faculty of Organic Agricultural Sciences of the University of Kassel as a thesis for acquiring the academic degree of Doktor der Agrarwissenschaften (Dr. agr.).

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Defense day: 19 December 2013

Bibliographic information published by Deutsche Nationalbibliothek
The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data is available in the Internet at http://dnb.dnb.de.

Zugl.: Kassel, Univ., Diss. 2013
ISBN 978-3-86219-722-4 (print)
ISBN 978-3-86219-723-1 (e-book)
URN: http://nbn-resolving.de/urn:nbn:de:0002-37235

www.uni-kassel.de/upress

Printing Shop: docupoint GmbH, Barleben
Printed in Germany

Preface

This thesis is submitted to the Faculty of Organic Agricultural Sciences of the University of Kassel, Germany to fulfill the requirements for the degree Doktor der Agrarwissenschaften (Dr. agr.). This dissertation is based on three papers as first author and a list of the original papers including the chapter in which they appear in this dissertation will be given on the next page. A list of other publications (contributions to conference proceedings) is given in chapter 11.

The work presented in this manuscript was accomplished under the inspiring guidance and dynamic supervision of Prof. Dr. Michael Wachendorf, University of Kassel, Germany, who provided me an opportunity to improve my research skills and shared with a lot of his expertise & research insights. He frequently and unhesitatingly gave support and guidance in data analysis and scientific writing and was ready to discuss a huge number of issues whenever there was need.

I would also like to express my gratitude to my second supervisor Prof. Dr. Asif Ali Khan for his support and guidance during my field research. I also feel pleasure to thank Prof. Dr. Andreas Bürkert for his suggestions and comments for my research and for pre-reviewing my articles. Furthermore, I would like to thank Prof. Dr. Eva Schlecht for her suggestions and comments in the start of the study.

The working atmosphere in the Department of Grassland Science and Renewable Plant Resources has been very pleasant and encouraging during my stay here. Furthermore, huge thanks go out to the entire staff of the Department of Grassland Science and Renewable Plant Resources, especially to Dr. Thomas Fricke and Andrea Gerke, who managed most of the lab work and analysis of the data with me and to Sirgid Haber for administrative support. Thanks to Mr. Tariq for helping me in mapping the households of the study area and to Mr. Shoaib for his support during the field studies. Special thanks to Christian Möllmann and Kathrin Stenchly for the administrative support from the International Center for Development and Decent Work (ICDD).

A deep sense of appreciation is owed to all friends and colleagues from Pakistan for their close collaboration and encouragement. I owe a huge gratitude to my friends and colleagues in my working group, GNR at the University of Kassel-Witzenhausen, and to all my colleagues within the ICDD for the good time we spent together and their moral support.

I am deeply grateful to the German Academic Exchange Service (DAAD) for a scholarship and financial support for the field work within the ICDD at University of Kassel, Germany. I acknowledge the Fiat Panis foundation for providing funds for the laboratory work. I also acknowledge the Higher Education Commission (HEC) of Pakistan for allowing me to continue my studies at University of Kassel, Germany.

I don’t have adequate words to express my deepest sense of gratitude to my family members especially my parents and brothers for their eternal affection, support and encouragement during my academic career. They always supported me throughout my life to achieve the destination of higher education.

Witzenhausen, October 2013

Sami-Ul-Allah

List of papers

Chapter 5: Ul-Allah, S., A.A. Khan, A. Bürkert and M. Wachendorf. 2013. Socio-economic aspects and crop management in urban and peri-urban fodder production of Faisalabad. Pakistan Journal of Agricultural Sciences, Submitted.

Chapter 6: Ul-Allah, S., A.A. Khan, T. Fricke, A. Bürkert and M. Wachendorf. 2013. Effect of fertilizer and irrigation on forage yield and irrigation water use efficiency in semi-arid regions of Pakistan. Experimental Agriculture, submitted.

Chapter 7: Ul-Allah, S., T. Fricke, A.A. Khan, A. Bürkert and M. Wachendorf. 2013. Fertilizer and irrigation effects on forage protein and energy production under semi-arid conditions of Pakistan. Field Crop Research, accepted.

Dedicated

to

My Mother,

and

The memories of my Father (late)

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Abbreviations

ADF:	Acid detergent fiber
CCS:	Common cropping system
CL:	Crude lipid
CP:	Crude protein
DACS:	Drought adopted cropping system
DAS:	Days after sowing
DMY:	Dry matter yield
ESOM:	Enzyme soluble organic matter
FYM:	Farm yard manure
HRI:	Half recommended irrigation
IWUE:	Irrigation water use efficiency
IWUE-CP:	Irrigation water use efficiency for crud protein
IWUE-ME:	Irrigation water use efficiency for metabolizeable energy
LH:	Land holding
LSH:	Livestock holding
ME:	Metabolizeable energy
MIN:	Mineral fertilizer
NDF:	Neutral detergent fiber
NIRS:	Near infrared spectroscopy
RI:	Recommended irrigation
UPA:	Urban peri-urban agriculture

General Summary

Pakistan has an agriculture based economy and share of the agriculture in GDP of the country is 21% and about 65% of the population is directly or indirectly related to this field. Livestock farming is a very important economic activity in the urban and peri-urban (UPA) areas of Faisalabad and other cities in this climate zone, where green forage is the major source of animal feed. Area and production of forages is declining due to rapid urbanization and competition of forages with cash crops, which increases the need to enhance the productivity on the remaining area. Taking the constraints of forage production into consideration, the major objective of the study was to contribute to a sustainable forage production with acceptable nutritional quality to overcome the gap between forage production and demand and to ultimately improve the profitability of farmers.

An initial baseline survey was conducted in the forage growing areas of Faisalabad to study the socio-economic aspects and farming practices of the fodder growing farmers in 2010-11. It was revealed from the survey that the farmers had two types of land holdings; either they owned the land (88%) or they rented land in (44%), but also mixed tenure systems existed. On the basis of total cultivated land and livestock heads, the households were divided into four groups. The first group comprised small farmers with 2.6±1.7 ha of land and 3.2±2.4 heads of livestock, the second and third groups included households with larger amounts of land (9.1±3.2 and 8.5±5.3 ha), respectively with 9.1±3.2 and 26.1±9.0 of livestock heads respectively. A fourth group had 39.2±12.0 ha with 12.9±5.8 livestock heads. Wheat, maize, sorghum and Egyptian clover (berseem) were common crops in all groups. Farm yard manure (FYM), urea and di-ammonium phosphate (DAP) were used as sources of plant nutrition whereas integrated use of fertilizer (combination of FYM and MIN) was common as practiced by 86% of the respondents. Canal water was the major source of irrigation but many famers also used tube well to irrigate their fields as supplementary source. Livestock was one of the most important sources of income in peri-urban farming systems and thus played a major role in the household economy. Within in the studied area, 92% of the respondents had livestock, with buffalo being the pre-dominant animal (86% of the respondents) that was kept either alone or in conjunction with other livestock like cattle and goat etc. Farmers in the study area encountered multiple challenges with water shortage being the main problem (reported by

94% respondents) that frequently resulted in crop losses. Fertilizer shortage was recorded as the second most important problem (reported by 55% of the respondents) in the study area. Marketing was also one of the major problems and was reported by 46.5% of the respondents. This problem was mostly mentioned by farmers who cultivated sugarcane, forages and vegetables, as there were no fixed prices for these commodities. Development of policies to control the price and quality of seed, pesticides and fertilizers might be helpful to improve the situation. Research is needed to identify water and nutrient efficient crops with acceptable forage quality to improve the productivity and profitability of the UPA farmers.

Considering the outcomes of the baseline survey, a field experiment was conducted to (i) evaluate the effects of crop species, fertilizer type and irrigation level on yield, (ii) determine the corresponding water use efficiencies and (iii) investigate relationships between chlorophyll content and crop yield as a basis for a simple sensor-based prediction of crop yield for the practice. A two-year field experiment was conducted in Faisalabad, Pakistan, with a split plot arrangement of a combination of fertilizer treatment (control, farm yard manure (FYM) and mineral fertilizer (MIN)) and irrigation (recommended irrigation (RI), half recommended irrigation (HRI)) as main plot. Subplots were assigned to two cropping systems (common (CCS): Egyptian clover followed by corn, drought-adopted (DACS): Oat followed by Sudan grass). Crops were grown in two consecutive growth periods within one year, i.e. winter (November to April) and summer (May to August). Both FYM and MIN were applied with 107 kg N ha^{-1} and 26 kg P ha^{-1}. Actual total irrigation applied for Egyptian clover, oat, corn and Sudan grass under RI was 840, 729, 689 and 689, respectively and HRI was done by doubling the irrigation interval. Collected data were analyzed with the software package MSTAT-C, considering the split-plot design of the experiment. Results revealed that crop effects were always significant and depended both on fertilization and irrigation. In case of total annual yield the DACS produced 14.8% more than the CCS, and the yield difference was bigger with reduced than with recommended irrigation (17.8% vs. 11.78%, respectively). Differences were bigger in winter crops than in summer crops. Considering the actual environmental conditions during our study, there were 169 and 45 mm additional precipitation in summer and in winter season, respectively, which may have contributed to lower drought effects in summer. Fertilizer effects were very similar for all crops and interactions with the crop species and irrigation, although statistically significant, of minor magnitude. Contrasts revealed no significant yield difference between the fertilized treatments, whereas compared to the control fertilization increased the yield by 20.9 % (average across all crops and irrigation levels). Fertilizer effects on total annual yield were stronger with recommended irrigation (23.3%) as compared with the control, while with reduced irrigation the difference was only 18.4%.

The IWUE further highlights the effectiveness with which crops are able to make use of this essential resource. Crop effects for IWUE in the present study were generally significant and interacted both with fertilization and irrigation. Overall crop effects were identical in direction i.e. DACS was more efficient than CCS but stronger in HRI (0.61 kg DM m^{-3}) than in RI (0.29 kg DM m^{-3}). Total annual IWUE of the DACS was 22 and 28% higher than of the CCS in both RI and HRI conditions respectively. Fertilizer effects, although there were significant interactions, were very similar within both cropping systems. IWUE of the fertilized treatments were significantly higher than the control, i.e. 17.9% in the CCS and 22.3% in the DACS. Irrigation effects in our study showed the same tendency in all treatments. CCS and DACS were 63.7% and 74.4% more efficient in HRI than in RI respectively. From these results we can say that there is need to increase the irrigation interval for efficient use of available irrigation water. Since the proper time for irrigation varies depending on the distribution of rainfall and other environmental conditions, it should be adjusted according to local conditions. Relationships between dry matter yield and relative SPAD contents were investigated. Positive linear relationships were found between SPAD value and DMY for all crops with R^2 values between 0.63 and 0.96, indicating a proportional increase in leave greenness during growth of crops.

The samples from the field experiment were preserved to study the nutritional quality of the forage crops. The major objectives of the study were to i) evaluate the effect of crop species, fertilizer and irrigation on nutritive quality and ii) determine the irrigation water use efficiency (IWUE) in terms of crude protein (CP) and metabolizeable energy (ME) production per unit of irrigation water. Samples were taken from 0.25 m^2 randomly and 500 g of fresh matter was dried at 55 °C for 48 h. Subsequently, 20 g each of the dried samples were ground with a 1-mm sieve with Cyclotec sample mill (Foss Tecator AB, Höganaäs, Sweden) in order to determine their nutritive value by near infrared spectroscopy (NIRS) followed by wet analysis of selected samples. Data obtained were analyzed with the software package MSTAT-C, considering the split-plot design of the experiment. Quality traits were significantly affected by crop species whereas fertilization, irrigation and interaction effects were mostly non-significant or inconsistent and relatively small. No significant effect of fertilizer and irrigation on CP concentration was found whereas crop species effects were significant ($P<0.05$). Significant crop effects were found in both seasons which accounted for a major portion of the total variation. Over the whole year CCS had a 44% higher CP concentration on dry matter basis than DACS. Mean CP contents of CCS were 130.4 g kg^{-1} which indicates a high quality and 90.3 g kg^{-1} for DACS which is graded as fair quality forage. Irrigation water use efficiency for protein production (IWUE-CP) characterizes the efficiency of crops to produce protein per unit of land with a given amount of water. All treatment effects were significant ($P<0.05$) for IWUE-CP in winter, summer season and the total year. IWUE-CP in fertilized plots was 24, 22 and 23% higher than in the unfertilized for the winter and summer seasons and for the total year, respectively, whereas no significant ($P<0.05$) differences were found between the two fertilized treatments. IWUE-CP of HRI was 75, 69 and 69% higher than for RI in winter, summer and total year, respectively. Over the full year CCS was 13% more efficient than DACS. Due to higher dry matter yield of DACS, CP yield of the both systems were almost similar even CCS had higher concentration. ADF represents the highly indigestible part of forage and is frequently used to assess the forage quality. Analysis of variance revealed no effect of fertilizer and irrigation on the concentration of this component whereas crop effects were significant ($P<0.05$) for winter, summer and the total year. Mean ADF values of CCS and DACS were 337.6 and 366.6 g kg^{-1}, respectively, which falls in good quality standards. Metabolizeable energy is the most important limiting factor in dairy nutrition. Fertilizer and irrigation effects on ME contents were found non-significant for winter crops and total year, whereas in summer irrigation effect was significant. However, ME contents were 1.1% higher with reduced irrigation than with recommended irrigation, but effect size of irrigation was very small and its contribution to total variability was only 5%. The total year ME contents of DACS were 9.5% higher than of CCS. Irrigation water use efficiency for ME production (IWUE-ME) characterizes the efficiency of crops to produce ME per unit of land with a given amount of water. ANOVA for IWUE-ME showed significant differences for all treatments and interactions in winter, summer and for the total year. Contrasts revealed that IWUE-ME of fertilized treatment was 21, 19 and 20% higher than unfertilized in winter, summer seasons and total year respectively, whereas differences among the two fertilized treatments were not significant ($P<0.05$). IWUE-ME of half recommended irrigation was 80, 60 and 70% higher than recommended irrigation in winter, summer and total year, respectively. IWUE-ME of DACS was higher than CCS in both seasons (46 and 33 % in winter and summer, respectively) and for the full year (38%) and was due to DACS's superior biomass yield and ME concentration.

From the whole study it can be concluded that, the implementation of DACS in Pakistan's agriculture may contribute to a more efficient and sustainable forage production and by this may enhance also the profitability of the farmers.

German summary – Zusammenfassung

Die Wirtschaft Pakistans ist im Wesentlichen agrarisch geprägt. Der Anteil der Landwirtschaft am BIP beträgt 21% und ca. 65% der Bevölkerung sind direkt oder indirekt in diesen Sektor eingebunden. Dabei ist die Tierhaltung ein bedeutendes Wirtschaftsfeld in den städtischen und vorstädtischen Gebieten Faisalabads und anderer Städte in dieser Klimazone, in der Grünfutter das Hauptfuttermittel darstellt. Sowohl die Anbaufläche als auch die Produktion des Futters nehmen aufgrund der schnellen Stadtentwicklung und der Konkurrenz mit Marktfrüchten stark ab. Dies erhöht den Bedarf nach einer gesteigerten Produktivität auf den verbliebenen Flächen. Das übergeordnete Ziel dieser Studie war, unter Berücksichtigung der relevanten Rahmenbedingungen der Futterproduktion, einen Beitrag zu leisten zur Entwicklung einer nachhaltigen Futterproduktion, die einen akzeptablen Nährwert sicherstellt, die Lücke zwischen Produktion und Nachfrage schließt und letztlich die Wirtschaftlichkeit der Produktion verbessert.

In den Jahren 2010-11 wurde eine erste Studie in den Futteranbaugebieten Faisalabads durchgeführt, um sozio-ökonomische Aspekte sowie die landwirtschaftliche Praxis der Futterbereitstellung zu erheben. Dabei stellte sich heraus, dass die Bewirtschaftung der Flächen zum einen auf eigenen Flächen der Landwirte (88 %), zum anderen auf gepachteten Flächen (44 %) erfolgt. Darüber hinaus gibt es Mischformen beider Eigentumsverhältnisse. Auf Basis der gesamten Anbaufläche sowie des Tierbestandes wurden die Haushalte in vier Gruppen eingeteilt. Die erste Gruppe umfasste kleine landwirtschaftliche Einheiten mit 2.6 ±1.7 ha Land und 3.2 ±2.4 Tieren, die zweite und dritte Gruppe bestand aus Einheiten mit größerer Fläche (9.1 ±3.2 und 8.5 ±5.3 ha), beziehungsweise 9.1 ±3.2 und 26.1 ±9.0 Tieren. Die vierte Gruppe umfasste Einheiten mit 39.2 ±12.0 ha und 12.9 ±5.8 Tieren. In allen Gruppen gehörte Weizen, Mais, Sorghum und Alexandrinerklee zu den häufigsten Kulturen. Die eingesetzten Düngemittel waren Wirtschaftsdünger (FYM), Harnstoff und Diammoniumphosphat (DAP), wobei die Kombination aus FYM und DAP von 86 % der Studienteilnehmer angewendet wurde und damit die gebräuchlichste Form darstellte. Für die Bewässerung wurde im Wesentlichen Abwasser eingesetzt, viele Landwirte nutzten jedoch auch zusätzlich Brunnenwasser. Die Tierhaltung war einer der wichtigsten Bestandteile des Einkommens in der vorstädtischen Landwirtschaft und spielte damit eine wichtige Rolle im Wirtschaften der Haushalte.92 %

der Studienteilnehmer waren Tierhalter, wobei die Büffelhaltung, entweder als alleinige Tierart oder in Verbindung mit anderen Tierarten wie Rindern oder Ziegen etc. den größten Anteil ausmachte(86 % der Studienteilnehmer).Die Landwirte im Studiengebiet waren vielfältigen Herauforderungen ausgesetzt, wobei die Wasserknappheit und daraus folgende Mindererträge als das Hauptproblem (94 % der Studienteilnehmer) dargestellt wurde. Der Mangel an Dünger wurde als zweitwichtigstes Problem innerhalb des Untersuchungsgebietes genannt (55 % der Studienteilnehmer). Ebenso wurde das Marketing als eines der Hauptprobleme von 46,5 % der Studienteilnehmer aufgeführt. Hierauf verwiesen vorwiegend Landwirte, die Zuckerrohr, Rauhfutter und Gemüse anbauten, da für diese Produkte keine festen Preise existieren. Die Entwicklung von Strategien zur Kontrolle von Preisen und Qualitäten bei Saatgut, Pestiziden und Düngern könnten helfen die Situation zu verbessern. Weitere Untersuchungen sind notwendig um die Effizienz der Wasser- und Nährstoffversorgung für eine akzeptable Futterqualität zu identifizieren und damit die Produktivität und den Profit der UPA.

Vor dem Hintergrund der Ergebnisse aus der genannten Bestandesaufnahme erfolgte die Anlage eines Feldexperiments, um (i) die Effekte von Kulturpflanzenart, Typ des Düngers und Höhe der Bewässerung auf den Ertrag zu evaluieren, (ii) die damit verbundene Wassernutzungseffizienz zu ermitteln und (iii) die Beziehungen zwischen Chlorophyllgehalt und Pflanzenertrag als Grundlage für eine einfache sensor-basierten Ertragsschätzung in der Praxis zu eruieren. Die Untersuchung erfolgte über zwei Jahre in Faisalabad, Pakistan, in Form einer Spaltanlage (Split-Plot) mit Kombinationen aus Düngerbehandlung (Kontrolle, Hofdünger (FYM) und mineralischer Dünger (MIN)) und Bewässerung (empfohlene Bewässerungsmenge (RI) und halbierte empfohlene Menge (HRI)) in den Hauptparzellen. Die Unterparzellen wurden zwei Anbausystemen zugeordnet, bestehend aus einer üblichen Variante (CCS: Alexandrinerklee gefolgt von Mais) und einer trockenheitstoleranten Variante (DACS: Hafer gefolgt von Sudangras). Die Kulturen der jeweiligen Variante wurden in zwei aufeinander folgenden Jahreszeiten angebaut (Winter: November – April; Sommer: Mai – August). In den Düngungsvarianten wurden für FYM und MIN jeweils 107 kg N/ha und 26 kg P/ha appliziert. Die Bewässerungsmengen (RI) summierten sich für Alexandrinerklee auf 840mm, für Hafer auf 729mm, für Mais auf 689mm und für Sudangras auf 689mm. Die Halbierung der Bewässerungsmenge (HRI) erfolgte durch eine Doppelung der Pausen zwischen den Bewässerungsterminen. Die erhobenen Daten wurden mit dem Statistikpaket MSTAT-C unter Berücksichtigung des Spaltanlagendesigns analysiert. Die Ergebnisse zeigten signifikante Effekte der Kulturpflanzen sowohl in Bezug auf die Düngungs- als auch Bewässerungsvarianten. So lag der Jahresertrag im DACS um 14,8 % über dem CCS. Die Ertragsunterschiede waren größer bei der halbierten Bewässerungsmenge (17,8 %) gegenüber der üblichen Variante (11,78 %). Winterkulturen zeigten deutlichere Unterschiede als Sommerkulturen. Unter Berücksichtigung der umweltbedingten Wuchsbedingungen im Verlauf der Untersuchung können zusätzliche Niederschläge von 169 mm im Sommer und 45mm im Winter und zu geringeren Trockenstresseffekten im Sommer beigetragen haben. Effekte der Düngervariante waren sehr ähnlich bei allen Kulturpflanzen und Interaktionen zwischen Kulturpflanzenart und Bewässerung waren zwar signifikant doch von geringer Bedeutung. Kontraste zeigten keine signifikanten Ertragsunterschiede zwischen den Düngertypen, gegenüber der Kontrolle jedoch einen Ertragsanstieg von 20,9 % (Mittel aus allen Kulturen und Bewässerungsstufen). Düngeeffekte auf den Gesamtjahresertrag waren bei empfohlener Bewässerung im Vergleich zur Kontrolle stärker ausgeprägt (23,3 %), während mit reduzierter Bewässerung der Unterschied nur bei 18,4 % lag. Die Wassernutzungseffizienz (IWUE) gibt Auskunft über die Effizienz der Kulturpflanzen diese essentielle Ressource nutzen zu können .Der Zusammenhang zwischen Kulturfrucht und der IWUE war in der vorliegenden Studie grundsätzlich signifikant und interagierte sowohl mit dem Dünge- als auch den Bewässerungseffekt. Der Effekt der Anbausysteme war gleichgerichtet, d. h. DACS war effizienter als CCS aber ausgeprägter im HRI (0.61 kg TM m^{-3}) als im RI (0.29 kg TM m^{-3}). Die IWUE im bezogen auf das gesamte Jahr war beim DACS 22 bzw. 28% höher als beim CCS unter jeweils RI bzw. HRI Bedingungen. Düngeeffekte waren sehr ähnlich in beiden Kulturen, obwohl auch signifikante Interaktionen auftraten. Die IWUE der gedüngten Varianten war signifikant höher als in der Kontrolle, d. h. 17,9 % im CCS und 22,3 % im DACS. Bewässerungseffekte zeigten in unserer Studie über alle Behandlungen die gleichen Tendenzen. CCS und DACS waren unter HRI 63,7 % bzw. 74,4 % effizienter als unter RI. Daraus lässt sich schlussfolgern, dass eine Verlängerung des Bewässerungsintervalls zu einer effizienteren Nutzung des zur Verfügung stehenden Wassers führen würde. Im Hinblick darauf, dass der passende Bewässerungszeitpunkt vom Niederschlag und anderen Umweltfaktoren abhängt, sollte er auf die lokalen Bedingungen abgestimmt werden. Die Zusammenhänge zwischen den

Trockenmasseerträgen und den relativen SPAD-Gehalten wurden untersucht. Dabei wurde ein positiver linearer Zusammenhang mit einem R^2 zwischen 0,63 und 0,96 gefunden, der auf eine proportionale Zunahme des Blattgrüns während des Wachstums der Kulturpflanzen hindeutet.

Die Proben des Feldexperiments wurden auch verwendet, um die Futterqualität der Kulturpflanzen zu untersuchen. Die Hauptanliegen der Studie waren i) den Effekt von Pflanzenart, Dünger und Bewässerung auf die Nährstoffqualität zu bewerten und ii) die Wasserverbrauchseffizienz (IWUE) in Bezug auf die Produktion von Rohprotein (CP) und Kaloriengehalt (ME) pro Einheit Bewässerungswasser zu ermitteln. Die Proben wurden randomisiert auf einer Fläche von 0,25 m^2 genommen und 500g Rohmaterial wurde für 48 h bei 55°C getrocknet. Anschließend wurden 20 g jeder getrockneten Probe mit einer Cyclotec-Mühle (FossTecator AB, Höganaäs, Sweden) auf 1 mm gemahlen, um die Nährwerte mit der Nahinfrarotspektroskopie (NIRS) zu bestimmten. Ausgewählte Proben wurden anschließend nasschemisch analysiert. Die gewonnen Daten wurden mit dem Software-Paket MSTAT-C unter Beachtung des „Split-plot designs" des Experiments ausgewertet. Die Qualitätsmerkmale wurden signifikant durch Düngung, Bewässerung und Kulturpflanzenart beeinflusst, während Interaktionen meist nicht signifikant oder widersprüchlich von geringer Bedeutung waren. Es konnte kein signifikanter Effekt von Düngung und Bewässerung auf den CP-Gehalt nachgewiesen werden, demgegenüber wurde ein signifikanter Einfluss ($P<0.05$) der Pflanzenarten festgestellt, der in beiden Jahreszeiten nachgewiesen werden konnte und einen Großteil der Gesamtvariation abdeckte. Bezogen auf die ganzjährigen Anbausysteme zeigte das CCS eine um 44% höhere CP-Konzentration in der Trockenmasse als das DACS. Der durchschnittliche CP-Gehalt wies im CCS mit 130,4 g/kg eine hohe Futterqualität auf und erreichte mit 90,3 g/kg beim DACS ein ausreichendes Qualitätsniveau. Die Wassernutzungseffizienz der Bewässerung zur Proteinproduktion (IWUE-CP) beschreibt den CP-Ertrag von Pflanzen bezogen auf eine definierte Landfläche bei einer festgelegten Wassermenge. Alle Behandlungen zeigten signifikant Effekte ($P<0.05$) hinsichtlich der IWUE-CP bei den Winterkulturen und Sommerkulturen sowie bei ganzjähriger Betrachtung der Anbausysteme. IWUE-CP war auf gedüngten Flächen 24, 22 und 23% höher als auf ungedüngten Flächen bei differenzierter Betrachtung von Winter (24 %), Sommer (22 %) und des ganzen Jahres (23 %). Keine signifikanten Unterschiede

(P<0.05) konnten zwischen den beiden Düngungsverfahren gefunden werden. Bezogen auf die Bewässerungsvarianten lag IWUE-CP bei HRI um 75 % (Winter), 69 % (Sommer) bzw. 69 % (ganzjährig) höher als bei RI. CCS war bezogen auf das gesamte Jahr um 13% effektiver als DACS. Bei einem höheren Trockenmasseertrag des DACS und höheren CP-Gehalten des CCS lagen die CP-Erträge auf nahezu gleichem Niveau. Die Unterschiede der Wassernutzungseffizienz waren daher dominierend geprägt durch die Mengen des verfügbaren Wassers. ADF macht den schwer verdaulichen Teil bei Futtermitteln aus und wird häufig verwendet, um die Futtermittelqualität zu bestimmen. Die Varianzanalyse zeigte keine Effekte von Düngung und Bewässerung auf die Konzentration dieser Komponente, während Pflanzeneffekte in Winter, Sommer und ganzjährig signifikant waren (P<0.05). Die durchschnittlichen ADF-Gehalte der Anbausysteme zeigten mit 337,6 g/kg im CCS und 366,6 g/kg im DACS ein gutes Qualitätsniveau. Die verdauliche Energie (ME) ist der wichtigste limitierende Faktor in der Milchviehernährung. Düngungs- und Bewässerungseinflüsse auf ME waren bezogen auf die Winterkulturen und die Anbausysteme nicht signifikant. Sommerkulturen zeigten dagegen einen signifikanten Einfluss der Bewässerung auf ME. ME lag bei HRI um 1,1% höher als bei RI, aber der Effekt im statistischen Model war gering und trug nur zu 5 % zur gesamten Variabilität bei. Bezogen auf den Gesamtjahreszeitraum lag der ME-Gehalt im DACS 9,5% über dem des CCS. Die Wassernutzungseffizienz der Bewässerung zur Produktion der verdaulichen Energie (IWUE-ME) beschreibt den ME-Ertrag von Pflanzen bezogen auf eine definierte Landfläche bei einer festgelegten Wassermenge. Die Ergebnisse der ANOVA für IWUE-ME zeigte signifikante Unterschiede für alle Haupteffekte und Interaktionen der Varianten in Sommer- und Winterkulturen, als auch für die auf das ganze Jahr bezogenen Anbausysteme. Vergleiche zeigten, dass IWUE-ME in gedüngten Varianten um 21 % (Winter), 19 % (Sommer) bzw. 20 % (ganzjährig) höher war als in den ungedüngten Varianten. Unterschiede zwischen den zwei Düngungsverfahren waren dagegen nicht signifikant (P<0.05). IWUE-ME bei reduzierter Bewässerung war 80 % (Winter), 60 % (Sommer) bzw. 70 % (ganzjährig) höher als bei empfohlener Bewässerung. Im DACS lag IWUE-ME um 46 % (Winter), 33 % (Sommer) bzw. 38 % (ganzjährig) höher als beim CCS, begründet sowohl in höheren Biomasseerträgen als auch ME-Gehalten.

Aus den Ergebnissen der Studie kann geschlossen werden, dass die Implementierung des trockentoleranten Anbausystems in Pakistans Landwirtschaft zu einer effizienteren und nachhaltigeren Futtermittelproduktion beitragen und gleichzeitig den Profit der Landwirte verbessern kann.

General Introduction

Agriculture is the most important and dynamic sector of the Pakistan‘s economy as it employs 45% of the labor force and contributes to the growth and economy of other agro-based industries by providing the raw material (Farooq, 2013). In agriculture based rural areas, agricultural growth and poverty reduction has positive relationship. But with the time, as the population is increasing and people are migrating to the urban areas due to the social and natural disasters and lack of health and educational facilities in rural areas; new residential colonies are squeezing the agricultural lands. Thus, demand for food is increasing with continuous decreasing productive lands and it becomes important to find ways to grow more food with fewer resources and even to practice agriculture in urban and peri-urban areas to fulfill the demands of food and feed. Peri-urban areas, the transitory or interactive zone where urban and rural activities take place side by side, are usually characterized by a high growth rate and high rate of immigration from rural areas or city itself (FAO, 2001) and include valuable agricultural lands (Douglas, 2006). Agriculture in these areas provides several benefits like short transportation and availability of fresh food at comparative low prices. However these benefits are associated with problems, such as pressure on limited resources of land, inadequate services of water, sanitation and health.

Faisalabad is an industrial city but is equally important with respect to agriculture as it is situated in the irrigated part of Punjab with semi-arid climate. Agricultural practices are mostly done in peri-urban and rural areas. Livestock sector is very important in these areas which provide milk and milk products for auto-consumption and for sale as well. Due to livestock, forages are important crops in the peri-urban areas. Hussain et al. (2011) reported agriculture as a major source of income with 35-50% less yield of crops than potential yield in irrigated areas of the Punjab. For a sustainable production of forages with limited land facilities, it is important to know the socio economic patterns and activities and agricultural practices of the farmers living in the peri-urban areas.

In surroundings of the livestock production territory forage production is an important and common agricultural activity as green forage is the most economic source of nutritious feed for livestock. Farmers grow their own fodder or they buy it daily from the market. Forage production in Pakistan varies with climate and season. In irrigated areas, most important forages are sorghum and corn in summer season, while Egyptian clover is a major crop in winter season. Some legumes are also grown mixed with summer forages to enhance the quality of the overall forage. Oat and brassica species are mixed with berseem to enhance the first cut yield of berseem. Most of the farmers grow forage crops on their marginal lands with low input therefore the yield of forages remains low (Sarwar et al., 2002). Forage production can be improved by growing crops with high yields and limited demands for resources of inputs. Researchers had suggested a variety of crops for different areas like sorghum-Sudan grass hybrids (Bibi et al., 2012), Egyptian clover (Al-Khateed et al., 2006), oat (Martin et al., 2001; Amanullah and Stewart, 2013), maize (Ayoola and Mankind, 2009; Baksh et al., 2012), Mott grass (Bilal et al., 2001), sorghum (Ahmed et al., 2007) and pear millet (Sivakumar and Salam, 1999) for sustainable production depending on the conditions and requirements of the area. However all these studies and suggestions were exclusively based on single season or single crop. So far no study included whole year cropping systems.

Due to the semi-arid climate of Faisalabad, crop production predominantly depends on supplementary irrigation and fertilizers. Scarcity of irrigation water severely affects the growth, development, physiological processes and yield of crops (Bouazzama et al., 2012; Hussain et al., 2010; Khan et al., 2001; Singh and Singh, 1995). When available water is insufficient, then it is critically important to adjust the timing of irrigation to extend water available for the whole season. Drought is an emerging threat in Pakistan due to the erratic rainfall and shortage of irrigation water. High inflation in the prices of oil and electricity made it very difficult for the poor farmers to afford the ground water for irrigation. It is important to identify crops with improved efficiency to utilize the available water. Bakhsh et al. (2012) suggested deficit irrigation to increase the water use efficiency of corn. Out of total five irrigations, they found 2nd and 3rd irrigation least sensitive for green forage yield and suggested that water can be saved during the first quarter of vegetative growth. Bibi et al. (2012) reported variable effects on different genotypes of sorghum-Sudan grass hybrids at the same level of water stress. All these studies suggested that there is a great potential to increase forage production with limited resources if suitable crops for specific region are selected. Thus, such crop management practices should be implemented which result in effective and sustainable use of irrigation water. Increasing the water use efficiency of crops or selecting crops with high water use efficiency can be a way to deal with water stress. Changing the irrigation interval can result in higher water productivity (Payero et al., 2009). Unawareness among the farmers about suitable timing of irrigation and lack of appropriate techniques and methods for uniform water application throughout the field are major causes of sub-optimum water productivity. By increasing the irrigation interval to a certain limit, irrigation water use efficiency can be increased (Ismail et al., 1994; Peuke et al., 2006). In water stress condition, maximum capture of soil moisture to be used in transpiration is very important and effective water use (yield/water applied) is a major driver of yield (Blum, 2009). Due to this reason, some researchers preferred irrigation water use efficiency over water use efficiency where crops produced per unit of applied water is determined in a specific soil and environmental conditions (Blum, 2009; Howell, 2001; Passioura, 2006). Along with irrigation, proper plant nutrition is very important to achieve higher yields. Mostly nitrogen (N) and phosphorus (P) based fertilizer are used along with farm yard manure (FYM). Different researchers have reported effects of excessive and under use of fertilizer for different crops. Amanullah and Sterwart (2013) reported negative impact of excessive nitrogen (200 mg kg^{-1} of soil) and no effect of excessive phosphorus (200 mg kg^{-1} of soil) on crop growth rate of oat under controlled conditions. They also reported increases in water use efficiency with P application. Bilal et al. (2001) compared different combinations of N and FYM for yield of mott grass and reported maximum green forage yield with 300 kg N ha^{-1}. Frame et al. (1976) reported variable response of various red clover genotypes to same level of N fertilizer and reported a superiority of tetraploid genotypes over diploid. Hokmalipour and Darbandi (2011) reported positive effects of N fertilizer on chlorophyll contents and leaf dry weight of corn.

Along with macro nutrients, availability of micro nutrient is also very important. Trace mineral elements such as calcium, magnesium, iron, iodine, boron depleted by crops cannot be replaced by inorganic fertilizers. Organic fertilizers e.g. manure and compost contains naturally-occurring macro and micro nutrients. In addition to increasing yields and fertilizing plants directly, they can improve the biodiversity and long-term productivity of soils as well. In Faisalabad there are around 2.7 million farm animals including cattle, buffaloes, goats, sheep, horses, camels and donkeys (Mustafa, 2009). According to a rough estimate the dung produced from these animals contains 73 tons of nitrogen (N), 52 tons of phosphorus (P) and 50 tons of potassium (K) and furthermore other mineral nutrients such as calcium, magnesium, iron, iodine and boron etc. These nutrients can potentially be used as source of fertilizer and might be important by-products of livestock production when they are effectively managed and utilized for field crop production. In Pakistan animal dung is frequently used by women to produce dung cakes (Fafchamps and Quisumbing, 2000; Hassan et al., 2007) for burning in private households which is related with substantial losses of nutrients. However, with a proper management it could be used as fertilizer because it is a rich source of mineral nutrients. Thereby, the value of the dung could be increased and the reliance on costly commercial fertilizers could be reduced. Thus, the cost of production would decrease and farmers would generate higher profits which would be an important step towards a sustainable development.

Livestock farmers do not accept forage with low quality hence it is important to concentrate on the sustainable forage production with an acceptable nutritional quality. As green forage is a cheap source of animal feed, high quality of forage also reduces the costs of supplementary feeds. The efficiency of ruminants for milk and meat production is related to the quality of forages mainly in terms of fiber, protein and energy contents. Famers like to adopt crop species which produce high quality forage with comparatively less inputs. Crude protein (CP), acid detergent fiber (ADF) and metabolizeable energy (ME) contents of forage are mostly used to assess the quality of forage.

Results on the effect of inputs like fertilizer and irrigation on the concentration of nutritive compounds are inconsistent. Barton et al. (1976) reported a higher digestibility of ADF when extracted from tropical species than from temperate species. The forage intake depends on physical and chemical properties of the forage and on type and age of the animal. Buxton (1996) reported that a 1 week delay in harvesting of alfalfa (Medicage sativa L.) can reduce crude protein (CP) concentration up to 20 g kg^{-1} DM and increase cell wall concentration up to 30 g kg^{-1} DM. He also reported that an NDF concentration of more than 750 g kg^{-1} severely affects the forage intake of beef cows. Crude protein is an important nutritive component in animal feed and it tends to be higher in temperate forage species than in tropical ones and in legumes than in grasses. If forage does not contain sufficient crude protein, then the animal's requirement can be fulfilled by supplementation which in turn increases the cost of production. Thus, assessment of forage quality is very important to ensure the better productivity of livestock.

For a substantial improvement of animal production in Pakistan, research methods have to be developed which are efficient, time saving and economic in terms of feed quality and productivity. Forage quality is frequently assessed by chemical methods, as these require no animal trials and only small quantities of feed (Mahyuddin, 2009; Van Soest and Wine, 1967). However, they become laborious and expensive if large numbers of samples have to be screened. Near infrared spectroscopy (NIRS) is an efficient and reliable method (Abrams et al., 1987; Biewer et al., 2009; Marten et al., 1983) which makes it easy to measure the nutritive value of large number of samples in relative short time.

Chlorophyll contents are related to plant productivity and are usually assessed by acetone extraction method which is laborious and time consuming but now it is commonly measure with the help of modern chlorophyll meters. There are lots of studies which confirm the accuracy of chlorophyll meter across the species but calibration is specific for each crop/species (Chang and Robison, 2003; Costa et al., 2001; Loh et al., 2002; Markwell et al., 1995).

Research Objectives

Taking the constraints of urban and peri-urban forage production into consideration, the major objective of the study was to contribute to a sustainable forage production with acceptable nutritional quality to overcome the gap between forage production and demand and ultimately to improve the profitability of the farmers. This will help to improve the livelihood in the rural areas where forage production and livestock farming are major sources of income. The present study emphasized on the following specific objectives:

To address the various aspects of urban and peri-urban agriculture in Faisalabad in order to support the development of future policies for improved agricultural farming practices (Chapter 5).

To determine the effect of fertilizer, irrigation and crop species on yield and irrigation water use efficiency and to investigate the relationship between the chlorophyll contents and the crop yield (Chapter 6).

To investigate the effect of fertilizer and irrigation on the nutritive quality of different cropping systems and on the irrigation water use efficiency of CP and ME production per unit of land (Chapter 7).

Socio-economic aspects and crop management in urban and peri-urban fodder production of Faisalabad

Abstract Fodder production and livestock farming are major farming activities in peri-urban areas of Faisalabad. A baseline survey was conducted to study the socio-economic aspects and farming practices of the fodder growing areas in 2010-11. A total of 109 households, selected by snowball method, were interviewed based on a structured questionnaire. Results revealed that all households were headed by male and most of them (53%) had only completed primary education or even less. Agriculture was the predominant occupation as 89% of the households relay on it for income. Average income per household was US$ 550 per month with great variability. Berseem, maize and sorghum were identified as major commercial crops of the area grown by around 90% of the respondents. Most of the farmers (86%) rely on integrated fertilizer use (combination of mineral fertilizer and farm yard manure). Alternate canal and tube well watering was common as reported by 80% of the respondents. Major problems reported were the scarcity of irrigation water (97%), poor access to fertilizer (55%) and marketing of the farm products (45%). It was concluded that high illiteracy rate, shortage of irrigation water and an imbalanced use of fertilizers were the major reasons for low productivity. Introducing water and nutrient efficient crops and extension services for improved technology could provide good perspectives for a sustained fodder production in these peri-urban areas.

5.1 Introduction

In 2011-12 total population of Pakistan was about 180 million with a growth rate of 2% while urban population was 67.55 million. Pakistan is an agricultural country where the major part of the population lives in rural areas. Due to scarce employment possibilities, underdeveloped education and health infrastructure, migration from rural to urban areas continues and leads to ever higher demands for food, space and employment. Labour force of Pakistan was 57.24 million in 2010-11 out of which 3.4 million were unemployed (Mazhar, 2012). Poverty is thought to be synonymous with rural areas due to lower chances of employment opportunities but with population growth, the number of the urban poor seemed to increase as unemployment rate in urban areas is increasing (Farooq, 2013). Urban and peri-urban conditions can be worse in terms of poverty and food security without preventive measures. To fulfil the increasing demands of food and feed with reduced agricultural land due to increase in population and residential colonies is a big challenge. To meet this challenge growing of food crops in the residential areas was proposed to ensure the sustainable availability (Cofie et al., 2003). Urban and peri-urban farming constitute a source of indirect income, since some food does not have to be purchased from the market. The urban and peri-urban farming not only includes growing of food crops but also animal husbandry, agro-forestry and horticulture. It has become an extremely visible economic activity all over the world (Kwasi, 2010; Mkwambisi et al., 2011) due to short transportation ways, immediate availability of fresh food, less vulnerable to food price change and recycling of waste. The benefits are confronted with associated risks such as increased competition of land, water and labour.

Faisalabad is third largest city of Pakistan after Karachi and Lahore. Due to its textile industry, Faisalabad is also known as Manchester of Pakistan, but its agricultural basis in the Punjab where irrigated cropping of wheat (Triticum aestivum L.), rice (Oryza sativa L.), cotton (Gossypium hirsutum L.) and fodder crops cultivated for livestock prevail, is equally strong. The district of Faisalabad comprises 5,856 km2 with an estimated population of 2.6 million growing annually at 2%. At present 23.4% of the district's population resides in urban areas and this percentage is rapidly increasing due to better employment, education and health facilities in urban areas (Anonymous, 2009). Most people residing in peri-urban areas are livestock, fodder and vegetable farmers and their farming system ranges from self-consumption to commercial orientation. Due to the reduction of agricultural land in peri-urban areas, it is hard to fulfil the fodder requirements of the livestock farmers wherefore fodder has to be brought from other areas.

This study aims at addressing various aspects of urban and peri-urban agriculture (UPA) in Faisalabad to provide policy input for improving agricultural farming practices. To achieve this objective, a baseline survey was conducted comprising mainly fodder growing farmers, which is discussed in this paper.

5.2 Materials and Methods

5.2.1 Study area

Geographically Faisalabad is situated between 73˚ to 74˚ E and 30˚ to 31.5˚ N with an elevation of 604 feet above sea level and is located in the central Punjab province. Mean annual rainfall is about 550 mm with maximum and minimum temperatures of 50 °C and -1 °C in summer and winter, respectively (Faisalabad, 2012).

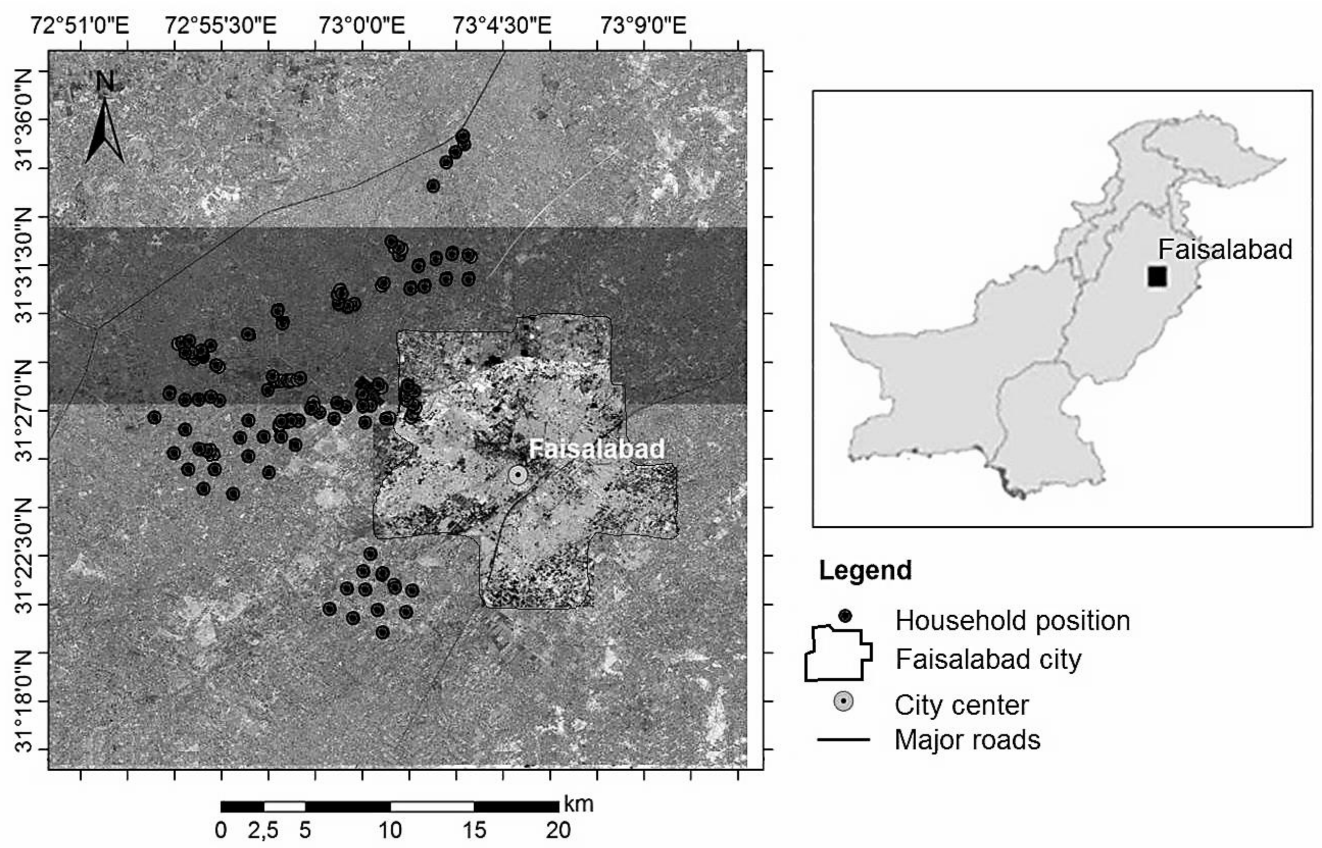

Figure 5.1 GIS-based map of Faisalabad (Pakistan) with the approximate expansion of the urban area (inside the polygon), major roads, city center and position of interviewed households.

There are two main cropping seasons i.e. winter (Rabi) and summer (Kharif). Rabi (October-March) include different winter crops such as vegetables, Berseem (*Trifolium alexandrinum*), wheat and sugarcane (*Saccharum officinarum* L.) and Kharif (April-September) include summer crops like vegetables, cotton, rice (*Oryza sativa* L.), fodder maize (*Zea mays* L.) and Sorghum (*Sorghum bicolour* L.).

For the purpose of our interview, fodder producing zones were selected from the adjoining areas of the city. There are two major fodder markets located in the West and South-west of the city; these were visited to determine the survey areas following a snowball sampling method (Berg, 1988; Sadler et al., 2010). Finally, 109 household were interviewed for their demographic and socio-economic characteristics, agricultural practices and production constraints in 2010-11 using a structured questionnaire. The geographical coordinates of all interviewed households were recorded with a Trimble Geoexplorer II (Sunnnyvale, CA, USA) for mapping purposes (Fig. 5.1).

5.2.2 Statistical analysis

Descriptive analysis was carried out for the demographic characteristics, agricultural practices and problems while hierarchical cluster analysis was employed to identify different farming types using Ward’s method and squared Euclidean distances. Discriminant analysis was carried between groups and to determine the importance of the variables used for clustering (Blashfield, 1976; Klecka, 1980). All analyses were done with SPSS statistical software (Statistics, 2008).

5.3 Results

5.3.1 Household characteristics

The results showed that males were the main earners of cash income and that most household heads (80.7%) were married and had agriculture as their main source of income. Most of the respondents were illiterate (26.6%), had only primary education (26.6%) and few (10%) were graduates (Table 5.1). Average distance from the next agricultural market was 7.5 km and the major way of transport (92%) of agricultural products was the tractor trolley, some farmers also used animal driven carts for transport of goods.

The age of the respondents ranged from 20 to 80 with an average 46.2 years. Most of the households were characterized by a joint family system with 5.4 adults and 4.8 children. Annual income of a household of the studied area varied widely with an average of US$ 6,600. Only 11.9% of the households reported an annual income of more than $ 10,000 (Table 5.1).

5.3.2 Farming types

Farmers had two types of land holdings; either they owned land (56%) or they rented land (13%), but mixed tenure systems also existed (32%). On the basis of total cultivated land and livestock numbers, the cluster analysis divided households into four groups. The first group comprised small farmers with 2.6±1.7 ha of land and 3.2±2.4 heads of livestock, a second and third group included households with larger amounts of land (9.1±3.2 and 8.5±5.3 ha), respectively with 9.1±3.2 and 26.1±9.0) of livestock heads respectively. A fourth group had 39.2±12.0 ha with 12.9±5.8 livestock heads (Table 5.1). Wheat, maize, sorghum and berseem were common crops in all groups. Except for the second group, all households were growing sugarcane.

5.3.3 Livestock profile

Livestock was one of the most important sources of income in peri-urban farming systems and thus played a major role in the household economy. Within in the studied area, 92.7% of the respondents had livestock, with buffalo being the pre-dominant animal (86.2% of the respondents) that was kept either alone or in conjunction with other livestock. Only few respondents (17.4%) had male adults those were kept for reproduction or beef purpose while female adults were kept for milk purpose. Cattle was the second most important livestock animal, kept by 46.8% of the total respondents out of which only 36% had male adults kept for draught or reproduction. Other animals kept in conjunction with buffalo and cattle included goats, donkey, horses and sheep.

5.3.4 Agriculture practices

Farmers grew different type of crops, whereby the crop choice depended on weather conditions and market value. Mostly all farmers of the study area cultivated wheat as the major crop, whereas fodder crops like berseem, maize and sorghum were cultivated by 94.50, 90.80 and 83.5% of the respondents respectively. Crops like sugarcane, rice, cotton and vegetables were grown by 49.5, 19.3, 14.7 and 18.3% of the respondents. Apart from these major crops some other crops like pearl millet (*Pennisetum glaucum*), oat (*Avena sativa*) and sesame (*Sesamum indicum*) were also grown by some farmers for auto-consumption (Fig. 5.2).

Farm yard manure (FYM) was used as organic fertilizer while urea and di-ammonium phosphate (DAP) were used as mineral fertilizer sources. Integrated use of fertilizer (combination of FYM and mineral fertilizers) was common as practiced by 86% of the respondents (Table 5.1).

Table 5.1 Demographic characteristics of 109 households interviewed in urban and peri-urban areas of Faisalabad, Pakistan during 2010 - 2011.

Household characteristics	Category	Frequency (n)	Percentage of total (%)
Marital status	Married	88	80.7
	Single	20	18.4
	Widowed	1	0.9
Occupation	Agriculture	88	80.7
	Others	21	19.3
Education	Illiterate	29	26.6
	Primary	29	26.6
	Metric	40	36.7
	Graduate	11	10.1
Farm typology	Low LH*, Less LSH**	44	40.4
	Ordinary LH, Ordinary LSH	42	38.5
	Ordinary LH, large LSH	16	14.7
	Large LH, Ordinary LSH	7	06.4
Irrigation	Canal	17	15.6
	Tube well	2	1.8
	Canal + Tube well	80	73.4
	Waste water	10	9.2
Fertilizer type	MIN╥	8	7.3
	FYM╥╥	1	0.9
	MIN + FYM	94	86.2
	No fertilizer	06	5.5
Average number of family members	≤ 5	16	14.7
	6-10	53	48.6
	11-15	26	23.8
	> 15	14	12.9
Household estimated annual income (US$)	≤ 2500	20	18.3
	2501 - 5000	34	31.2
	5001 – 10,000	42	38.5
	> 10,000	13	11.9

* = Land Holding ╥ = Mineral Fertilizer

** = Livestock Heads ╥╥ = Farm Yard Manure

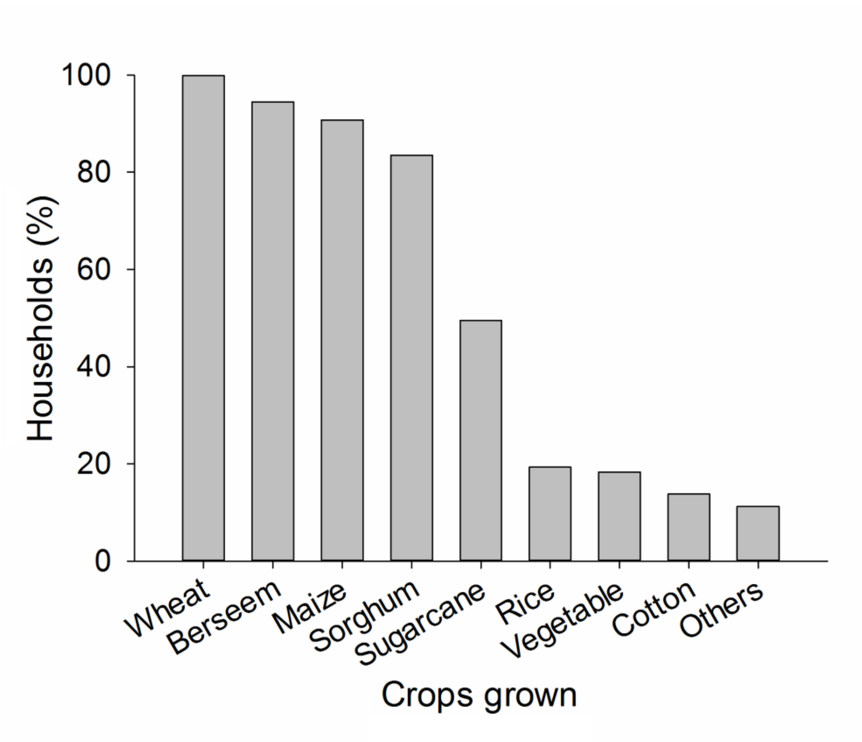

Figure 5.2 Major crops grown in urban and peri-urban areas of Faisalabad, Pakistan, during 2010-2011 (n=109).

Mostly farmers grew wheat for auto-consumption while surplus was sold. Average area per household under wheat cultivation was 2.5±3.1 ha. All respondents sowed wheat by broadcasting and most farmers used herbicides, but none of the farmer used any insecticide or fungicide for this crop. Average yield was 3.9±0.5 t ha^{-1} and expenses US$ 179.0±46.6. Rice was second important food crop. It was also grown for domestic purpose and surplus was sold. The average area per under rice cultivation was 1.1±1.8 ha. All rice was transplanted and treated with insecticides as needed. Average yield and cost of production per hectare was reported 2.8±0.8 t and US$ 206.1±75.3, respectively. Average area under berseem per respondent was found 1.06±1.6 ha. It was sown by broadcast method. Only few farmers (2.9%) applied insecticides to this crop at early stage. It had three to five cuts per season. Average green fodder yield was found 82.2±13.8 t/ha. Average input expenses/ha were found $ 206.3±126.6. Most of the growers (77.7%) were supplying it to the market. Average area per respondent under maize was 1.6±1.8 ha. It is sown by broadcast method in summer and spring seasons. Most of the farmers (75.8%) used insecticides for this crop at early stages of growth to control sucking insects. Average yield and input expenses for this crop were reported

37.2±8.6 t and $ 158.9±60.5 respectively. The majority of farmers (96.9%) sold it as fodder to the market. Average area under sorghum per respondents was 1.1±1 ha. Sowing method for this crop was broadcast method. Majority of the respondents (94.35%) growing sorghum, supplied it to the market. Average fodder yield and input expenses per hectare were 42.4±7.4 t and $ 118.5±59.8 respectively. The average area under sugarcane was 2.1±3.5 ha/respondent. Farmers grew it as a commercial crop by using cuttings from the previous crop. About 83% of the respondents cultivated sugarcane and used insecticides for crop protection. Average yield and input expenses per hectare were reported 80.3±19.7 t and $ 398.2±164.0 respectively. Average area under cotton crop was 0.88±0.71 ha per respondent. It was sown on ridges. All the respondents used insecticides for this crop as insects were the most important threat. Average yield and expense per hectare of this crop were reported 2.2±1.2 t and $ 307.8±98.9 respectively. High input expenses were due to intensive use of insecticides. Vegetables are also important crops in peri-urban area. Average area under vegetable was found 2.9±3.1 ha. Vegetables were sown on ridges. Cauliflower (*Brassica oleracea* L.), spinach (*Spinacia oleracea* L.), tomato (*Solanum lycopersicum*), cucumber (*Cucumis sativus*), radish (*Raphanus sativus*) and carrot (*Daucus carota*) were major vegetables. Most of the respondents (91.3%) used pesticides for crop protection. Average yield and expenses of vegetables was 27.5±6.5 t and $ 347.7±83.9 respectively. Expenses for vegetable production are higher as more management and care is needed for vegetable crops.

5.3.5 Problems

Farmers in the study area encountered multiple challenges with water shortage being the main problem (reported by 94% respondents) that frequently resulted in crop losses (Fig. 5.3). In contrast, respondents using waste water irrigation had no problem with water shortage, but reported deficiencies in soil quality. Tube well water users, who were using such water due to shortage of canal water, reported high production costs. In some areas farmers even left their land barren due to lack of water. Fertilizer shortage was the second most important problem that was encountered in the study area. More than half of the respondents reported that the use of fertilizer affected crop production through increased market prices and an imposed shortage of fertilizer by distributers and middlemen. However, this problem was mostly mentioned by peasants who were not able to raise the capital to buy mineral fertilizer. Marketing was also one of the main problems and was reported by 46.5% of the respondents. This problem was mostly mentioned by farmers who cultivated sugarcane, fodder and vegetables, as there were no fixed prices of these commodities. High prices of pesticides and unavailability of high quality seed and high seed prices particularly of early varieties were reported by vegetable growers as additional challenges for food production. Pesticides were used intensively in cotton and some bogus non-registered pesticide companies supplied low quality products which jeopardized cotton growers' health.

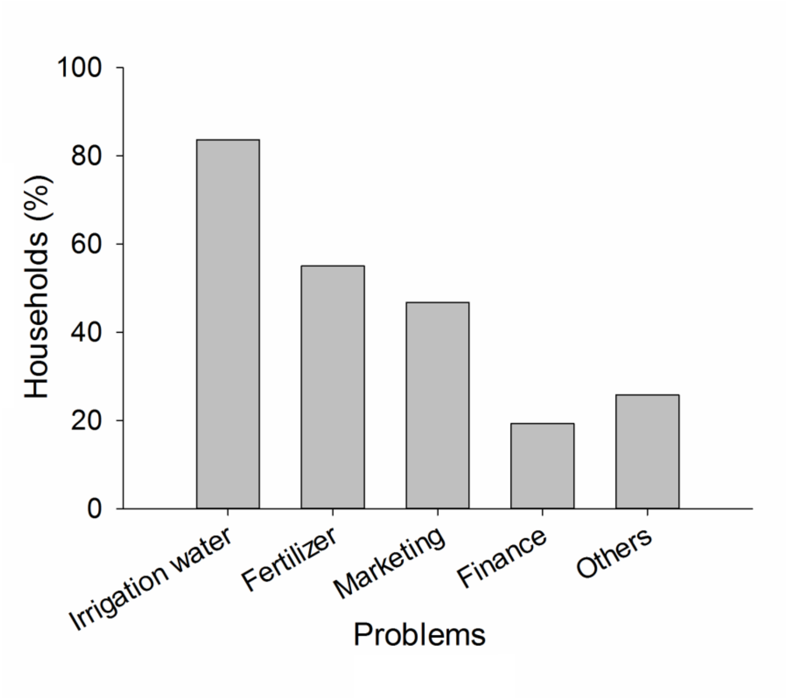

Figure 5.3 Major problems experienced by the farmers in urban and peri-urban areas of Faisalabad, Pakistan, during 2010 – 2011 (n=109).

5.4 Discussion

In Pakistan it is common that the household responsibility rests with a senior male and only in the cases where there is no male household head or male members of the family are too young, household responsibility may rest with women. These results are also supported by many other researchers (Fafchamps and Quisumbing, 1999; Naqvi et al., 2002; Hagmann, 2012) who worked in different areas of Pakistan. But there are some agricultural tasks such as hoeing of vegetables and transplanting of rice that are mostly done by women who contribute substantially to household income (Ali and Ahmad, 1984). Education plays an important role in the adoption of innovations such as balanced use of fertilizer and new machinery (Whartion, 1966; Asfaw and Admassie, 2004). More than 50% of respondents reported to be illiterate or having only primary school education. These results are supported by findings of Moaeen-ud-Din and Babar (2006) and Yasin et al. (2012) who worked on social aspects in peri-urban and city areas of Faisalabad and Multan and suggested improvements of health and education facilities as major avenues to improve household's livelihoods. Annual per capita income was found to be between US$ 1,000 and $ 2,500 for almost half of the respondents which correspond to a national per capita income of US$ 1372 (Pakistan, 2013).

Crop production and livestock farming as major sources of income in rural and peri urban areas has also been reported by others (Dorosh et al., 2003; Ali, 2007). In our study four major farming types were identified and all of them included crop and livestock farming. Most farmers growing fodder also kept animals so that at least they could produce dairy products for self-consumption. The majority of livestock holders had low land holdings which is common in Pakistan, India and other agricultural countries (Iqbal et al., 1999; Devendra and Thomas, 2002; Holden and Yohannes, 2002; Köbrich et al., 2003; Ali, 2007).

For crop production almost all the farmers used farm yard manure and mineral fertilizers, with nitrogenous fertilizer being dominant. Salam (1975) reported a high use of nitrogenous fertilizer with a reduced phosphorus use in irrigated areas of Punjab. Farmers used farm yard manure together with mineral fertilizer according to the resources they had without any calibration which may have been the main reason for yield differences among different farms. Almost all of the farmers applied fertilizer by broadcasting. These findings are supported by other researchers (Ishaq et al., 2003; Jamil, 2004; Vitousek et al., 2009), who stated yield reduction due to low or imbalanced use of fertilizer. Coady (1995) reported very variable rates of fertilizer application according to the resources of farmers, ranging from zero to more than the recommended rates in developing countries. Faisalabad is situated in the irrigated zone of Pakistan. Farmers had access to irrigation water supplied by canal system. But insufficiency of this irrigation water for crop production leads farmers to use ground water. Some farmers had their own tube wells to pump ground water for domestic and commercial use. By using this ground water costs of production increased significantly, while in some areas ground water was not appropriate for irrigation, so farmers had to rely on canal water only which resulted in low production. Murray-Rust and Velde (1994) and Meinzen-Dick (1996) reported access of farmers to ground water for irrigation in irrigated areas of Punjab and KPK. Herbicides and insecticides were most commonly used pesticides. All cotton, rice and sugarcane growers were using insecticides to protect their crops. Fodder crops were sprayed by insecticides only at early stages of growth because at later stages, when crops are fed to the animals, insecticides may harm them.

Maize, berseem and sorghum were most important fodder crops in the study area. Most farmers grew fodder on a commercial basis, but some also grew it for their own livestock and the extra fodder was sold (Sarwar et al., 2002; Younas and Yaqoob, 2005). For small land holders fodder production and milk sale is a main income source (Moaeen-ud-Din and Babar, 2006). Fodder was mainly grown by farmers with small land holdings, marginal lands or by farmers who could not afford the capital for high crop inputs. Byerlee and Husain (1993) and Kurosaki and Fafchamps (2002) worked at various sites distributed throughout Pakistan and reported crop-livestock interactions in marginal areas. Farmers marketed their extra fodder in different ways; they either sold fodder in the standing field or they supplied it to the fodder markets, where prices varied strongly according to the season. Rates were higher in the early season and were the lowest in the peak season due to changes in fodder supply. Similar trends in fodder markets were also reported by other researchers (Raja, 2001; Dost, 2003; Reynolds et al., 2005).

Pakistan is facing serious problems with irrigation water supply and this problem prevails also in urban and peri-urban areas of Faisalabad. Farmers reported that due to insufficient supply of canal water they had to rely on costly ground water. This was also reported by Masood et al. (2012) and Trimmer (1990). Trimmer (1990) suggested partial irrigation (supplying less water than crops need) to cope with this problem. Farmers who practiced waste water irrigation reported problems of soil deterioration and reduction in crop quality due to waste water associated chemicals and pathogens which can cause enteric diseases to the consumers (Fattal et al., 1986; Mara et al., 2007). Friedel et al. (2000) and Mapanda et al. (2005) reported accumulation of heavy metals and changes in microbial biomass with long term use of waste water. Irrigation and drought problems also exist in tropical countries of Africa, such as in Kenya and Ethiopia (Abate et al., 1985; McWilliam, 1986; Holden and Shiferaw, 2005; Lal and Gupta, 2009). Adequate use of fertilizer is correlated with high yields, but major problems of the studied area, i.e. high costs and black marketing of fertilizer, resulted in low yields of small land holders who cannot afford it. Correspondingly, Masood et al. (2012) and Salam (1975) reported high fertilizer prices decreasing their use by poor farmers. Unavailability of good quality seed and pesticides may also have affected crop yield (Hussain et al., 2011; Salam, 2012). Hussain et al. (2011) reported a 35-50% reduction compared to potential yield due to the low quality seed, pesticides and fertilizer application.

5.5 Conclusions

Fodder production and livestock farming are major sources of income in urban and peri-urban areas of Faisalabad. But a high illiteracy rate and insufficient knowledge about innovations prevent farmers from more efficient technologies. The shortage of irrigation water, imbalance use of fertilizers unavailability of pure inputs like seed and pesticides and ignorance of farmer’s problems by the government are responsible for low productivity of crops. To improve the situation, availability and affordable prices of quality of seed, pesticides and fertilizer may be ensured. Research is needed to identify water and nutrient efficient crops with acceptable forage quality to improve the productivity and income of UPA farmers.

Effect of fertilizer and irrigation on forage yield and irrigation water use efficiency in semi-arid regions of Pakistan

Abstract In many parts of Pakistan availability of green forage is critical to livestock farmers. Forage production is often conducted with two succeeding crops grown within one year and it is highly affected by uncertain availability of irrigation water and low levels of applied mineral fertilizers. The objectives of the present study were to (i) evaluate the effects of crop species, fertilizer type and irrigation level on yield, (ii) determine the corresponding water use efficiency and (iii) investigate relationships between chlorophyll content and crop yield as a basis for a simple sensor-based prediction of crop yield for on-farm use. To this end a two-year field experiment was conducted in Faisalabad, Pakistan, with a four time replicated completely randomized design in a split plot arrangement of a combination of fertilizer treatment (control, farm yard manure and mineral fertilizer) and irrigation (recommended irrigation, half recommended irrigation) as main plot. Subplots were assigned to cropping systems (common (CCS): Egyptian clover (*Trifolium alexandrinum* L.) followed by corn (*Zea mays* L.), drought-adopted (DACS): Oat (*Avena sativa* L.) followed by Sudangrass (*Andropogon sorghum subsp. drummondii*). Yield and irrigation water use efficiency of DACS was higher than CCS (14.8 and 26% respectively), the differences were bigger with reduced irrigation and fertilized crops used the available water better than the control. Positive linear relationships were found between chlorophyll concentration estimated by a chlorophyll meter and yield for all crops (R^2=0.63-0.96), suggesting this technique as a fairly accurate approach to predict yields of crops in vegetative growth stage.

6.1 Introduction

Agriculture plays an essential role in Pakistan's economy, as it represents a 21% share in the national gross domestic product and about 60% in total export earnings (Farooq, 2012). About 45% of the total labour force is dependent on agriculture and about 65% of the population is directly or indirectly related to this field. Livestock is the most important subsector in agriculture and adds more than 50% value to it. While other development sectors experienced a decline, the livestock sector increased in recent years. In view of the country's fast growing population, an improvement in the agricultural sector is very important for national food security and economic development. In many locations the area and production of forages is declining due to rapid urbanization and competition of forages with cash crops, which increases the need to enhance productivity on the remaining area. Particularly in irrigated areas livestock farmers rely on non-conserved fodder for animal feeding and 85-90% of the nutritional requirements of livestock are met by it (Sarwar et al., 2002). Poor availability of nutrients is considered a major constraint in livestock farming which is deficient by 38% and 24% with respect to crude protein and total digestible nutrients (Devendra and Sevilla, 2002; Sarwar et al., 2002). Pakistan has two major cropping seasons, winter (from October-November until April-May) and summer (from May-June until September-October). Choice of crop species varies with climate and season. In irrigated areas the most important forage crops are Egyptian clover (*Trifolium alexandrinum* L.) in winter and corn (*Zea mays* L.) and sorghum (*Sorghum bicolor* L.) in summer.

Fertilization and irrigation are the two most important practices in crop and resource management and much research effort concentrates on the improvement of forage production with different fertilizer and irrigation intensity (Bibi et al., 2012; Ross et al., 2004). Amanullah and Stewart (2013) found that excessive nitrogen (N) application (200 mg N kg^{-1} of soil) has a negative effect on growth and yield of oat (Avena sativa L.) while nitrogen and phosphorus (P) applied together (100 mg of each kg^{-1} of soil) can lead to large increases in final dry matter yield. Continuous use of farm yard manure (FYM) along with inorganic fertilizers increased soil fertility and ultimately forage crop yield (Ahmad et al., 2007). These authors therefore, suggested an integrated use of organic and inorganic fertilizer to enhance fodder production. For decades Pakistan has been facing problems with water scarcity due to less and erratic rainfalls and unavailability of irrigation water at critical stages of crop growth (Cheema et al., 2006; Qureshi, 2005). Under limited water availability farmers often have to choose either to fully irrigate only parts of their land or to partially irrigate the whole land. Also from a global perspective, future agriculture will be increasingly affected by water scarcity and, thus, research emphasis will rather be on the increase of production per unit of water than per unit of area (Blum, 2009; Jalota et al., 2011; Payero et al., 2009). Dry matter yield of oat and Sudangrass was less reduced under water and nutrient limited conditions than Egyptian clover and corn (Al-Khateeb et al., 2006; Bibi et al., 2012; Soler et al., 2007). However, these experiments were conducted in individual seasons or with single crops and to the best of our knowledge there is no experimental study which simultaneously tested the effect of crop type, fertilizer type and irrigation on forage yield over a whole year.

The response of crop plants to water deficits has been investigated with a wide range of techniques (Payero et al., 2009; Singh et al., 2012) and there is ample knowledge that water stress results in chlorophyll losses mainly in the mesophyll cells of crops (Li et al., 2011; Sikuku et al., 2010) which accounts for the reduced functional organization and efficiency of the photosynthetic unit. A multitude of studies confirm the accuracy of chlorophyll meter across the species but calibration is specific for each crop/species (Chang and Robison, 2003; Markwell et al., 1995). Chlorophyll meters allow the determination of the relative amount of chlorophyll by comparison of transmittance of leaf at two wave lengths i.e. 650 nm and 940 nm (Manetas et al., 1998). Many studies have shown the relationship between N and chlorophyll concentration in plants (Cai et al., 2010; Hokmalipour and Darbandi, 2011), but more research is required to explore the relationship between crop yield and leaf chlorophyll concentration.

The objectives of this study therefore were to (i) evaluate effects of crop species, fertilizer type and irrigation level on crop yield and total annual yield, (ii) determine the irrigation water use efficiency of these treatments and (iii) investigate relationships between chlorophyll concentration and crop yield as a basis for a simple sensor-based prediction of crop yield.

6.2 Materials and Methods

6.2.1 Experimental site and treatments

A field experiment was conducted at the research station of the University of Agriculture Faisalabad, Pakistan (73˚ to 74˚ E and 30˚ to 31.5˚ N) from 2010 to 2012. The area is located in a sub-tropical climate with a long-term average annual rainfall of 375 mm and temperatures extremes ranging from 0˚C in winter to 50˚C in summer (Rasul and Mahmood, 2009). Rainfall and temperature data for the experimental period were taken from the meteorological station of the University of Agriculture Faisalabad, located 500 meters away from the experimental site (Fig. 6.1). The soil was a sandy loam and has been characterized as Aridsol derived from alluvial river deposit sand. A three-factorial field experiment comprising four replications was established with i) fertilizer type (farm yard manure (FYM), mineral fertilizer (MIN) and an unfertilized control (C)), ii) irrigation level (recommended irrigation (RI) and half recommended irrigation (HRI)) and iii) cropping system (common cropping system (CCS) (Egyptian clover followed by corn) and drought-adopted cropping system (DACS) (Oat followed by Sudangrass) as experimental factors. Main plots had an area of 51.9 m^2 with four sub-plot of 11.7 m^2 area each, out of which only two were concerned for this study.

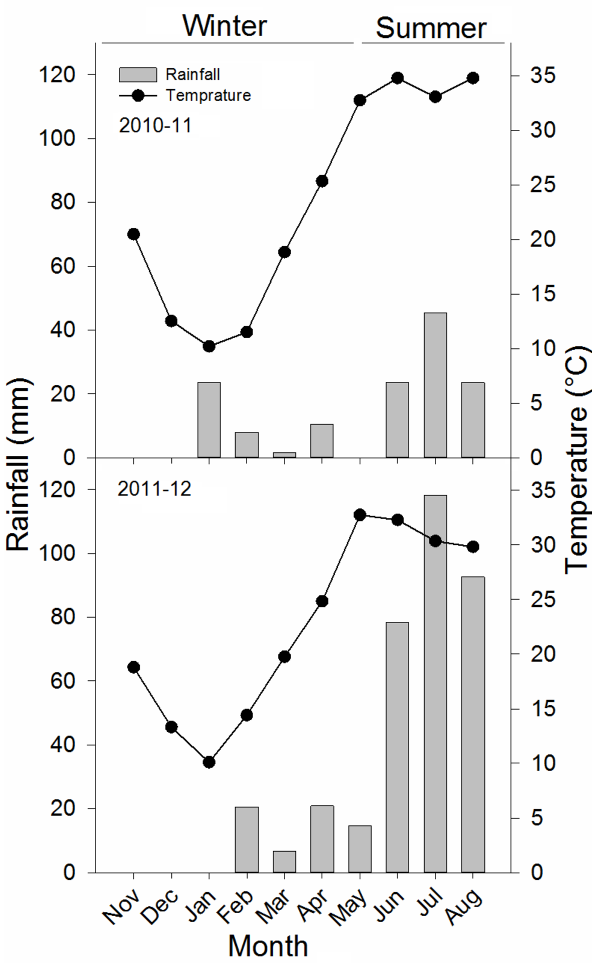

Figure 6.1 Monthly total rainfall and average temperature in Faisalabad during 2010-12.

Crops were grown in two consecutive growth periods within one year, i.e. winter (November to April) and summer (May to August). Winter crops (Egyptian clover and Oat) were sown on the 24 and 26 November in 2010 and on 22 and 21 November in 2011, respectively, while summer crops (corn and Sudangrass) were sown on the 30 May 2011 and on 23 and 27 May in 2012, respectively. Both FYM and MIN (urea and di-ammonium phosphate) were applied with 107 kg N ha^{-1} and 60 kg P^2O^5 ha^{-1}. Whole FYM and P was applied at the time of each sowing, whereas N was applied in split, half at the time of sowing and half with the second irrigation. Potassium (K) was not applied, as the soil was rich in K prior to the experiment and K did not decline during the two experimental years (Fig. 6.2). The government recommendation for irrigation in the area is at 600-800mm per season (Critchley and Siegert, 1991). Actual total irrigation applied for Egyptian clover, oat, corn and Sudangrass under RI was 840, 729, 689 and 689, respectively. Irrigation water was applied through water channels between the subplots, releasing 70-75 mm per irrigation. A 91.44 cm cutthroat flume meter with an 20.30 cm wide throat was installed at the entry point of the water to measure the amount of irrigation water applied (Siddiqui et al., 1996). To accomplish RI, irrigation interval was kept two weeks in winter and one week in summer. HRI was done by doubling the irrigation interval i.e. amount of time between the two irrigations.

6.2.2 Soil and plant sampling and analysis

Prior to the start of the experiment and at each harvest, five soil sub-samples were taken at two depths (0-20 cm and 21-40 cm) from each plot using an auger and pooled to obtain composite samples. Samples were air-dried, ground and stored until analysis. Soil pH was measured with a glass electrode in a 1:2.5 soil/water suspension. Soil N was determined as described by Bremner and Mulvaney, (1982) and available P was measured according to the procedure of Olsen and Watanabe (1957). Exchangeable K was measured by flame photometry (Dean, 1960).

Egyptian clover was harvested in three cuts, while the other crops were cut only once within a growing period. Final yield data of all crops were recorded in vegetative stages, with Egyptian clover, oat and Sudangrass in the flowering stage and corn in the milk ripeness stage. First cut of Egyptian clover was taken 67 days after sowing (DAS), while subsequent cuts were harvested after 48 days each.

Yield development within each cut was measured by taking samples during growth of crops. Data was recorded four times for each cut of Egyptian clover, whereas for oat, corn and Sudangrass, it was noted five times during the growth. Initial sampling took place 27, 46, 21, and 21 DAS for Egyptian clover, oat, corn and Sudangrass, respectively.

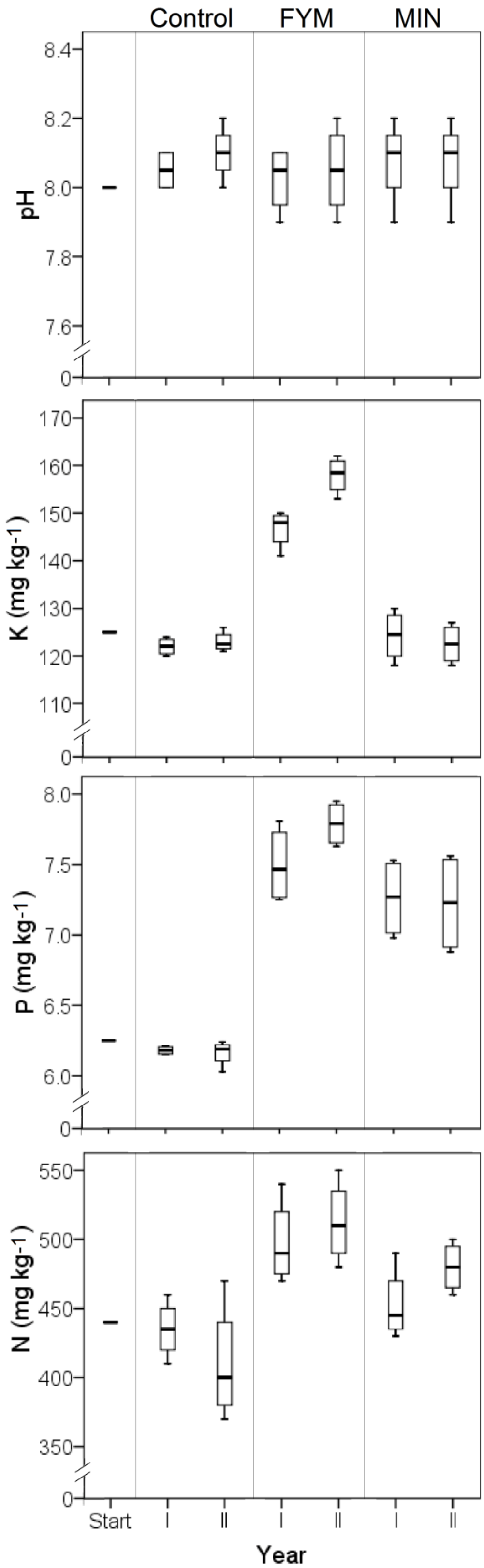

Figure 6.2 Development of nutrient status and pH in soil of fertilized (farmyard manure, FYM; mineral fertilizer, MIN) and unfertilized (Control) treatments as obtained in Faisalabad. Data shown are averages of cropping systems. Vertical bars represent median ± quartile and whiskers show minimum and maximum values.

Subsequent samples were taken every 12, 21, 14 and 14 days for Egyptian clover, oat, corn, and Sudangrass respectively. Samples of aboveground biomass were taken at a stubble height of 2.5 cm from 0.25 m2 quadrats and weighed and dried at 55 °C for 48 h. At the time of each crop sampling, relative chlorophyll concentration of leafs were estimated with a SPAD-502 meter (Spectrum Technologies, Inc., Plainfield, IL, U.S.) by measuring in the middle of 15 randomly selected leafs per plot (Hoel, 1998). Data for all parameters were recorded for two years except SPAD data that was taken only in second year.

Irrigation water use efficiency (IWUE) was calculated by using the formula of Singh et al. (2012):

$$\boldsymbol{IWUE} = \frac{\mathbf{Yi - Yd}}{\mathbf{Ii}}$$

Where Yi is the yield at irrigation level i, Yd is the yield at total dry conditions, which was assumed to be zero according to Howell (2001) and Payero et al. (2009), and Ii is the total amount of water applied at irrigation level i including rainfall water.

6.2.3 Statistical analysis

Fertilizer and irrigation were completely randomized as main-plot factors, within which cropping systems were arranged as sub-plots. The experimental treatments were identically located in both years. As the main focus was on the evaluation of annual cropping systems with respect to fertilizer and irrigation, total annual yield as average of two years was used in statistical analysis. Yield and IWUE data were analyzed with the software package MSTAT-C (Russell, 1994), considering the split-plot design of the experiment and Tukey's HSD test was used for the comparison of means. Dry matter development and SPAD data taken during growth was analyzed with the mixed models procedure in SPSS (George, 2003), considering growth stage as a random factor. Linear regressions were calculated with Sigma plot (Systat Software, Inc., 2008).

6.3 Results and Discussion

Analyses of soil for N, P, K and pH before the start of the experiment and after each season indicated a small nutrient decline in control during the study years (Fig. 6.2).

6.3.1 Dry matter yield

Cropping system (CS) effects were always significant and depended both on fertilization and irrigation (Table 6.1, Fig. 6.3).In case of total annual yield, proportion of summer crops was 50.3 and 53.9 % in CCS and DACS respectively.

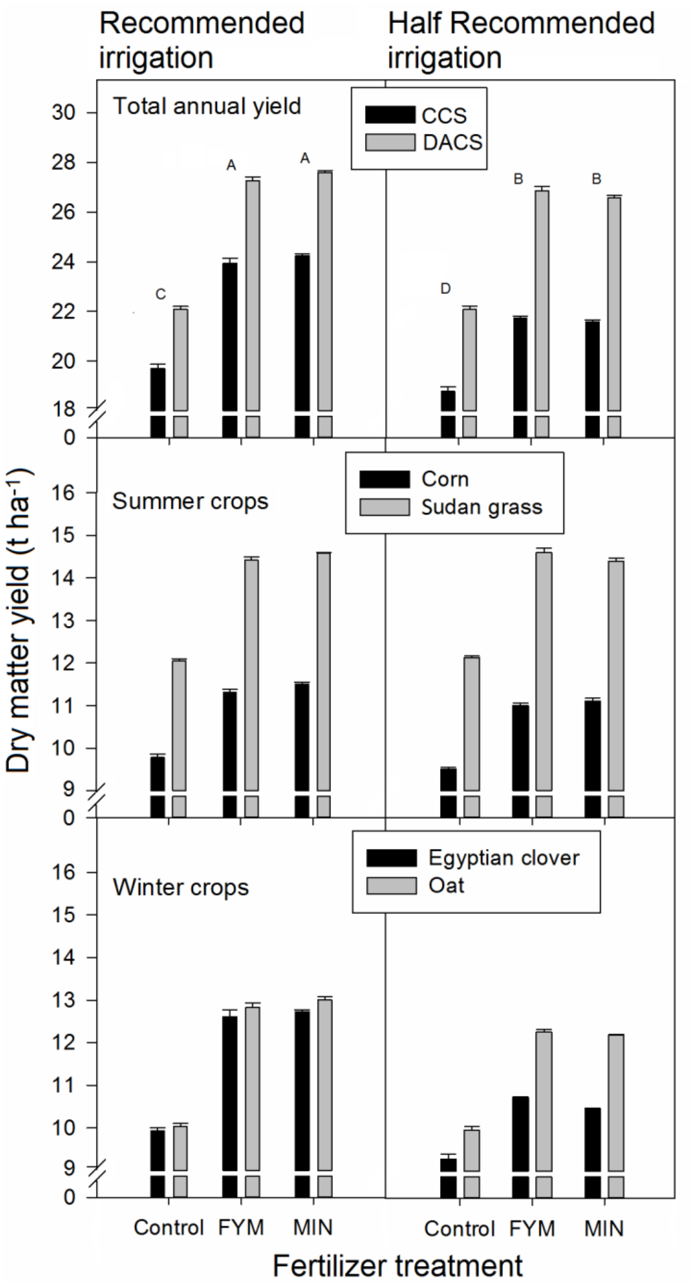

Figure 6.3 Dry matter yield of winter crops (Egyptian clover, E and oat, O) and summer crops (Corn, C and Sudan grass, S) and total annual yield of common (CCS) and drought adopted cropping systems (DACS), as affected by fertilizer (control, farmyard manure, FYM; mineral fertilizer, MIN) and amount of irrigation as obtained in a factorial on-station experiment in Faisalabad, Pakistan.. Vertical bars represent ± standard error (n = 2 yr × 4 replications; see Table 1 for statistical analysis). Means of the total annual yield are compared with Tukey's HSD test for three fertilizer and two irrigation levels.

Over all DACS produced 14.8% more than CCS and the yield difference was bigger with HRI than with RI (17.8% vs. 11.7%, respectively). Similarly overall performance of both CS was better in RI than HRI but the difference for CCS was bigger (9%) than DACS (2%). In literature there is a wide variation in irrigation effects reported for the crops investigated in the present study (Lazaridou and Koutroubas, 2004; Soler et al., 2007). Lazaridou and Koutroubas (2004) and Soler et al. (2007) reported a 65 and 25 % reduction in yield for Egyptian clover and corn, respectively, under water stress imposed by reducing irrigation by 50% in semi-arid conditions. Considering the actual environmental conditions during our study, there were 169 and 45 mm additional precipitation in summer and in winter season, respectively, which may have contributed to lower drought effects in HRI. Relative low irrigation effects were reported for oat and Sudangrass under water stress ranging from zero to full drought conditions (Bibi et al., 2012; Martin et al., 2001), which support our findings.

Table 6.1 Significant terms† from the effects of cropping system, fertilizer type and irrigation on dry matter yield (DMY) and irrigation water use efficiency (IWUE) averaged over 2010 and 2011 as obtained in a factorial on-station experiment in Faisalabad, Pakistan.

Independent variables	DMY	IWUE
Fertilizer type (F)	2133.8***	1743.7***
Irrigation (I)	369.9***	3205.4***
Cropping system (CS)	2651.5***	5673.8***
F × I	41.1***	48.6***
CS × F	39.0***	64.8***
CS × I	100.1***	727.8***
CS x F × I	ns‡	13.1***

*Significant at the 0.05 probability level.

**Significant at the 0.01 probability level.

***Significant at the 0.001 probability level.

†F-values.

‡ns, not significant.

Fertilizer effects were positive for CS and were significant ($P<0.05$), whereas interactions with CS and irrigation, although statistically significant, were of minor magnitude. Tukey's HSD test revealed no significant yield difference between the fertilized treatments, whereas compared to the control, fertilization increased the yields by 20.9 % (average across all crops and irrigation levels). Unlike to legumes in temperate climates, where no yield increases were observed when additionally N fertilized (Frame et al., 1976), Egyptian clover in the present study responded strongly to fertilization (21.2 % on average). This may be due to poor nodule formation at the roots of the establishing legumes in the first and second cut, which was also found by Clark (2007) for Egyptian clover. But this increase in the yield partly may also be due to "P" in the fertilizer. Fertilizer effects on total annual yield were stronger with RI (23.3%) as compared with the control, while with HRI the yield difference was only 18.4%. These results are supported by the other findings with corn and sorghum under comparable climatic conditions (Mubarak et al., 2009). Some researchers reported higher yields of sorghum and mott grass (*Pennisetum purpureum* S.) with the use of mineral fertilizer than with organic fertilizer (Ahmad et al., 2007). However, the reason for that may partly be that the amount of available nutrients in the mineral fertilizer treatment was much higher than in the organically fertilized treatment.

6.3.2 Irrigation water use efficiency

The IWUE further highlights the effectiveness with which crops are able to make use of this essential resource. Overall CS effects in the present study were generally significant and interacted both with fertilization and irrigation (Table 6.1, Fig. 6.4). The effects were identical in direction, but stronger in HRI (0.61 kg DM m^{-3}) than in RI (0.29 kg DM m^{-3}). IWUE of the DACS was 22 and 28% higher than of the CCS in both RI and HRI conditions respectively. Fertilizer effects, although there were significant interactions, were very similar within both cropping systems. IWUE of the fertilized treatments were significantly higher than the control, i.e. 17.9% in the CCS and 22.3% in the DACS but there were no significant difference between two fertilized treatments (Fig. 6.4). Positive effect of fertilizer on water use efficiency (84% average across all treatments) of pearl millet (*Pennisetum glaucum* L.) was also reported by Sivakumar and Salaam (1999). Irrigation effects in our study showed the same tendency in all treatments. The CCS and DACS were 63.7% and 74.4% more efficient in HRI than in RI respectively.

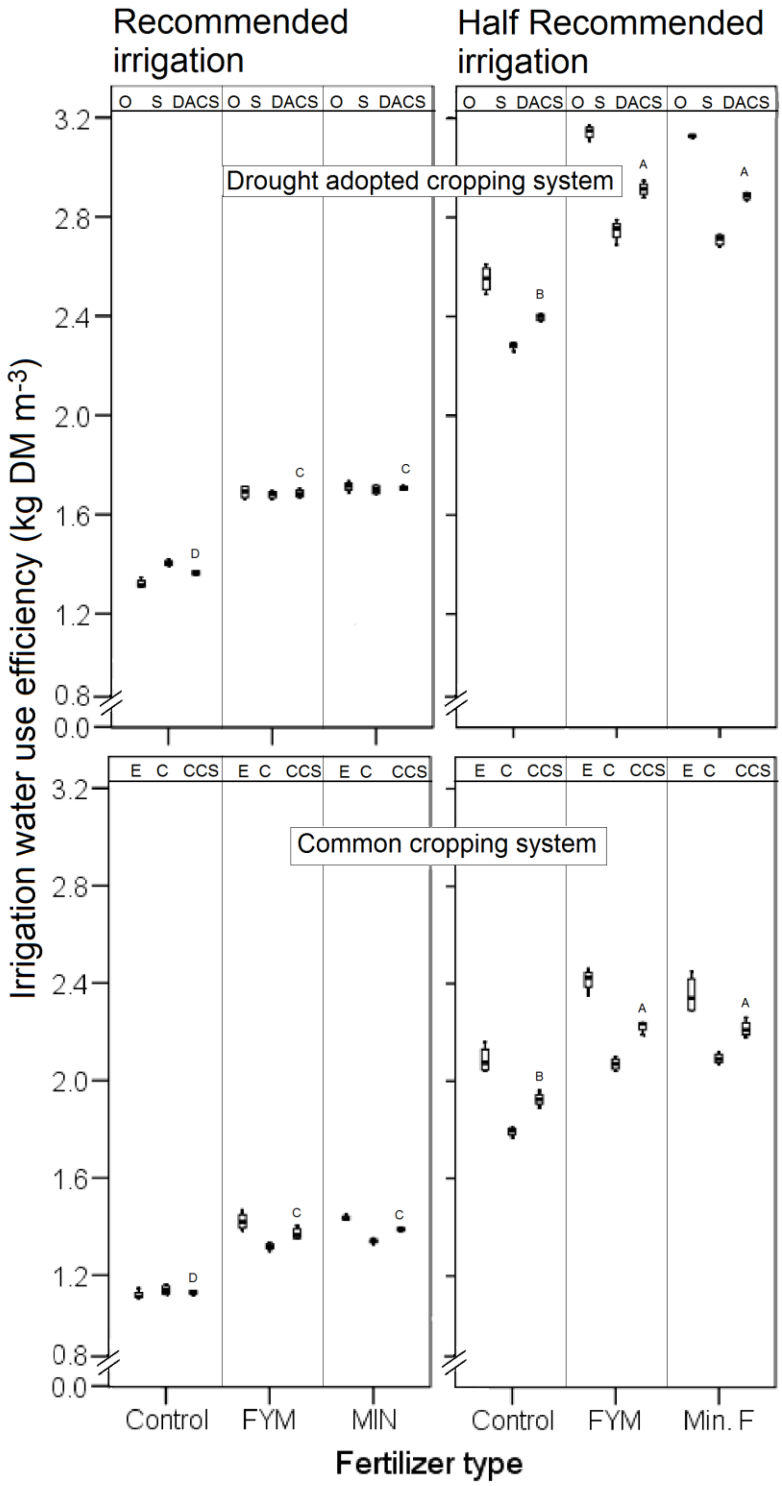

Figure 6.4 Irrigation water use efficiency (IWUE) of common cropping system (Egyptian clover, E and Corn, C and total annual, CCS) and drought adopted cropping system (Oat, O and Sudan grass, S and total annual, DACS) as affected by fertilizer (control, farm yard manure, FYM; mineral fertilizer, MIN) and amount of irrigation as obtained in a factorial on-station experiment in Faisalabad, Pakistan. Data are averages observed for the two study years 2010 and 2011 (n = 2 yr × 4 replications; see Table 1 for statistical analysis). Means of the whole cropping system are compared with Tukey's HSD test for three fertilizer and two irrigation levels.

The irrigation effects found in our study are supported by findings of Payero et al. (2009) who worked on corn under different climatic conditions, using irrigation levels from 60% to 100% of the required amount. Their results indicate that water limitation on growth does not necessarily increase even if it is reduced to 40%. Singh et al. (2012) reported that applying less water than recommended at a proper time can be a way to enhance the IWUE. Since optimal timing for irrigation varies depending on the distribution of rainfall and other environmental conditions, it should be adjusted according to local conditions.

6.3.3 SPAD value

SPAD values during growth of crops ranged between 38 (in leaves of seedlings of Egyptian clover in the 2nd cut, oat and corn) and 59 (for Egyptian clover at harvest of the 3rd cut). The values increased with increasing crop maturity, as indicated by a significant effect of growth stage for almost all crops (Table 6.2; data not shown). It is only in the week before the final harvest of corn and Sudangrass where SPAD values declined although crop yield still increased. This was also found by Bokari (1983), Costa et al. (2001) and Sanger (1971) who reported that in mature plants fibrous components were accumulating while chlorophyll-proteins were breaking down.

Fertilizer effects were significant ($P<0.05$) for winter crops, indicating an increased greenness of leaves (SPAD values) when more N was available. A close relationship between nitrogen availability and chlorophyll content in leaves was also found by Abbasi et al., 2010 and Rorie et al. (2011). Interactions of climate with SPAD values and fertilizer treatment and correlations between temperature and chlorophyll contents could be the reasons for non-significant effects in summer (Bredemeier and Schmidhalter, 2003; Talebi, 2011). No irrigation effect was found in our study for crops both in winter and in summer. There is some evidence of positive effects of irrigation on SPAD value in literature (Bredemeier and Schmidhalter, 2003; Széles et al., 2012). However, much more severe water stress of up to 80% was applied in these studies, whereas in our study water stress in HRI was still moderate.

Positive linear relationships were found between SPAD value and DMY for all crops with R^2 values between 0.63 and 0.96 (Fig. 6.5), indicating a proportional increase in leaf greenness during growth of the crops. However, for Egyptian clover, different relationships were found for each cut, which limits the applicability of the technique. It seems that insufficient information is provided with the two wavelengths used (650 and 940 nm) in the SPAD meter. Investigations on a multitude of temperate legumes showed that, by including more wavelengths or by hyper-spectral measurements crop-specific or even common models were found which allowed an accurate prediction of biomass and quality characteristics across several cuts within one year (Biewer et al., 2009).

Although the relationship for fertilized oat differed from that for the unfertilized control, differences were minor and contrasts revealed that models did not differ between the fertilized treatments. Contrarily to winter crops, common models could be fitted to corn and Sudangrass data. The lower fit in summer crops was mainly due to the chlorophyll breakdown in mature corn and Sudangrass which increased the residuals at higher levels of SPAD value.

The analysis with a reduced dataset comprising only data from vegetative growth stages increased R^2 to 0.95 and 0.78 for corn and Sudangrass, respectively. Positive relationships between yield and chlorophyll contents were also reported by other researchers who worked on different warm season grasses (Bokari, 1983) and pearl millet (Gérard and Buerkert, 2001) which supports our findings. However, low correlations were found by Costa et al. (2001) between grain yield and SPAD readings for corn, and the authors concluded that "maize researchers using SPAD should use caution when transferring published relationships to other hybrids." Thus, based on our results there is some scope that for vegetative forage crops, DMY can be predicted fairly accurately with a commercial SPAD meter.

Table 6.2 Significant terms† from the effects of fertilizer type, irrigation and growth stage on SPAD value and dry matter yield (DMY) data of different crops as obtained in 2011 in a factorial on-station experiment in Faisalabad, Pakistan.

Independent variables	Egyptian clover (1st cut)		Egyptian clover (2nd cut)		Egyptian clover (3rd cut)		Oat		Corn		Sudan grass	
	SPAD	DMY	SPAD	DMY	SPAD	DMY	SPAD	DMY	SPAD	DMY	SPAD	DMY
Fertilizer (F)	25.5***	13.1**	70.4***	15.6**	6.9*	17.3**	15.6**	8.3**	ns	4.7*	ns	9.5**
Irrigation (I)	ns‡	11.5*	ns	13.6*	ns	12.9*	ns	ns	ns	7.0*	ns	ns
Growth stage (G)	ns	127.0***	ns	92.1***	49.7***	85.6***	72.3**	164.9***	132.20*	356.6***	30.0***	289.2***
F × I	ns	ns	ns	7.6*	ns	11.0**	ns	4.3*	ns	5.6*	ns	ns
F × G	ns	7.1*	ns	8.8**	ns	ns	ns	62.9***	ns	101.6***	4.9*	144.1***
I × G	ns	11.4**	ns	6.2*	ns	10.9*	ns	ns	ns	10.8**	ns	ns
F × I × G	ns	ns	ns	3.5**	ns	ns	ns	ns	ns	ns	ns	ns

*Significant at the 0.05 probability level.
**Significant at the 0.01 probability level.
***Significant at the 0.001 probability level.
† F-values.
‡ ns, not significant.

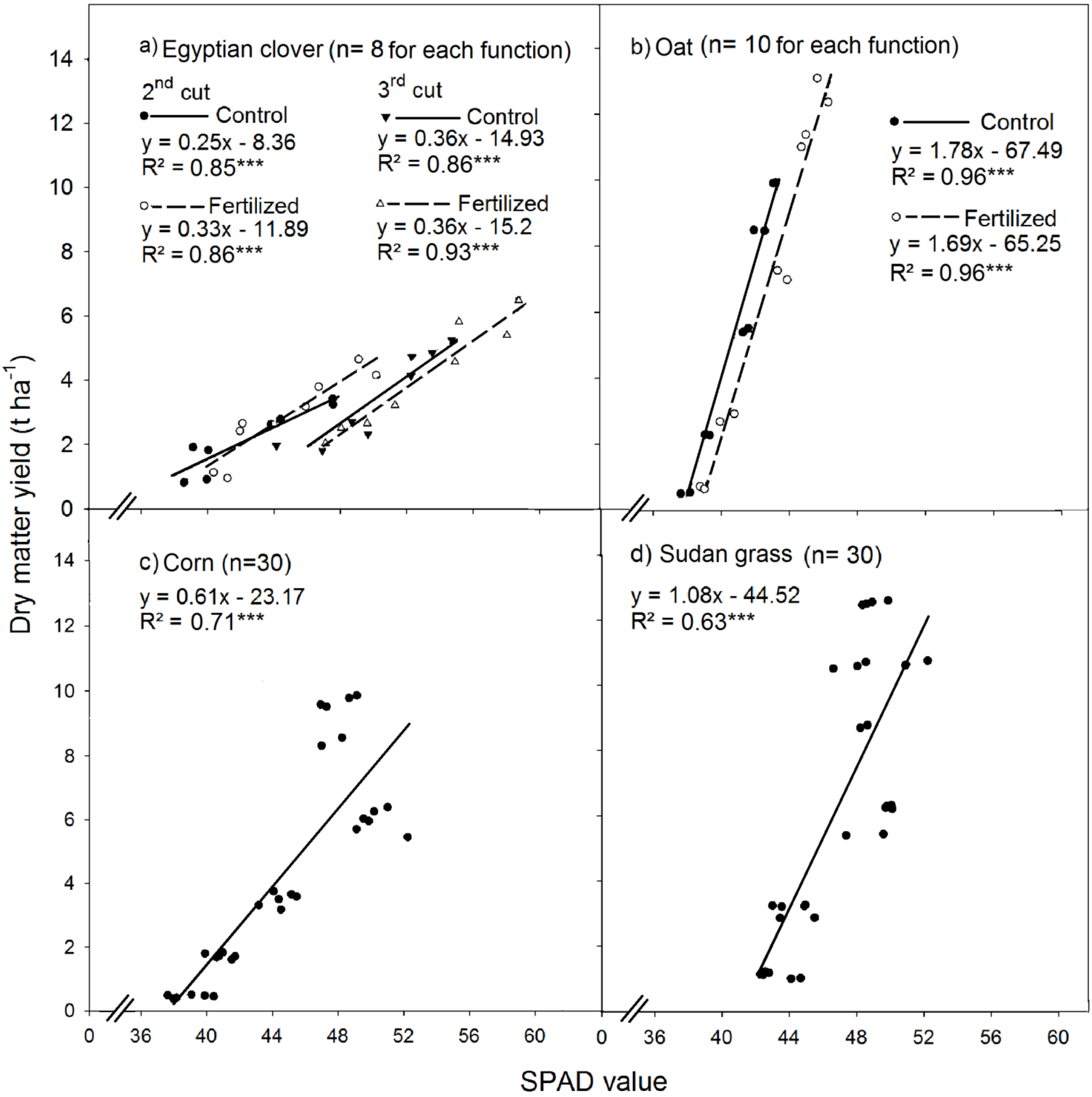

Figure 6.5 Relationship between dry matter yield and SPAD value recorded at progressing growth stages of different crops in 2011 in a factorial on-station experiment in Faisalabad, Pakistan (each data point is an average of four replications and for Egyptian clover and oat data points of the fertilized treatment are average values of farm yard manure and mineral fertilizer)

6.4 Conclusions

Results of our experiment suggest that in the semi-arid climate of Pakistan, water use efficiency of forage production can be improved by reducing the amount of irrigation water to an appropriate level. With only 721 mm of irrigation water, a cropping system with oat and Sudangrass proved to be more productive than the common cropping system with a generally recommended irrigation of 1530 mm. Fertilization increased production and water use efficiency irrespective of the cropping system. Thus, Pakistan's agriculture could be more profitable with use of animal manures, as their effect on crop productivity is similar to mineral fertilizer but available at much lower costs. The use of chlorophyll meters may facilitate a quick and reliable assessment of crop yield, contributing to a sufficient and constant daily feedstock supply, but more information is needed regarding calibrations for further crop species under varying environmental conditions. Water remains the key issue and research must continue to identify and test more water use efficient and drought tolerant crops. As Pakistan and other countries in this climate zone are facing an increasing water scarcity, additional work targeted on strategies for water efficient cropping systems can master the challenges of feeding a growing population.

Fertilizer and irrigation effects on forage protein and energy production under semi-arid conditions of Pakistan

Abstract Fertilizer and irrigation water are major inputs for forage production in semi-arid areas, and to ensure sustainability, nutrient and water efficient crop species should be used. The major objectives of the present study were to i) evaluate the effect of crop species, fertilizer and irrigation on nutritive value and ii) determine irrigation water use efficiency (IWUE) in terms of crude protein (CP) and metabolizeable energy (ME) production per unit of land. A two-year field experiment was conducted in Faisalabad, Pakistan, with a four times replicated completely randomized design in a split-plot arrangement of a combination of fertilizer treatment (control, farm yard manure (FYM) and mineral fertilizer (MIN)) and irrigation (recommended irrigation (RI), half recommended irrigation (HRI)) as main-plots. Sub-plots were assigned to two cropping systems Egyptian clover (*Trifolium alexandrinum* L.) followed by corn (*Zea mays* L.) (common cropping system, CCS) and the drought-adopted cropping system (DACS) oat (*Avena sativa* L.) followed by sudangrass (*Andropogon sorghum* subsp. *drummondii*). Crude protein concentration and IWUE of CP production per unit of land in CCS was 44 and 13% higher than in DACS, whereas ME contents and IWUE of ME production in DACS was 9.5 and 38% higher than in CCS. In view of ME as the major limiting nutritive property in roughages for feeding dairy cows, it is concluded that the tested DACS may be more suitable for sustainable forage production under water and nutrient limited conditions in semi-arid areas of Pakistan.

7.1 Introduction

Livestock production is the most important component of Pakistan’s agriculture, contributing more than 50% in value added and green forage is the basic feed for livestock, especially in peri-urban areas. Declining water availability is a big threat to sustainable production in many semi-arid regions of the world where crop production depends on supplementary irrigation (Marsalis et al., 2010), and it is predicted that availability of irrigation water may decline in the near future which may influence the price of irrigation water (World Water Assessment Program, 2009). Fertilizer is another important factor influencing Pakistan’s fodder production, whereby import and prices of fertilizer in Pakistan increased by 34 and 320%, respectively, in the past decade (Farooq, 2013). There are many commercial and semi-commercial livestock farms in Pakistan. Dung is frequently used by women to produce dung cakes (Fafchamps and Quisumbing, 1999; Hassan et al., 2007) for burning in private households which is related substantial losses of nutrients. These nutrients can potentially be used as source of fertilizer and might be important by-products of livestock production when they are effectively managed and utilized for field crop production.

Most lactating cows are fed concentrates to compensate for quality deficits in roughage especially in terms of crude protein and energy (Sarwar et al., 2002; Younas and Yaqoob, 2005) jeopardizing the profitability of dairy farming. Fulkerson et al. (2007) and Vuuren (1993) identified metabolizable energy (ME) as a major factor limiting the performance of dairy cows. There is ample knowledge on the effects of fertilizer and irrigation on fodder quality of specific crops. Philipp et al. (2005) reported an increase in ME and a decrease in fiber concentrations with reduced irrigation in three bluestem grass species (*Bothriochloa caucasica, ischaemum*, and *bladhii)*. Islam et al. (2012) investigated the effect of irrigation (0 to 480 mm) and fertilizer (0 to 158 kg N ha^{-1}) on corn forage and found that the increase in forage yield with increased fertilizer and irrigation was accompanied by decreased nutritive value. Yosef et al. (2009) reported a decrease in crude protein (CP) and water soluble carbohydrates with reduced irrigation. Simsek et al. (2011) detected a yield reduction in corn with reduced irrigation (0 to 75%), but nutritive value remained unaffected. Significant effects of nitrogen fertilizer on crude protein and fiber contents of corn (Carpici et al., 2010), bermudagrass (Kering et al., 2011) and oat (Iqbal et al., 2013; Collins et al., 1990) have also been shown.

Among the many forage crops grown in Pakistan, sorghum (*Sorghum bicolor* L.), corn (*Zea mays* L.) and Egyptian clover (*Trifolium alexandrinum* L.) are major crops for irrigated areas (Dost, 2003). Egyptian clover and corn require high amounts of water to produce adequate yields. Recent research showed that by growing oat (*Avena sativa* L.) and sudangrass, 12 and 22% higher dry matter yields could be produced than with Egyptian clover and corn, respectively, when irrigation was reduced by half (Ul-Allah et al., 2013).

Multiple cropping systems, which include more than one crop over the whole year, can be more water and nutrient efficient than cropping systems based on a single crop only.

Newton et al. (2003) reported that forage with a high nutritive value can be produced using multiple cropping systems with manure fertilizer and that nutrient recovery in multiple cropping systems is higher than in single cropping systems. Macoon et al. (2002) assigned a stronger effect to cropping system than to nitrogen fertilizer (450-900 kg N ha^{-1} $year^{-1}$) on forage quality over a full year in semi-arid conditions. Up to now, little data is available on the quality of fodder grown in cropping systems with two succeeding crops over a full year under semi-arid conditions of Pakistan. Major objectives of this study therefore were 1) to investigate the effect of fertilizer and irrigation on the nutritive value of different forage crops and cropping systems and 2) to evaluate the different cropping systems regarding the irrigation water use efficiency of CP and ME production per unit of land.

7.2 Materials and Methods

7.2.1 Experimental site and treatments

The experiment was conducted at a research station of the University of Agriculture Faisalabad, Pakistan (73˚ to 74˚ E and 30˚ to 31.5˚ N; 184 m above sea level) for two consecutive years, 2010 and 2011. The area is located in a sub-tropical semi-arid climate with cool winters and hot summers and a long-term average annual rainfall of 375 mm (Rasul and Mahmood, 2009). Rainfall and temperature data for the experimental period were taken from the meteorological station of the University of Agriculture Faisalabad, located 500 meters away from the experimental site (Fig. 7.1). The soil was a sandy loam and had been classified as an Aridisol (USDA, 1998) derived from alluvial river deposit sand.

The experimental design for each year was a three factorial completely randomized split-plot arrangement with four replications. The factors comprised i) fertilizer type (farm yard manure (FYM), mineral fertilizer (MIN) and an unfertilized control (C)), ii) irrigation level (recommended irrigation (RI) and half recommended irrigation (HRI)), as main-plot factors and iii) cropping system (common cropping system (CCS)) Egyptian clover followed by corn and drought-adopted cropping system (DACS) oat followed by sudangrass as subplot factors. Main plots had an area of 51.9 m^2 with four sub-plot of 11.7 m^2 area each, out of which only two were considered in this study.

Crops were grown in two consecutive growing periods within one year, i.e. winter (November to April) and summer (May to August). Winter crops (Egyptian clover and oat) were sown on the 24 and 26 November in 2010 and on 22 and 21 November in 2011, respectively, while summer crops (corn and sudangrass) were sown on 30 May 2011 and 23 and 27 May in 2012, respectively. Both FYM and MIN (Urea and di-ammonium phosphate) were applied with 107 kg N ha^{-1} and 26 kg phosphorus (P) ha^{-1}. Whole FYM and P were applied at the time of each sowing, whereas N was applied in split, half at the time of sowing and half with the second irrigation.

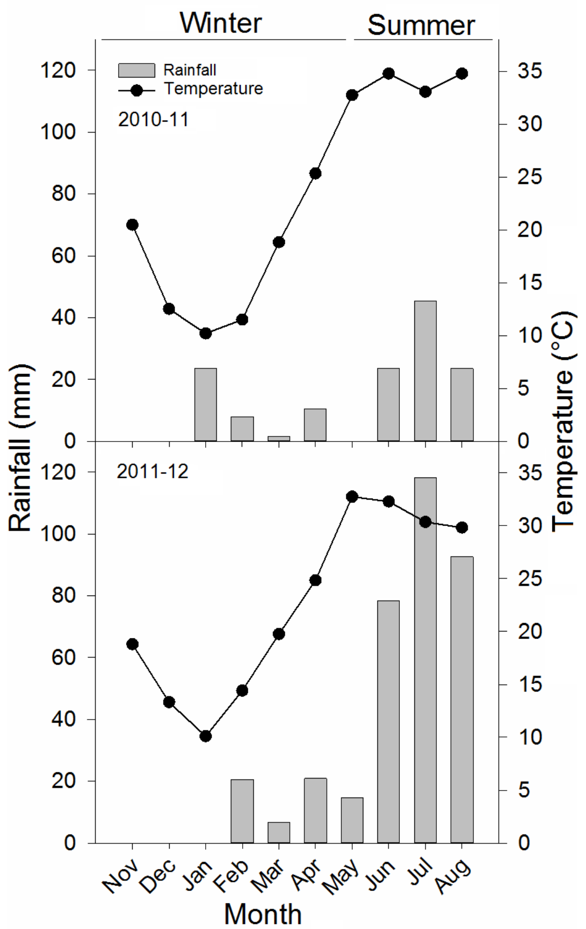

Figure 7.1 Monthly total rainfall and average temperature in Faisalabad during 2010-12.

Potassium (K) was not applied, as the soil was rich in K prior to the experiment and K did not decline during the two experimental years. The official recommendation for irrigation in the area is at 600-800mm per season (Critchley and Siegert, 1991). Actual total irrigation applied for Egyptian clover, oat, corn and sudangrass under RI was 840, 729, 689 and 689, respectively. Irrigation water was applied through water channels between the sub-plots, releasing 70-75 mm per irrigation event. A 90 cm cutthroat flume meter with an 20 cm wide throat was installed at the entry point of the water to measure the amount of irrigation water applied (Siddiqui et al., 1996). To accomplish RI, irrigation interval was kept two weeks in winter and one week in summer. Half recommended irrigation was done by doubling the irrigation interval. Thus, HRI refers to an amount of half the total seasonal applied irrigation.

7.2.2 Plant sampling and sample processing

Egyptian clover was harvested three times, while the other crops were harvested only once within a growing period. All crops were harvested in early reproductive stage, with Egyptian clover, oat and sudangrass in the flowering stage and corn in the milk ripe stage. Egyptian clover was first cut 67 days after sowing (DAS), while subsequent cuts were taken after 48 days each. Data of Egyptian clover used for statistics and figures are weighted averages of three cuts.

Samples were taken from 0.25 m^2 randomly and 500 g of fresh matter was dried at 55 °C for 48 h. Subsequently, 20 g of dried samples were ground with a 1-mm sieve with a Cyclotec sample mill (Foss Tecator AB, Höganaäs, Sweden) in order to determine their nutritive value by near infrared spectroscopy (NIRS) followed by wet analysis of selected samples.

7.2.3 Assessment of spectral data

Near infrared spectroscopy measurements were carried out to obtain reflectance spectra with a XDS-spectrometer (Foss NIR System, Hillerod, Denmark). Spectra of visible and infrared range (400-2500 nm) were collected with a data collection of every 2 nm. The spectrum of a sample was an average of 25 subscans and was recorded as the logarithm of the inverse of the reflectance [log (1/R)]. Spectral data were reduced by keeping the first of every eight consecutive spectral points. Standard normal variate and de-trend scatter correction (SNV-D) was used to correct for differences in particle size and spectral curvature of the samples. Samples for reference data analysis were selected according to spectral similarity within a Mahalanobis-distance of 0.5 to 1.0. Number of reference samples differed between experimental years with n = 40 (2011) and n = 60 (2012) due to a greater spectral heterogeneity in the second year. Furthermore, annual spectral data sets were not compatible years. Hence, two independent calibrations were established (Table 7.1).

Table 7.2 Statistics of the common NIR calibration (including Egyptian clover, corn, oat and Sudan grass) for acid detergent fiber (ADF), neutral detergent fiber (NDF), crude lipids (CL), crude protein (CP), enzyme soluble organic matter (ESOM) and ash for two years as obtained in in an experiment in Faisalabad, Pakistan**.**

		Calibration				Cross-validation		
Parameter	**N**[†]	**Mean**	**SD**	**SEC**[‡]	**R^2**	**SECV**[§]	**1-VR**[¶]	**RPD**[#]
2010-11								
ADF, g kg^{-1} DM[††]	40	319.2	64.7	17.3	0.93	25.8	0.85	2.5
NDF, g kg^{-1} DM	38	470.9	137.3	11.2	0.99	18.9	0.98	7.3
CL, g kg^{-1} DM	38	25.8	7.8	1.3	0.97	2.0	0.93	3.8
CP, g kg^{-1} DM	38	188.0	75.0	4.0	0.99	6.3	0.99	11.9
ESOM, g kg^{-1} DM	39	225.7	108.4	12.5	0.99	20.0	0.97	5.4
Ash, g kg^{-1} DM	39	126.8	31.8	5.6	0.96	8.2	0.94	3.9
2011-12								
ADF, g kg^{-1} DM	58	329.4	69.8	10.2	0.98	13.9	0.96	5.0
NDF, g kg^{-1} DM	57	513.9	145.3	20.8	0.98	28.2	0.96	5.2
CL, g kg^{-1} DM	59	20.5	7.9	1.9	0.94	2.9	0.86	2.7
CP, g kg^{-1} DM	58	147.2	70.1	7.0	0.99	9.0	0.98	7.8
ESOM, g kg^{-1} DM	33	288.7	92.1	22.2	0.94	29.5	0.90	3.1
Ash, g kg^{-1} DM	58	102.8	38.4	7.7	0.95	10.7	0.92	3.6

[†]N, number of samples used in caliberation
[‡]SEC, standard error of calibration.
[§]SECV, standard error of cross validation.
[¶]1-VR, coefficient of determination of cross-validation.
[#]RPD, ratio of standard deviation of the measured results to standard error of cross validation.
[††]DM, dry matter.

7.2.4 Laboratory analysis

The ANKOM filter paper bag method (ANKOM-200 fiber analyzer, ANKOM Technology Corp., Fairport, NY) was used to determine acid detergent fiber (ADF) and neutral detergent fiber (NDF) of the selected samples for calibration development (Vogel et al., 1999). Neutral detergent fiber was determined with a heat stable α-amylase and ADF and NDF were expressed exclusive of residual ash. Crude lipids (CL) were determined by using the ether extract method according to Naumann and Bassler (2004). Nitrogen was measured by an elemental analyzer (Vario MAX CHN Elementar

Analysensysteme GmbH, Hanau, Germany) and multiplied with 6.25 to calculate crude protein (CP). Enzyme soluble organic matter (ESOM) was determined according to Naumann and Bassler (2004). Ash was determined by putting samples in a muffle furnace at 550°C for 5 hours. The calibrations were developed with WinISI software (Version 1.63, Foss NIRSystems / Tecator Infrasoft International, LLC, Silver Spring, MD, USA) (Table 7.1).

Metabolizeable energy (ME) was calculated by using crop specific equations as stated below:

Egyptian clover (GFE, 2008):

$$ME\ (MJ\ kg^{-1}\ DM) = 5.51 + 0.00828\ \text{ESOM} - 0.00511\ \text{Ash} + 0.02507\ \text{CL} - 0.00392\ \text{ADF} \quad (1)$$

Corn and sudan grass (GFE, 2008):

$$ME\ (MJ\ kg^{-1}\ DM) = 7.15 + 0.0058\ \text{ESOM} - 0.00283\ \text{NDF} + 0.03522\ \text{CL} \quad (2)$$

Oat (Brüsemeister, 2006):

$$ME\ (MJ\ kg^{-1}\ DM) = 9.97 + 0.016268\ \text{CP} - 0.007025\ \text{ADF} \quad (3)$$

Water use efficiency can be calculated in many ways depending on the objectives of the research. Some researchers used evapotranspiration to calculate the water use efficiency (Lelièvre et al., 2011; Neal et al., 2011). In semi-arid conditions, where major concern is with the supplemented irrigation, irrigation water use efficiency (IWUE), which is based on total water applied to the crop, is more important (Blum, 2009; Payero et al., 2009; Singh et al., 2012). The objective of our study was to evaluate the water use efficiency of two cropping systems based on total water received. Rainfall in the area is not normally distributed and amount of irrigation varies with rainfall. Consequently, IWUE for crude CP and ME was calculated on the basis of total water received by the crop through irrigation and rainfall according to Purcell and Currey (2003):

$$IWUE.CP\ (g\ m^{-3}\ ) = \frac{CP\ yield\ (g\ ha^{-1})}{Total\ water\ recieved\ by\ the\ crop\ (m^3\ ha^{-1})} \quad (4)$$

$$IWUE.ME\ (MJ\ m^{-3}\ ) = \frac{ME\ yield\ (MJ\ ha^{-1})}{Total\ water\ recieved\ by\ the\ crop\ (m^3\ ha^{-1})} \quad (5)$$

7.2.5 Statistical analysis

Fertilizer and irrigation were completely randomized as main-plot factors, whereas cropping systems were established as sub-plots. The experimental treatments were identically located in both years. As the main focus was on the evaluation of whole cropping systems with respect to fertilizer and irrigation, total annual production as average of two years was used in statistical analysis. Data for ADF, CP, ME and IWUEs were analysed with the software package MSTAT-C (Russell, 1994), considering the split-plot design of the experiment and Tukey's test was used for the comparison of means. Classical eta-squared values (η^2) were calculated to measure the effect size of specific treatments and interaction (Pierce et al., 2004).

7.3 Results and Discussion

Analyses of soil for N, P, K and pH before the start of the experiment and after each season indicated a small nutrient decline in the control treatment during the study years (data not shown).

Crude protein is an important component of forage quality and a critical component in cattle diet. Deficiency of protein can lead to reduced growth and milk production. Our data did not indicate any significant effect ($P<0.05$) of fertilizer and irrigation on CP concentration (Table, 7.2; Fig. 7.2) which had also been reported for corn (Marsalis et al., 2010; Islam et al., 2012) and tall fescue (Probasco and Bjugstad, 1980) under semi-arid and warm temperate conditions with a N rate of up to 178 kg ha^{-1}. Increased CP concentration with high fertilizer application rates (up to 400 kg N ha^{-1}) was reported for sorghum, oat (Marsalis et al., 2010, Restelatto et al., 2013) and pearl millet (Rostamza et al., 2011) under subtropical and semi-arid conditions. Inconsistent effects of irrigation on CP have been reported by different researchers. No effect of irrigation stress up to 75% on CP in corn silage under semi-arid conditions was reported by Simsek et al. (2011) while others even reported a decrease with increasing irrigation level in corn (Islam et al.,

2012) and pearl millet (Sasani et al., 2004; Rostamza et al., 2011). Our data revealed significant cropping system (CS) effects in both seasons and accounted for a major portion of the total variation (Table, 7.2; Fig. 7.2). Over the whole year CCS had a 44% higher CP concentration on a dry matter basis than DACS. The difference was mainly due to the winter season with Egyptian clover having much higher concentrations than oat (Fig. 7.2). Mean CP content for CCS was 130.4 g kg^{-1} which indicates a high quality and 90.3 g kg^{-1} for DACS which is graded as fair quality forage (Trotter and Johnson, 1992; Redfearn et al., 2004).

Irrigation water use efficiency for protein production (IWUE.CP) characterizes the efficiency of crops to produce protein per unit of land with a given amount of water. All treatment effects were significant ($P<0.05$) for this trait (Table 7.2). IWUE.CP in fertilized plots was 24, 22 and 23% higher than in the unfertilized for the winter and summer seasons and for the total year, respectively, whereas Tukey's HSD test depicted no significant ($P<0.05$) differences between the two fertilized treatments. With respect to overall variability, the effect size was highest for irrigation (79% on average), while for all other effects and interactions values were much lower. Irrigation water use efficiency for protein production of HRI was 75, 69 and 69% higher than for recommended irrigation (RI) in winter, summer and total year, respectively. Over the full year IWUE.CP of CCS was 13% more than DACS. Plotting IWUE.CP against CP content showed that the superior CP concentrations of CCS in winter and DACS in summer resulted in higher values for IWUE.CP in each case and virtually neutralized the effect of each other in total year (Fig. 7.3). The difference for IWUE.CP between the cropping systems was, although significant, not very large where the efficiencies were in a similar range from 111 to 319 g CP m^{-3} and η^2 value was only 0.05 (Table 2). It was therefore concluded that with DACS, CP yield was almost similar as with CCS, but at a lower CP concentration.

Table 7.2 Significant terms† and effect size‡ for cropping system, fertilizer type and irrigation effects on crude protein (CP), acid detergent fiber (ADF), metabolizeable energy (ME) and irrigation water use efficiency (IWUE) for CP and ME production per unit of land averaged over 2010 and 2011 as obtained in in an experiment in Faisalabad, Pakistan.

Independent variable	CP		ADF		ME		IWUE-CP		IWUE-ME	
	F	η^2	F	η^2	F	η^2	F	η^2	F	η^2
Fertilizer type (F)	ns§	<0.01	ns	0.01	ns	<0.01	67.1***	0.11	727.8***	0.07
Irrigation (I)	ns	<0.01	ns	<0.01	ns	<0.01	969.9***	0.79	13657.7***	0.64
Cropping system (CS)	456.6***	0.91	118.1***	0.67	651.9***	0.94	49.4***	0.05	3664.3***	0.25
F × I	ns	<0.01	ns	0.01	ns	<0.01	4.1*	<0.01	21.7***	<0.01
CS × F	ns	<0.01	3.9*	0.05	ns	<0.01	ns	<0.01	31.7***	<0.01
CS × I	ns	<0.01	ns	<0.01	ns	<0.01	ns	<0.01	357.0***	0.02
CS x F × I	ns	0.01	ns	<0.01	ns	<0.01	4.1*	<0.01	8.4**	<0.01

*Significant at the 0.05 probability level.

**Significant at the 0.01 probability level.

***Significant at the 0.001 probability level.

†F-values.

‡η2-values.

§ ns, not significant.

Acid detergent fiber represents the highly indigestible part of forage and is frequently used to assess forage quality. Analysis of variance revealed no effect of fertilizer and irrigation on the concentration of this component (Table 2; Fig. 2). Similar results reported for ruzi grass (*Brachiaria ruziziensis*) using NPK (15:15:15) from 0 to 312 kg ha^{-1} (Panchaban et al., 2007) and corn using N from 0 to 158 kg ha^{-1} and irrigation from 0 to 480 mm (Islam et al., 2012) support these results. In contrast to our findings Kering et al. (2011) reported a 25% decrease in ADF of bermudagrass due to an increase in N application from 0 to 448 kg ha^{-1}. One reason for this finding might be the use of a very high N dose, whereas in our trial only moderate rates were used. They further reasoned that high N rates combined with optimum moisture conditions increased vegetative growth and leaf-to-stem ratio which led to the reduced fibre content.

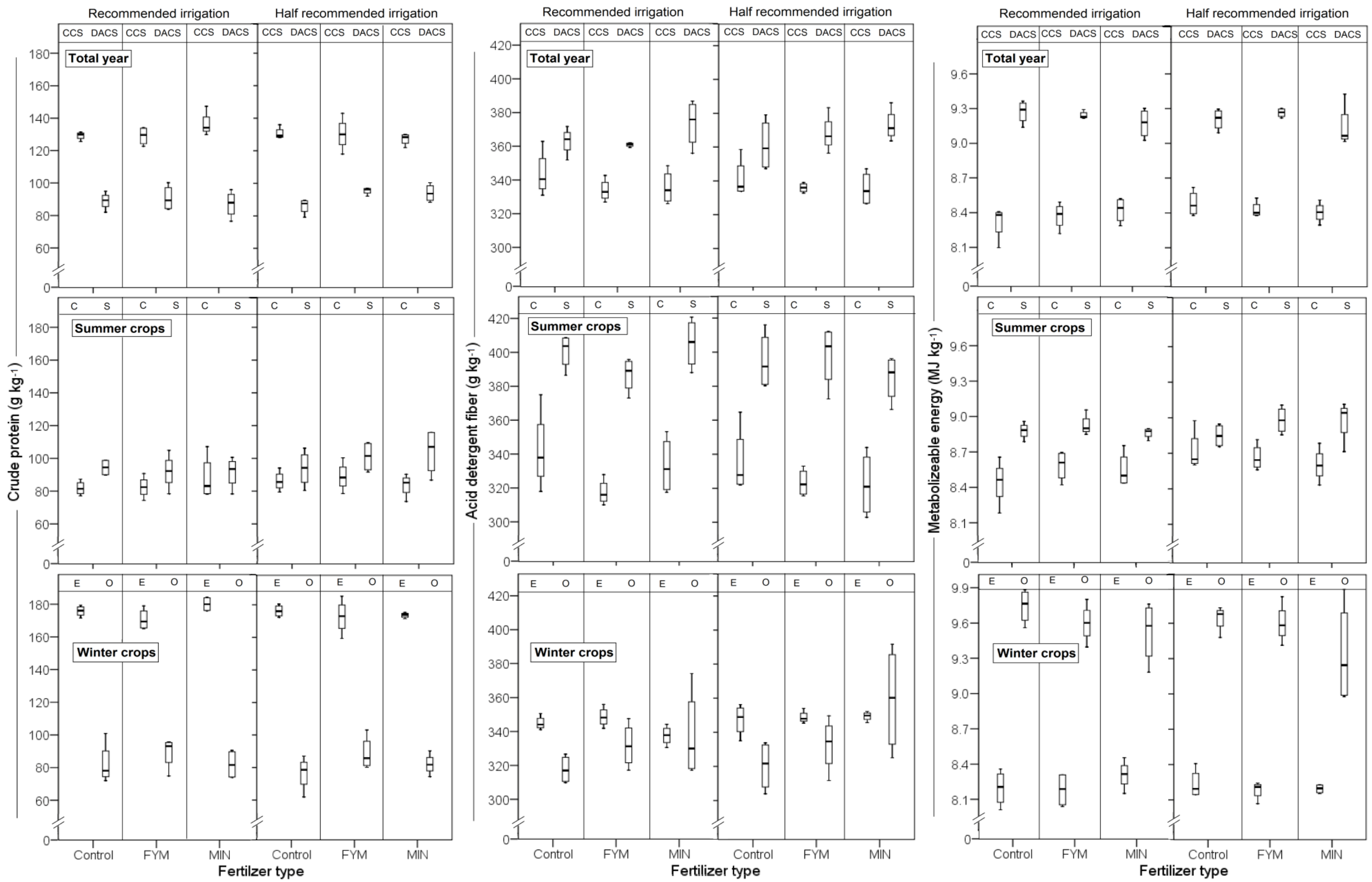

Figure 7.2 Crude protein, acid detergent fiber and metabolizeable energy of winter crops (E, Egyptian clover; O, oat), summer crops (C, corn; S, Sudan grass) and total year (CCS, common cropping system; DACS, drought adopted cropping system) as affected by fertilizer type and irrigation level as obtained in Faisalabad, Pakistan. Data are averages observed for the two study years 2010 and 2011 (see Table 7.1 for statistical analysis).

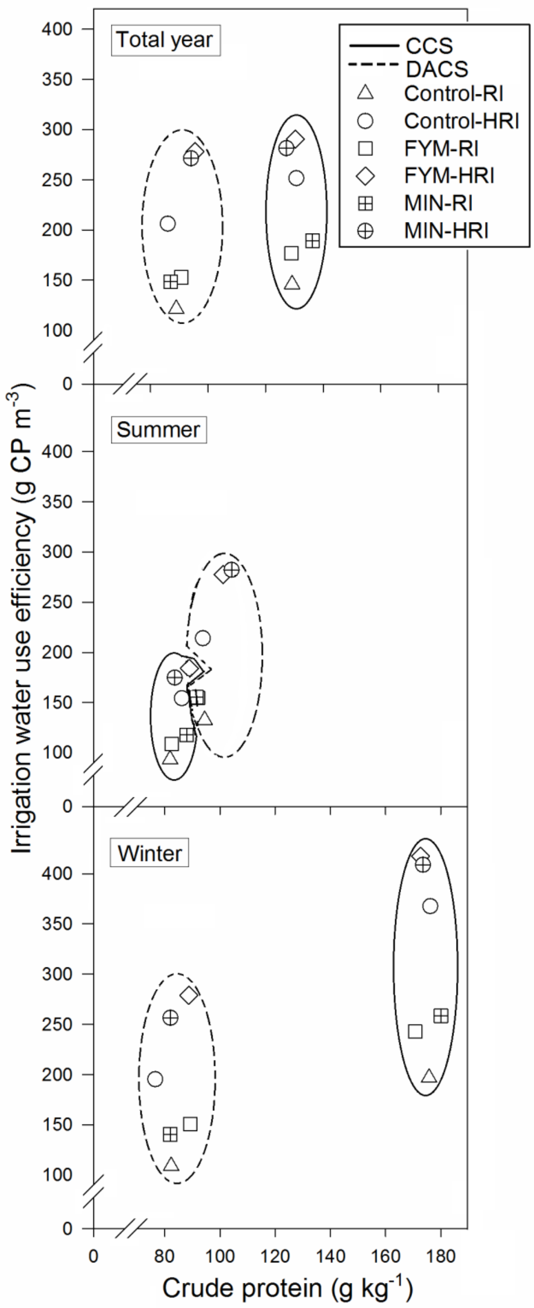

Figure 7.3 Relationship between irrigation water use efficiency of CP production per unit of land (g CP m^{-3}) and crude protein content (g kg^{-1}) of common cropping system (CCS, i.e. Egyptian clover in winter and corn in summer) and drought adopted cropping system (DACS, i.e. oat in winter and Sudan grass in summer) as affected by fertilizer type (control, farmyard manure, FYM; mineral fertilizer, MIN) and level of irrigation (RI, recommended irrigation and HRI, half recommended irrigation) as obtained in an experiment in an experiment in Faisalabad, Pakistan. Data are averages observed for the two study years 2010 and 2011 (n = 2 year × 4 replications; see Table 7.1 for statistical analysis).

The CS effect was significant ($P<0.05$) with an effect size of 67%. The ADF concentration of DACS was 29 g kg^{-1} higher than CCS. In winter, ADF concentration of Egyptian clover was higher by 4.2% than in oat which is also reported by Ross et al. (2004 and 2005). A wide range of ADF concentration for maize (Llovers, 1990; Zaidi et al., 2012) and sudangrass (Lloveras, 1990) has been reported due to differences in maturity and environmental conditions. In summer, ADF concentration in sudangrass was 20% higher than corn. This is supported by the findings of Gul et al. (2008) and Sattler et al. (2010) who also worked in semi-arid environments. Mean ADF values of CCS and DACS were 337.6 and 366.6 g kg^{-1}, respectively, which falls in good quality standards (Trotter and Johnson, 1992; Redfearn et al., 2004).

Regression analysis was carried out to investigate the relationship between ADF and ME and to assess the potential to predict ME by time and cost saving fibre analysis. This analysis revealed that the relationship for the common dataset was weak ($R^2= 0.48$) and accuracy was variable for the separate crop species with R^2 values of 0.72, 0.89, 0.95 and 0.96 for corn, sudangrass, oat and Egyptian clover, respectively. It is well known that ADF cannot be compared among different crops, as the same amount of ADF in different crops corresponds to different energy levels (Lloveras, 1990; Fulkerson et al., 2007). Thus, ME was used for further comparisons among crops and cropping systems.

Metabolizable energy is the most important limiting factor in dairy nutrition (Poppi and McLennan, 1995; Fulkerson et al., 2007; Mahyuddin, 2009). Fertilizer and irrigation effects on ME were found non-significant ($P<0.05$), whereas CS effects were significant accounting 94% of the total variation (Table 7.2; Fig 7.2). Marsalis et al. (2010) reported no effect of N fertilizer (90 to 140 kg ha^{-1}) on lactation energy of corn and sorghum under semi-arid conditions and Islam et al. (2012) found non-significant effects of pre-sown N at 0 to 135 kg ha^{-1} and 4.9% increase with the post-sown N (0 to 158 kg ha^{-1}). Increase in ME (11.5%) with reduced irrigation has been reported for corn by Islam et al. (2012) under warm temperate climate. The concentration of ME in oat and sudangrass was 16 and 3.5% higher than in Egyptian clover and corn, respectively, whereas for the total year ME of DACS was 9.5% higher than of CCS. Higher values of ME for sudangrass than corn are contrary to data which Fulkerson et al. (2008) found in a warm temperate climate. The reason for this may be that in this study corn was harvested at milk ripe stage, where the ME value of the whole crop is lower than at later growth stages (Lütke et al., 2013). Concentrations of fibre were found to decrease after silks were emerged on at least 50% of the plants (R1 stage) (Darby and Lauer, 2002; Ritchie et al., 1996) which can be attributed to the dilution effect created by the increasing content of grain as corn matures (Coors et al., 1997). This is in agreement with findings by Johnson and McClure (1968) who found lowest in vitro true digestibility at R1 stage of corn and a continuous increase afterwards. In general, ME contents for sudangrass and corn in this study were lower than those reported by Millner et al. (2011), De Ruiter et al. (2007) and by Islam et al. (2012), Perbandt et al. (2010), respectively. The reason for this may be the extremely high temperatures during summer in the study area. It is well established that an increase in temperature has a negative effect on the digestibility of grasses (Buxton, 1996) which arises mainly from an increased proportion of cell wall and a decreased digestibility of both leaf and stem (Wilson et al., 1976; Moir et al., 1977; Wilson and Minson, 1980). Mahmood et al. (2010) reported that with increased temperature leaf-to-stem ratio decreased and lignin contents increased which led to reduced digestibility and ME. Although in our data, NDF concentration in sudangrass (648.6±13.1 g kg^{-1} DM) was slightly higher than in corn (629.13±23.2 g kg^{-1} DM), higher values of digestibility of organic matter (sudangrass 600.3±26.2; corn 563.5±22.1 g kg^{-1} DM) and CL (sudangrass 16.8±1.2; corn 11.0±1.5 g kg^{-1} DM) led to higher concentration of ME in sudangrass. Generally, comparison with ME values from previous studies should be drawn with care, as our data are based on most recent formulas for predicting the energy value of forages. The ME requirements of a 600 kg cow producing 30l milk/day with a daily forage intake of 19 kg DM was reported to be 11.5 MJ kg^{-1} DM (Fulkerson et al., 2007). The present study showed that ME of both systems does not meet these requirements when fed as a sole feedstock. These findings are supported by others who identified energy as a major limitation for milk production even if top quality forage was used (Miejs, 1981; Fulkerson et al., 2007).

Irrigation water use efficiency for ME production (IWUE.ME) characterizes the efficiency of crops to produce ME per unit of land with a given amount of water.

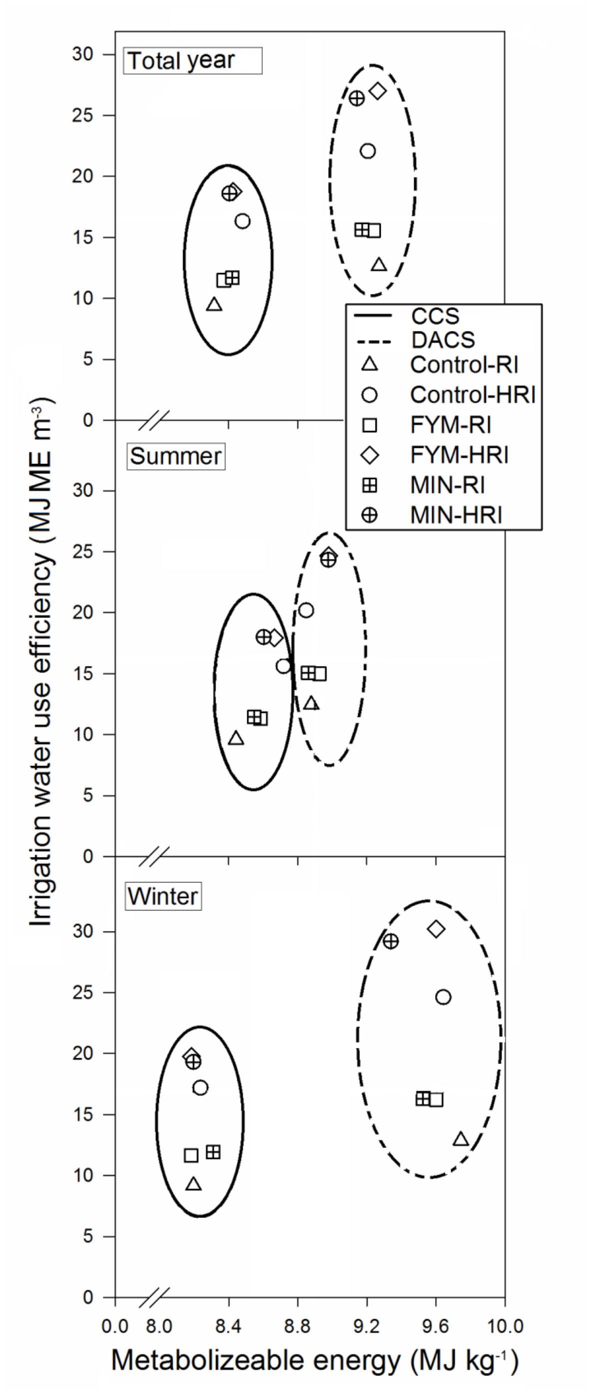

Figure 7.4 Relationship between irrigation water use efficiency of ME production per unit of land (MJ ME m^{-3}) and metabolizeable energy (MJ kg^{-1}) of common cropping system (CCS, i.e. Egyptian clover in winter and corn in summer) and drought adopted cropping system (DACS, i.e. oat in winter and Sudan grass in summer) as affected by fertilizer type (control, farmyard manure, FYM; mineral fertilizer, MIN) and level of irrigation (RI, recommended irrigation and HRI, half recommended irrigation) as obtained in an experiment in Faisalabad, Pakistan. Data are averages observed for the two study years 2010 and 2011 (n = 2 year × 4 replications; see Table 7.1 for statistical analysis).

ANOVA for IWUE.ME showed significant differences for all treatments and interactions (Table 7.2). Tukey's HSD test revealed that IWUE.ME of fertilized treatment (average of

FYM and MIN) was significantly higher (20%) than the unfertilized control, whereas differences among the two fertilized treatments were not significant. IWUE.ME of half recommended irrigation was 80, 60 and 70% higher than recommended irrigation in winter, summer and total year, respectively. Effect size of irrigation was highest (64%) followed by the crop effect (25%), whereas for fertilizer and interactions effect sizes were, although significant, less than 10% (Table 7.2; Fig 7.4). The IWUE.ME of DACS was higher than CCS in both seasons (46 and 33 % in winter and summer, respectively) and for the full year (38%) and was due to DACS's superior biomass yield (Ul-Allah et al., 2013) and ME concentration (Fig. 7.2).

Average milk yield per day for dairy cows in Pakistan is reported to amount to 8 litre (Pasha, 2007; Shah et al., 2009), but commercial farmers with better feed and management may obtain up to 20 litre (Hagmann, 2012). National human population increases faster than milk production (Bilal et al., 2006), although there is an increasing trend in milk production related to an increase in animal numbers (Khan et al., 2013). According Chattha et al. (2013) the performance of the dairy sector is far below its potential and can be increased by better nutrition and management practices. Assuming a doubled milk production as compared to the average dairy cow (i.e., 16 litre per day) without any increase in animal numbers, the estimated nutritive demand of a dairy cow weighing 550 kg would be 1762 g CP and 135 MJ ME per day. To meet these requirements cows would have to eat 19.6 kg DM per day containing 90 g CP kg^{-1} DM and 7.2 MJ ME kg^{-1} DM (FAO, 1998). Both cropping systems could fulfil these requirements as CCS contained 130 g CP kg^{-1} DM and 8.4 MJ ME kg^{-1} DM and DACS contained 90.3 g CP kg^{-1} DM and 9.2 MJ ME kg^{-1} DM. Broderick (2003) reported an increase in milk yield of dairy cows with increased concentration of CP and ME in forage. However, increasing CP reduced the N use efficiency, whereas increasing energy improved it. Poppi and McLennan (1995) reported a loss of N from the rumen due to the use of legumes and grasses high in CP and low in energy. Nitrogen gets lost in the form of NH_3 through urine, causing pollution to the environment. In summary, the implementation of DACS in Pakistan's agriculture may contribute to a more efficient and sustainable forage production and by this may enhance also the profitability of Pakistan's dairy industry.

General Discussion and Conclusions

8.1 General Discussion

Agriculture is a major source of income for the people living in rural or peri-urban areas. In Pakistan, major components of the agriculture are livestock and crop production which account more than 90% value added (Farooq, 2013). Major crops in the country include wheat, cotton, rice, sugarcane and corn while forages and pulses are considered as minor crops. Potential yield of crops increased due to genetic improvement and better production technology. However actual yield is much lower than the potential due to the unavailability of adequate amount of inputs like irrigation and fertilizers at proper time. Availability of irrigation water is very important in semi-arid regions but normal supplies of water are not sufficient for crop production. Most often the famers receive irrigation water even less than normal supplies (Farooq, 2013) consequently they have to pump ground water to fulfill the requirements of crop (Murray-Rust and Velde, 1994; Meinzen-Dick, 1996). This shortage severely affects their crop production if they have no access to ground water or increases cost of production due to high cost of ground water. Present study emphasizes on forage production with limited water and fertilizer availability especially in semi-arid regions and was carried out in Faisalabad. Baseline survey of the study area revealed that forage corn, sorghum and Egyptian clover were major commercial crops of the area whereas wheat and rice were mainly grown for domestic consumption. Most of the farmers had low land holdings or they were tenants with short term contracts. Therefore they hesitate to adopt modern technologies which might benefit them in a long run due to high initial cost. These results are supported by the findings of Sheikh et al. (2003) and Sharif (2011) who reported tenant system in irrigated regions of Punjab. The problem of small land holdings can be solved if famers with connected lands agree to work together to manage their land collectively but it is possible only when these famers decide to grow same type of crops. Successful adaptation of such kind of system in India has been reported by Ebrahim (2000). Livestock farming is another important sub-sector of agriculture in the study area where integrated crop and livestock farming was common. Most of the famers growing forage also kept milk and draught animals for domestic or commercial purposes. This system could be a key factor for achieving food security and environmental sustainability (Lemaire et al., 2013) as food and milk become available for household use and recycling of the nutrient occur when farm yard manure

(FYM) is used for crop production. This type of system with mixed crop and livestock farming has been reported as the backbone of agriculture in tropics (Thornton and Herreroa, 2001). For better livestock production, an appropriate amount of feed with good nutritive quality is very important. Sarwar et al. (2002) suggested proper fodder research in terms of inputs and agronomic practices to overcome the gap between forage demand and supply. Most important inputs for forage production are the availability of irrigation water and fertilizer. These two were reported as major problems of the study area. The farmers had access to FYM but due to unawareness and improper use, they could not get proper benefit from it. In the study area, farmers used FYM alone or integrate it with mineral fertilizer (MIN) according to the resources they had and did not calibrate it according to the nutrient availability. In this situation of limited nutrient and water availability, it is critical to improve the forage production with acceptable forage quality as these limitations may affect the forage quality. Identification of water and nutrient efficient crops could be a possibility to overcome these problems.

To deal the fertilizer and irrigation problems, in the present study a field experiment was conducted with two cropping systems i.e. common cropping system (CCS) and drought adaptive cropping system (DACS). Fertilized treatments (MIN and FYM) produced significant ($P<0.05$) higher yields than control whereas no significant differences were observed between the two fertilized treatments. Studies had been performed to evaluate the effect of fertilizer and irrigation on the yield of different crops but there were differences in the conclusions due to divergence in the conditions of the study areas (Jensen et al., 2001; Jing et al., 2007; Mohammad and Ayadi, 2005; Volesky and Berger, 2010). Improvement in the soil quality such as increased porosity and water holding capacity with low bulk density and recycling of nutrients with use of FYM have also been reported (Haynes and Naidu, 1998). Schjønning (1994) investigated the effect of long term cultivation with and without fertilizer on the physical properties a sandy soil and found improvement in the former case.

Most important component for plant growth is water which not only fulfills the needs of transpiration but also transports the mineral nutrients to different parts of the plant from the soil. Unavailability of water for crop growth; also known as drought, is an abiotic stress that limits plant growth, development, and productivity. It is unpredictable and depends on factors like soil moisture retention, distribution of rainfall and availability of irrigation water (Cairns et al., 2013; Rockström et al., 2003). Pakistan's agriculture is facing problem of drought due to less and erratic rainfalls and unavailability of irrigation water at critical stages of crop growth (Cheema et al., 2006; Mirza and Ahmed, 2005). The Determination of the crop response to irrigation water is very important for an effective irrigation management. Farmers with limited availability of water often have to choose either fully irrigated small area from the whole or partially irrigated whole area. By looking at water scarcity in the world, it seems that in future agriculture will take place under deficit irrigation and research emphasis would be on maximum production per unit of water instead of per unit area (Fereres and Soriano, 2007; Payero et al., 2009). To address the issue of water shortage current study focused on irrigation interval. For this IWUE was calculated instead of water use efficiency as it based on the amount of irrigation applied to the crop (Payero et al., 2009; Singh et al., 2012). When the availability of nutrients combined with recommended irrigation (RI), it produced maximum biomass yield while with half recommended irrigation (HRI) yield reduced due to the water stress. Due to the effect of water stress on nutrient availability, interaction of irrigation and fertilizer was also significant ($P<0.05$). Russelle et al. (1981) conducted an experiment in a humid continental climate with different combinations of irrigation and fertilizer treatments and reported maximum yield with relatively low N rate coupled with light and frequent irrigation. Heavy and frequent irrigation may cause wastage of water and leaching of nutrients (Behera and Panda, 2009) hence it is very important to know the timing of the irrigation. In this experiment higher yield was found with RI but for DACS differences were very small between the RI and HRI which gave nearly double IWUE value of DACS in HRI. Although DACS showed higher IWUEs than CCS at both irrigation levels but differences were huge with HRI revealing the relative better performance of the DACS in HRI. Less sensitivity of both crops used in DACS for water stress have also been reported by others (Bibi et al., 2012; Hlavinka et al., 2009; Martin et al., 2001).

A better crop growth is very important to attain good final yield. In the present study dry matter accumulation with advancement of growth was studied for all crops to observe the growth patterns. The growth of Egyptian clover was at maximum in the third harvest and it was at minimum in the first harvest. This growth behavior can be explained by the factors like temperature, availability of light and growth stage. In the first harvest, poorly developed seedlings with weak tillers along with short days and low temperature depressed the growth but in the second harvest all the things improved and finally in the third harvest growth was maximum because number of tillers increased with the cuttings and the leaf area was maximum with optimum temperature to capture light for photosynthesis that ultimately increase the dry matter accumulation. This type of growth pattern in Egyptian clover has also been reported (Medhat Y. Abou and Hoda, 2009; Ross et al., 2004 a, b). Fertilized treatments coupled with RI produced maximum dry matter. At early and late stages of the growth, rate of dry matter accumulation was poor for all crops while it was at maximum in the mid period of the growth. Growth was poor in the beginning because there were less tillers and leaf area to capture light for photosynthesis, but in the mid period there were maximum tillers and leaf area for photo synthesis resulting in maximum dry matter accumulation. With the advancement of growth reproductive phase of the crop started and produced energy goes to flower and seed formation, consequently dry matter accumulation decreased. These findings have been supported by others who found similar growth trend (Amanullah and Stewart, 2013; Bazán et al., 2009; Yazdani, 2013). Dry matter accumulation in summer was comparatively more even with short growth duration. Possible explanation might be that in summer season, there was more availability of sunlight than in winter and also forage species used in the summer were C-4 which have more photosynthetic efficiency than C-3 species that were grown in winter (Bokari, 1983).

Chlorophyll contents are responsible for light capture and photosynthesis which leads to dry matter accumulation. Therefore it was assumed here that there would be some relationship between chlorophyll contents and dry matter yield which can be used to estimate the biomass yield of standing crop from the chlorophyll contents. For this purpose dry matter yield and chlorophyll contents were recorded with the growth of crops. Chlorophyll contents were recorded with the help of chlorophyll meter (SPAD-502 Minolta Osaka Co., Ltd., Japan) which is an efficient, economic and non-destructive tool. It has been used to measure the chlorophyll content of different crops for many years (Markwell et al., 1995; Chang and Robison, 2003; Wang et al., 2013). SPAD meter does not have any units therefore relative chlorophyll contents (SPAD value) are used in this study (Loh et al., 2002; Wiersma, 2010). As plant grows from seedling to maturity, physiological and biochemical changes starts that goes along with the growth. Due to these changes concentration of different contents like chlorophyll, proteins, and toxins in the plant also changes. Change in the relative chlorophyll contents with growth was investigated. In the present study crops showed divergent behavior for changes in chlorophyll contents with growth because of the differences in the growth behavior. In the first and second harvest of Egyptian clover there was only vegetative growth therefore differences between different growth stages were non-significant and the light harvesting throughout the growing season remained same. In the third cut crop was harvested when it was in the reproductive phase therefore the differences were significant ($P<0.05$) for the growth stage. In oat and maize final data was taken when crops were at reproductive stage, thus the differences were slightly significant ($P=0.05$). In the Sudan grass final data was also taken at the productive stage but here the differences were significant ($P<0.05$). This might be due to the specific specie and environment interaction. The process of maturity may add more fibrous material along with breakdown of chlorophylls material that causes decline in chlorophyll contents. Similar findings reported by others (Sanger, 1971; Bokari, 1983; Mafakheri et al., 2010; Devi et al., 2011) support these results. Regression analysis between the dry matter yields and the SPAD values revealed direct relationship between both traits. However regression line was not same for all the crops so the calibration for specific crop cannot be used for others. These findings are supported by the results of others who worked on different crops but found similar type of relationship (Bokari, 1983; Blackmer and Schepers, 1995).

Besides yield, forage quality is also an important component of forage research programs as animal production and efficiency depends upon quality of the feed fed to them. Forages not only provide energy and protein but also the fibers to the animal for chewing and rumen health. Livestock farmers prefer good quality forage as it can give higher returns in the form of more milk or meat. Climate, maturity, nutrient availability and irrigation water are the most important factors influencing the forage quality. Samples from the field experiment were collected and stored for quality assessment. Researchers across the globe adopted various quality parameters to evaluate the forage. Crude protein, fiber contents and energy value are widely used parameters to assess the forage quality (Llovers, 1990; Trotter and Johnson, 1992; Getachew et al., 2002; Sasani et al., 2004; Rostamza et al., 2011; Zaidi et al., 2012). Energy and protein are most important nutritive components for dairy cows (Undersander, 2001) as these affect the milk yield. It is well known that grass forages have higher fiber contents and lower protein contents relative to legume forages but digestibility of the grass fibers is more than legumes. The reason is that grasses have much higher proportion of hemicellulose (NDF - ADF) which is digestible part of the fiber component (Fulkerson et al., 2007). In this study, two cropping systems (CCS and DACS) were evaluated for the forage quality components. CP concentration of CCS was relatively more while ADF and ME of DACS were relatively higher. DACS produced higher value of energy even it had higher ADF contents; reason behind it might be more digestibility of the ADF contents of DACS than CCS. Higher fiber digestibility of corn and Sudan grass than Egyptian clover and oat has also been reported (Downes et al. 1974; Tabana, 2000). Effect of irrigation on forage quality was inconsistent. It is reported that if water stress imposed at moderate level did not cause leaf loss, it can improve the quality of forage by delaying the maturity (Halim et al., 1989). In the presented study water stress was moderate, it does not had significant effect on the CP and ADF concentrations, but effect on the ME was significant ($P<0.05$). In stress conditions amino acids and carbohydrates may translocate from leave to stem resulting higher concentration in the stem and lower in the leaves, thus overall concentration remained same. These results are supported by the findings of (Wang and Frei, 2011) who reviewed the impact of abiotic stress on crop quality. Undersander et al. (1987) reported no effect of moderate stress on forage digestibility however he reported reduction in digestibility due to severe stress.

Irrigation water use efficiencies (IWUEs) of CP and ME production and their relationship with respective component concentration were studied. CCS was more water efficient for CP in winter whereas DACS was more efficient in summer resulting nearly similar IWUE-CP of both systems. Whereas the concentration of CP remained higher in CCS due to much higher CP contents in Egyptian clover. IWUE-ME of DACS was higher in both seasons and total year. As IWUEs were based on production of respective component, so it can be concluded that system with higher IWUE gave a higher production of the respective component. According to this, both systems had nearly similar CP yield but ME yield of DACS was higher than CCS. Hence DACS would be better option for the forage famers in water limiting areas.

8.2 Conclusions

Based on assessment of the whole study following conclusions can be drawn

i) On farm problems like shortage of irrigation water, imbalance use of fertilizer, unavailability of pure inputs and poor access to modern technologies were identified as major hurdles in getting higher yields.

ii) Use of chlorophyll meter may facilitate a quick and reliable assessment of crop yield, contributing to a sufficient and constant daily feedstock supply.

iii) Nutritive quality of both systems was in acceptable range but drought adoptive cropping system (DACS) was more productive as both cropping systems produced nearly similar CP yield whereas DACS produced higher dry matter and ME yields.

iv) Implementation of DACS in Pakistan's agriculture may contribute to a more efficient and sustainable forage production that may also enhance the profitability of the farmers.

Recommendations

Based on the results of the whole study some recommendations for farming practice and future research can be formulated:

At farmer's level

- There definitely is a need of a competent extension service which should teach farmers about new technologies and processes in crop production.
- Better control of prices and quality of seed, pesticides and fertilizers would improve the situation.
- Proper management of farm yard manure and irrigation water and selection of drought adopted crops would contribute to a more profitable crop production.

Future research

As Pakistan is facing an increasing water scarcity and costs for fertilizers, more work is necessary that targets strategies for water and nutrient efficient cropping systems to master the challenges of feeding a growing population. This work may include,

- Selection and development of new varieties of selected crops which can maintain growth in stress condition without having significant effect on nutritive quality.
- Further studies should test the effects of irrigation and available nutrients at various levels on selected cropping system to identify the most economic and profitable combination.
- Although assessment of chlorophyll contents with chlorophyll meter is reliable, more information is needed regarding calibrations of further crop species and varieties under varying environmental conditions. As the models were weak for corn and Sudan grass, additional parameter like specific leaf area might increase the accuracy of models.
- NIRS calibration work should be extended using forage samples of various growth stages ranging from start of growth to maturity for forage quality assessment and calibrations should be tested across various environmental conditions to broaden the applicability.

- For the evaluation of new cropping systems targeted field trials need to be carried out under varying soil and environmental conditions. Resulting data could be used for the validation of dynamic growth models, which would provide the possibility to transfer experimental findings to other soils and environments.

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Affidavit

I herewith give assurance that I completed this dissertation independently without prohibited assistance of third parties or aids other than those identified in this dissertation. All passages that are drawn from published or unpublished writings, either words-for-word or in paraphrase have been clearly identified as such. Third parties where not involved in the drafting of the materials contents, of this dissertation; most specifically I did not employ the assistance of a dissertation advisor. No part of this thesis has been used in another doctoral or tenure process.

Witzenhausen, December, 2013

Sami Ul-Allah

Green forage is the most important feed for livestock in Pakistan but with rapid urbanisation demands are increasing with reduced arable land. The first study of this book is about socio-economic structure of forage producing farmers. This study identified availability of irrigation water and high cost of fertilizers as major problems of the farmers. Second study of this book investigates the effect of cropping system, fertilizer and irrigation on total annual biomass yield of forage. This study found drought adoptive cropping system more productive and water use efficient with limited resources of fertilizer and irrigation. Third study evaluates the effect of fertilizer, irrigation and cropping system on crude protein (CP) and metabolizable energy (ME) and irrigation water use efficiency of CP and ME. This study also identified drought adoptive cropping system more productive and water use efficient with respect to CP and ME.

From the whole study it can be concluded that the implementation of DACS in Pakistan's agriculture may contribute to a more efficient and sustainable forage production and by this may enhance also the profitability of the farmers.

ISBN: 978-3-86219-722-4