THE IMPROVEMENT OF STRATEGIC CROPS PRODUCTION VIA A GOAL PROGRAMMING MODEL WITH NOVEL MULTI-INTERVAL WEIGHTS

IBRAHIM ZEGHAITON CHALOOB

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Awang Had Salleh
Graduate School
of Arts And Sciences

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Abstrak

Pada masa kini, keperluan untuk meningkatkan pengeluaran pertanian telah menjadi satu tugas yang mencabar bagi kebanyakan negara. Secara umumnya, terdapat banyak faktor-faktor sumber yang mempengaruhi kemerosotan tahap pengeluaran seperti paras air yang rendah, penggurunan, kemasinan tanah, kekurangan modal, kekurangan peralatan, impak eksport dan import tanaman, kekurangan baja, racun perosak dan peranan perkhidmatan pengembangan pertanian yang tidak berkesan dalam sektor ini. Objektif utama kajian ini adalah untuk membangunkan model matematik pengaturcaraan gol kabur (FGP) untuk memaksimumkan pengeluaran tanaman pertanian yang membawa kepada peningkatan manfaat pertanian (lebih tan hasil setiap ekar) berdasarkan peminimuman sumber utama untuk menentukan pemberat dalam fungsi objektif (air, baja dan racun perosak) tertakluk kepada kekangan yang berbeza (kawasan tanah, pengairan, buruh, baja, racun perosak, peralatan dan benih). GP dan FGP telah digunakan untuk menyelesaikan pembuatan keputusan pelbagai objektif (MODM). Daripada keputusan, kajian ini telah berjaya memperkenalkan kaedah alternatif baru yang menggunakan pemberat pelbagai selang dalam menyelesaikan masalah model multi-objektif FGP dan GP secara kabur, dalam persekitaran membuat keputusan yang tidak menentu bagi sektor pertanian. Di samping itu, analisis data (APD) telah digunakan untuk menilai kecekapan teknikal, alam sekitar dan ekonomi untuk zon pertanian dalam pengeluaran tanaman strategik bagi tahun yang berbeza. Kepentingan kajian ini terletak pada hakikat bahawa sebahagian daripada zon pertanian mempunyai had-had sumber manakala yang lain memberi kesan buruk kepada alam sekitar mereka disebabkan salah guna sumber. Akhir sekali, model ini digunakan untuk menentukan kecekapan setiap zon pertanian berbanding yang lain dari segi penggunaan sumber.

Kata kunci: Pemaksimuman Pengeluaran Pertanian, Pengaturcaraan gol kabur, Pengatuarcaraan gol, Pemberat multi-selang, Analisis Penyampulan Data

Abstract

Nowadays, the need to increase agricultural production has becomes a challenging task for most of the countries. Generally, there are many resource factors which affect the deterioration of production level, such as low water level, desertification, soil salinity, low on capital, lack of equipment, impact of export and import of crops, lack of fertilizers, pesticide, and the ineffective role of agricultural extension services which are significant in this sector. The main objective of this research is to develop fuzzy goal programming (FGP) model to improve agricultural crop production, leading to increased agricultural benefits (more tons of produce per acre) based on the minimization of the main resources (water, fertilizer and pesticide) to determine the weight in the objectives function subject to different constraints (land area, irrigation, labour, fertilizer, pesticide, equipment and seed). FGP and GP were utilized to solve multi-objective decision making problems (MODM). From the results, this research has successfully presented a new alternative method which introduced multi-interval weights in solving a multi-objective FGP and GP model problem in a fuzzy manner, in the current uncertain decision making environment for the agricultural sector. The significance of this research lies in the fact that some of the farming zones have resource limitations while others adversely impact their environment due to misuse of resources. Finally, the model was used to determine the efficiency of each farming zone over the others in terms of resource utilization.

Keywords: Agricultural Production Maximization, Fuzzy Goal Programming, Goal Programming, Multi-interval Weights.

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GLOSSARY OF TERMS

AHP	Analytic Hierarchy Process
DM	Decision Maker
DV	Decision Variable
FGP	Fuzzy Goal Programming
FLP	Fuzzy Linear Programming
FMOLP	Fuzzy Multi-Objective Linear Programming
GDP	Gross Domestic Product
GP	Goal Programming
IP	Integer Programming
IW	Interval Weight
LGP	Lexicographic Goal Programming
LP	Linear Programming
MADM	Multiple Attribute Decision Making
Max	Maximum
MCDM	Multi-Criteria Decision Making
Min	Minimum
MIP	Mixed Integer Programming
MIW	Multi-Interval Weight
MIWFGP	Multi-Interval Weight Fuzzy Goal Programming
MIWGP	Multi-Interval Weight Goal Programming
MOP	Multi-Objective Programming
NLP	Nonlinear Programming
OR	Operations Research
SIW	Single Interval Weight
SIWFGP	Single Interval Weight Fuzzy Goal Programming
SIWGP	Single Interval Weight Goal Programming
SFA	Stochastic Frontier Analysis

CHAPTER ONE
INTRODUCTION

In the history of mankind, agriculture is considered the pioneering profession. The practice of agriculture in its truest sense entails the domestication of both plants and animals, which can be traced back to at least 10,000 years ago. But, people started altering plant and animal communities to benefit from them through farming since the beginning of time (Zeder, 2011). As a human practice, agriculture aims to provide the humankind with the necessary food and sustenance to overcome the life's challenges. As such, a country that attempts to eliminate poverty will raise the productivity of the agricultural sector.

1.1 Agricultural Environment

Agricultural activities are normally associated with improved productivity due to changes in the agricultural process, such as the shift from the traditional human labour usage to advanced synthetic fertilizers and pesticides, selective breeding, and the mechanization of tools during the past century. However, agriculture has recently been related to many issues like water, land, bio-fuels, genetically modified organisms, farm subsidies, human resources, capital, tariffs, and import/export (Chirwa, Kumwenda, Jumbe, Chilonda, & Minde, 2008; World Bank, 2012). To solve these issues, multiple criteria have been considered (e.g., Hayashi, 2002) in studies on mechanized agricultural activities, support for the organic movement, and sustainable agricultural development (Bellon, Cabaret, Debaeke, Ollivier, & Penvern, 2014; Kassam, Friedrich, Reeves, & Pretty, 2011; Reynolds, Hobbs, & Braun, 2007). Agricultural production is an important issue as the farming environment has an impact on rural improvement and agricultural productivity (Srinivasarao, Lal, R., Kundu, & Thakur, 2015).

1.2 The Role of Agriculture in Economic Development

The role of farming in economic growth is an issue that still attracts the interest of scholars and particularly now when the whole growth approach is re-examined and evaluated. In the agricultural development, investment is important to achieve the development goals of the millennium. Most of the leaders in the developing countries are committed to exert effort and provide support for the development of agriculture and trade capacity-building in the agricultural sector (Adelman & Morris, 1973). This is because the agricultural development contributes highly to the economic growth of the developing countries. Moreover, the increasing agricultural production results in higher demands for processing equipment (Musvoto, Nortje, Wet, Mahumani, & Nahman, 2015; Timmer, 2005). Hence, the agricultural production plans and its dependence on natural conditions have significant implications for the economy. The agricultural production impacts the rest of the economic sectors with an added uncertainty of specifying input in the production process and prior to it (Murphy, Shleifer, & Vishny, 1989).

1.3 Agricultural Production

Some developing countries have no competitive edge in selling their agricultural products because of low land productivity and labour productivity. Following the liberalization of trade, domestic products could not compete with imported products that were of high quality and sold at a low price in countries such as Africa and

Central Asia (Timmer, 2005). Consequently, farmers lost interest in investing in new methods to enhance product quality, leading to the decline in the agricultural production. This causes a shortage in agricultural products and an increase in agricultural import.

1.4 Agricultural Planning

Agricultural planning has social and economic implications as it involves a complex interaction between economics and nature. The increasing population requires effective production to meet demand. However, the only way to do so is by increasing the crop production for every unit area. This requires a careful and systematic crop planning process in relation to various resources (land, water, labour, and capital) (Sarker & Quaddus, 2002) and an investigation of other factors including the irrigation methods, the soil characteristics, the cropping pattern, the cropping intensity, the topography, the socio-economic conditions, the climate etc.

Agricultural planning issues cover many goals that are conflicting in improving crop production. Overall benefit, labour expenses and water requirements among others, are impossible to be simultaneously fulfilled, resulting in other goals to be forsaken to achieve an effective solution in the decision-making process (Glen, 1987).

1.5 Agriculture in Iraq

According to statistics, Ministry of Planning (2011a) the land area of Iraq encapsulates four zones based on the division of topography. The total area of Iraq, which is 435,052 km^2 can be categorized topographically as follows: 39.2 percent desert land, 30.2 percent plain land, with the inclusion of marshes and lakes, 21 percent mountains, and 9.6 percent undulating land.

As shown in Figure 1.1, Iraq consists of 18 governorates from the north to the south. Iraq, which is strategically located in the Middle East region, is bordered by Iran to the east, Turkey to the north, Syria to the northwest, Jordan to the west, Saudi Arabia to the south and southwest, and the Arabian Gulf and Kuwait to the southeast. Two big rivers stream in the Iraqi lands, Tigris and Euphrates, (National Investment Commission, 2013), as shown in Figure 1.1.

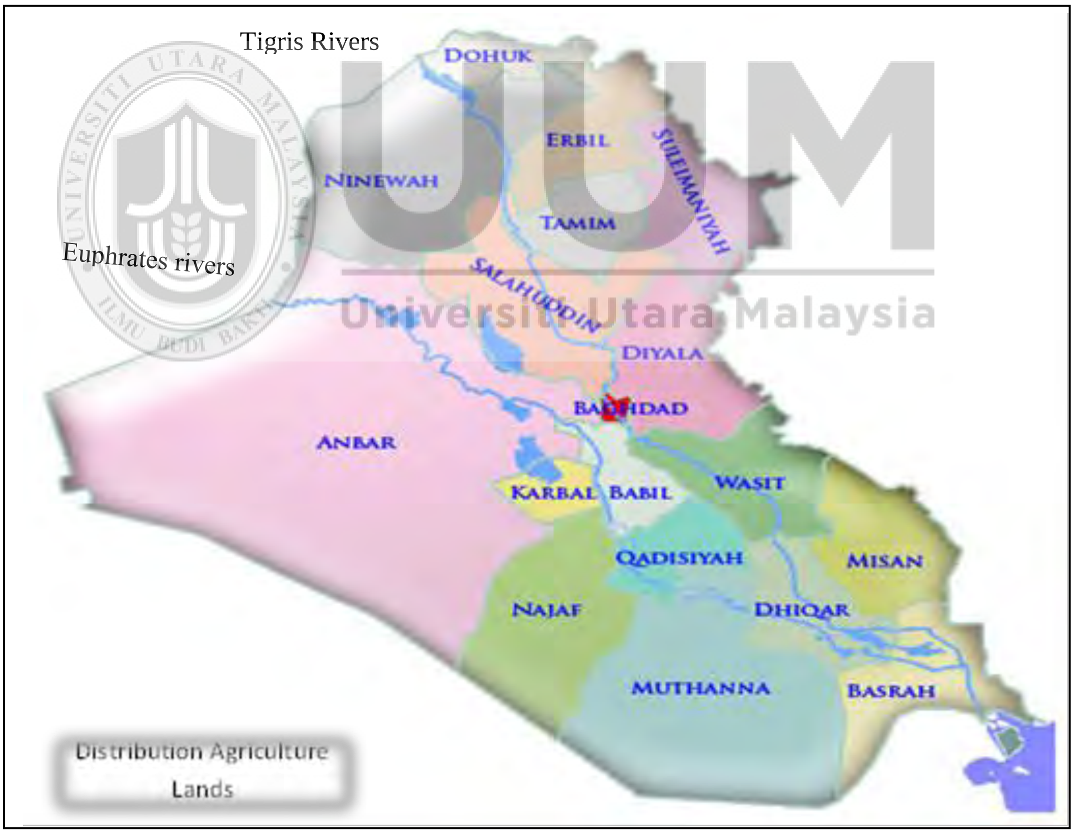


Figure 1.1. Iraq agriculture map zones

1.6 Obstacles to Agricultural Production in Iraq

Agricultural production contributes modestly to Iraq's economy which constitutes around 7 percent of Gross Domestic Production crops (UNFAO, 2012). A mere 4 to 5 million hectares of the Iraqi land is being cultivated in the arable land located in the north and northeast region of the country. In this particular area, summer and winter crops are primarily cultivated in the valleys of the Tigris and Euphrates rivers, the state controls cultivable land. With the land reforms in 1958, the sector's contribution to the GDP crops has significantly dropped since the beginning of the 1980s (USAID, 2006).

This is compounded by the need for more pesticides, fertilizers, and machinery along with the presence of imported agricultural products under the UN food-for-oil program enabling the sale of a certain amount of oil in lieu of basic food and medicine. Iraqi farmers also faced the adverse effects of drought and a century of wars (Ministry of Planning, 2009, 2011b).

1.7 Issues in Crop Production

The agricultural sector supplies the required elements to both animal and plant industries (Alnasrawi, 2001; Armitage, 1998) However, it is currently facing a number of barriers stemming from the economic blockade and more than a decade of wars. These barriers include salinity of soil, lack of water and technological resources, desertification, misuse of natural and chemical fertilizers, ineffective agricultural policies, lack of services of extension, lack of sufficient agricultural mechanization, and ineffective allocation of finance (Ahmad, 2002; Schnepf, 2003).

More recently, Iraq has become more dependent on the food sector for several reasons. The 1930s marked the development of the oil industry in Iraq and the population in the country shifted from farms to cities, hence decreasing the indigenous agricultural labour force. From the 1960s onwards, the increasing population growth and the limited arable land coupled with stagnant agricultural productivity resulted in the increase in food dependency (Schnepf, 2004). The demand for food went over the production of it throughout the years which created an increasing dependence on imported food.

Following the U.S. invasion in 2003, Iraq began importing its nutritional needs from abroad. Owing to the political crisis, environmental issues like salty lands, desertification (Ministry of Planning, 2009) and lack of water resources (Abdullah, Abdullah, & Hassoun, 2008) affected the agricultural sector. Added to this, ineffective planning and abuse of agricultural lands affected the production of both general and strategic crops. It should be noted that the crops become strategic when they are planned to be grown by the local government (Al Jawaheri & Al Shammari, 2009; Ministry of Planning, 2011a).

Iraq is originally a vast fertile land with various water resources and diversity of agricultural crops and soil between plains, hills, and mountains (Ministry of Planning, 2009; The Ministry of Planning and Development Cooperation, 2009). However, owing to the environmental changes, plant growth is receding and the country is now faced with a loss of fertile land, water (either from rain or rivers), increase in soil salinity, and increase in desertification (Gibson, 2012). In sum, various factors brought about the deterioration of the agricultural production in Iraq

(Kassas, 2008; Khalaf, 2011). Therefore, some of these factors such as low water level, fertilizers and pesticide should be given serious consideration or priority in agricultural production planning. The relevant factors are discussed as in the following sub-sections.

1.7.1 Low Water Level

Water is one of the top natural resources if not the first one, as human activities all depend on water including agriculture, industry, and even household uses. Water is also known to be a crucial resource in the desert or semi desert areas – like in Iraq. Water resources are, however, few and far between and the demands for more water, owing to the increasing population and industrial activities in the country, constitute the top challenge. Added to this is the change in the climate including high temperature and the decline of the annual rate of rain (MacQuarrie, 2004; Tolba & Saab, 2008). Several reasons stand out in light of the lack of water resources in the country; first, the decrease in annual water as a result of climate changes, the decreasing rate of rain, the increase in temperature, and the evaporation level which maximizes the rate of water wasted. Second, the high level of water pollution due to chemical, physical and bacteriological materials poses an environmental issue to every organism. Third, the Middle East political and geopolitical issues threaten the Iraqi water resources (Al Jawaheri & Al Shammari, 2009).

1.7.2 High Land Salinity

In Iraq, the agricultural land salinity is another issue in agriculture attributed to the misuse of irrigation water by farmers who are still stuck in the traditional method of irrigation. This issue also arises in some non-irrigated agricultural lands owing to the soil composition where salinity is likely to rise (Gibson, 2012). In addition, the misuse of the irrigated soil results in the sodium or solid clay layer presence that prevents drainage and cultivation process. Currently, the useless lands in Iraq constitute 2,934,507 hectares, amounting about 68.9 percent of the total area of the country (Khalaf, 2011).

1.7.3 Desertification

The United Nations Convention defines desertification as the deterioration of territories in arid, sub-wet, semi-arid, and dry regions because of various factors, such as climate change and human activities (Kassas, 2008). The Arab region is categorized as an arid land where the degradation of land through desertification minimizes the abilities of the land to produce. A clear presentation of the land degradation assessment can be visualized through productive lands in the arid regions including irrigated farmlands, rained farmlands, rangelands, and animal husbandry. Irrigated agriculture is highly dependent on water sources of the rivers in Egypt, Sudan, Syria, and Iraq where land degradation ranges from 17 percent to 70 percent (from Syria to Iraq).(Tolba & Saab, 2008). Irrigated agriculture has had a long history in Iraq (Mesopotamia) – the region of irrigated farming. Throughout its history, the various developments of agriculture are linked to the state of governance and political stability (Kassas, 2008).

1.7.4 Climatic Stations

Based on the current situation in Iraq, it requires the installation of approximately 200 superior quality climatic stations throughout the country. The distribution of these stations can be done in such a way that one station is distributed in small areas and over three stations in bigger areas. In reality, the number of climatic stations in Iraq is less than 20 and they are running ineffectively despite providing the necessary data for the benefit of farmers. These data are confidential and cannot be accessed despite its significance to farmers as it provides information concerning raining time, temperature, moisture, rate of evaporation, and speed of wind. These are important pieces of information for irrigation and the level of water utilized in the irrigation process (Ministry of Planning, 2009, 2011b).

1.7.5 Labour Force

In Iraq, back in 1947, the agriculture sector was the primary livelihood for over 60 percent of the overall population. Two phenomena stand out in Iraq – the receding of the labour force in agriculture from 16 percent in the 1990s to 10 percent in the millennium. This recession was associated with the high unemployment level in Iraq, particularly, in the youth population, resulting in the migration increase to the main cities of the country. Second is the increase in the dependence on female workers in the agricultural sector. The percentage of the female workers in the Iraqi agricultural sector was over 50 percent in 2000 and was expected to increase to 59 percent by 2010. The dependence upon the female population in the agricultural sector prevents the development of the country. Moreover, the primary causes of migration to major cities include violence, racism, sectarian, and political bias. On the basis of the statistics reported by the world organization of food and agriculture, over 79 percent of the land in Iraq is unsuitable for agriculture due to lack of water resulting from the such migration (Ministry of Planning, 2009, 2011b).

1.7.6 Drought

Drought is a long-term phenomenon that affects large regions and impacts adversely on human lives and economies. The cost of drought, collectively, is higher than any other form of natural disaster (Miyan, 2015) . Despite worldwide distribution, there is no clear, universal definition of drought. Generally, drought is the duration of low precipitation and soil moisture, which occurs through significant negative water balances. In other word, drought is described as a phenomenon characterized by a severe lack of rainfall and dry weather for significant periods of time because of lack of resources of water and degradation and desertification of land, which in turn, impact livestock and bring about famine and significant lack of food. The relationship between drought, desertification, and their development is very complex. According to the (FOA, 2008), four types of drought are defined: meteorological, agricultural, hydrological, and socioeconomic (Heim, 2002; Loukas & Vasiliades, 2004; Loukas, Vasiliades, & Tzabiras, 2008, 2007; Vasiliades & Loukas, 2009; Vasiliades, Loukas, & Liberis, 2011). Various regions in the world, such as Africa, Asia and the Arab region have experienced drought. Iraq is no exemption (Ministry of Planning, 2011b).

1.7.7 Overgrazing of Land

Overgrazing is a phenomenon describing pressure on the natural pasture of cattle herds. Herds are often taken care of as people rely on them as a food source. Meanwhile, overgrazing arises when large numbers of herds are allowed to eat on a confined spot of pasture for the herds to generate more meat. This consequently results in the degradation of soil and the reduction of its stability and usability. As erosion occurs with the help of wind and rain, the pastures may eventually lead to desertification (FOA, 2008; Tolba & Saab, 2008),

1.7.8 Pesticides

These are described as chemicals that get rid of unwanted organisms. They also include insecticides utilized to get rid of pests, such as harmful insects, herbicides utilized to kill harmful weeds, and rodenticides utilized to kill rats and harmful rodents. Pesticides have a key role in preventing the biological processes from happening in harmful organism, and hence, they are toxic. For instance, chemical pesticides are harmful pollutants to the atmosphere and the water environment (Van Der Werf, 1996), DDT and chlorinated pesticides like Parathion are the most widely utilized pesticides (Lewis, Brown, Hart, & Tzilivakis, 2003).

1.7.9 War Effects

In order to thrive, the agricultural industry calls for various requirements; a fertile and undisturbed farmland, a local workforce for traditional manual sowing and harvesting or a workforce to operate mechanized equipment to accomplish the same work, a market for the products (a local farmer’s market or international market)

(Glimun, 2008).Wars can have adverse and monumental effects upon all the above elements and it can directly impact farmers by driving them off the land such as in the cases of Iraq and Darfur region of Sudan, or risk being recruited as soldiers to fight in the war (FOA, 2008). Moreover, some areas may end up having land mine laden farm fields which would render them useless following years of conflicts. These effects may have perpetual impacts such as neglected, burned, polluted or maliciously poisoned farmland with the aim of rendering the impossible return of the land condition to its previous productivity (Gibson, 2012).

1.8 Issues in Agriculture Production Approaches

The mathematical programming approaches have been used in agricultural production problem since Waugh (1951) demonstrated the use of linear programming (LP) technique to establish the least-cost combinations of feeding stuffs and livestock rations. Since then, other types of mathematical programming approaches have widely been applied in many studies such as integer programming (IP) (Estrella, Cattrysse, & Van Orshoven, 2016; Recio, Rubio, & Criado, 2003) and mixed-integer programming (MIP) (Jena & Poggi, 2013; Sharifi & Rodriguez, 2002).

Due to the most of the agricultural production problems are multi-objective in nature, goal programming (GP) (Romero & Rehman, 2003) technique has been introduced to the field of crop production problems (Biswas & Pal, 2005). However, the nature of agricultural problems depends on many factors that are not easily quantified and often are not fully controllable such as water, labour, chemical fertilizer and pesticides (Mishra, Nishad, & Singh, 2014). These uncertain and subjective factors in agricultural production problems motivate us to further explore the fuzzy goal programming (FGP) to solve this type of problems.

1.9 Problem Statement

There are many factors that affect the deterioration of production level, for example, low water level, desertification, salinity in the soil, labour, obsolete mechanization, effects of export and import of crops, lack of fertilizer, pesticides, and the weak role of extension services (Cordesman, Mausner, & Derby, 2010). Similarly in Iraq the Ministry of Planning (2009b) attempted some ways to achieve perfect agricultural productions, such as by maximizing the production crops, maximizing the profit, and exploiting water irrigation, labour, fertilizer and pesticides. However, these strategies can still be improved.

Extensive literature indicates that there is an absence of comprehensive agricultural planning and optimizing of available resources (Gibson, 2012; Ministry of Planning, 2009; The Ministry of Planning and Development Cooperation, 2009). Therefore, there is a need to have a proper scientific plan to optimize the usage of lands, taking into account the direct and the indirect diversity of restrictions that can assist in optimizing the availability of resources while observing the flexibility of rotations of crops, especially the strategic crops.

Previously, Keramatzadeh, Chizari and Moore (2011) focused on water irrigation only in optimizing agricultural production in Iran. However, their study is still lacking and it can be improved by including other methods of irrigation in the agricultural sector. As Iraq is a neighbouring country to Iran, the problem faced in irrigation is similar. In addition, recent studies (Keramatzadeh et al., 2011; Walangitan, Setiawan, Raharjo, & Polii, 2012) have considered agricultural crop production constraints in general only.

Hence, this motivates us to improve the problem scenario by including several other constraints, such as yearly food crops constraints, industrial crops constraints, oil crops constraints, water constraints, and fertilizer constraints. Furthermore, our research also considers crops that can tolerate the salinity of lands. But, there is a gap in identifying what is the best and suitable approach to tackling the problem in a real situation of agricultural production, where there is a need to control the priority of different resources.

Regarding the approach, most literature suggested that the best suitable approach for this type of problem is through mathematical modelling such as goal programming (GP) and fuzzy goal programming (FGP), because the problem involves conflicting constraints or goals. The GP and FGP approaches can be used to prioritise different resources or constraints. But, little attention was paid to the negative effects of chemical fertilizers on the land in previous GP and FGP studies. By employing an FGP approach, our research could improve previous works by examining the best fertilizer utilisation of natural and chemical types from different perspectives. Also, our research can be enhanced by organizing the agricultural production goals based on the priorities, as only a few studies have worked on the issue (Pal, Kumar, & Sen, 2010). As this problem involves constraints or resources which cannot be controlled, such as water, therefore, this research explores the usage of a certain concept to control the priority of the objective functions in the model of agricultural production. One potential exploration is to control the objective functions through measuring the weights of unwanted deviational variable as intervals, as introduced by Sen and Pal (2013).

1.10 Research Questions

The following research questions were addressed in this study;

1. What are the most effective resources that can be examined for verification to increase the production crops under the effects of different environmental zones?
2. How can strategic crops production be improved with consideration of the available resources?
3. What are the effects of certain important resources when improving the crops production?
4. How can the proposed model be evaluated for its performance?

1.11 Research Objectives

The main objective of this research is to develop a mathematical model to improve crops production, while considering sustainable agricultural development. The specific objectives are as follows:

1. To determine the main resources which affect the crop production in an attempt to improve the benefit of an agricultural production.

2. To develop a mathematical model that integrates the FGP and GP with measurement of weights.

3. To identify the performance of goals which are resources such as water, fertilizer, and pesticides on the environment in improving crops production in different geographical zones.

4. To compare the proposed multi-interval weights FGP and GP models with the existing single-interval weights models.

1.12 Scope of the Research

In order to develop the proposed mathematical model in maximizing crops production, the environment of agricultural production in Iraq, was used as case problem. There are 15 agricultural zones located in the Mesopotamian plains by the Tigris and Euphrates rivers. However, in this research only five important zones were considered based on suggestions by the authority in the Ministry of Agriculture Iraq. These zones are also among the biggest of the 15 which cover most of the areas in Iraq.

The crops involved in the modelling of agricultural production are 20 out of 22, which are wheat, barley, onion, potato, lettuce, carrot, tomato, mash, pepper, green bean, rice, string bean, garlic, squash, cucumber, millet, corn, sunflower, cotton and sesame seed plant. The other two; sugar beet and sugar cane were not considered due to unavailability of data. These crops are also known as strategic crops since they are heavily consumed by the population.

All data related to this development of strategic crop production model were taken from the Manual of Agricultural Statistical Indicators of Iraq for 2002 and 2010. The data provided all information used in the planning of agricultural for these two years.

The modelling of strategic crops production problem in this research involved nine types of constraint. These constraints are related to land, water, fertilizer, pesticides, labour, equipment, seeds, demand, and individual crops production.

1.13 Research Contributions

This research contributes modestly towards understanding the agricultural crops production problem. The discussion on the contributions of this research is divided into three aspects: (a) theoretical contributions; (b) benefit to decision makers; and (c) benefit to policy makers. Theoretical contributions focus on the concept of the FGP and GP methodology, while the benefits to the decision makers look into the application of the proposed models to the agricultural sector problem and its benefits. Finally, the benefits to the policy makers emphasize the relevance in designing the model at the high level that can help in the planning of the agricultural sector in Iraq.

1.13.1 Theoretical Contributions

The main theoretical contribution in this research is the development of a mathematical programming model, i.e., based on the concept of multi-interval weights (MIW) method. It was developed using new multi-interval weight insights into each of the objectives function of a GP. Regarding the new insights on the agricultural problem constraints, we propose three new constraints, i.e., drought resistant crops, sprinkler irrigation and natural fertilizer usage. The proposed MIWFGP and MIWGP models are successful in providing a practical guide for the strategic crops production.

The most significant contribution of this research is a new method to find the most appropriate weights for the FGP and GP models. We called this as the multi-interval weight (MIW) method. This novel means of exploiting weights are in the form of intervals, but they are not the same as the conventional interval weights. Our recommendation of the multi-interval weights usage provides improved values or solutions from the FGP and GP models. The interval is divided into two sub-intervals to find the best representation. In this case, our method does not only focus on the two extreme values (i.e. the Min and Max), as reported in the previous literature but also covers all values of decision makers' responses. In this strategy, we find the representative value based on the computation of the geometric mean.

Moreover, in the solution process, the interval weights (derived from a pairwise interval judgment matrix) associated with the unwanted deviational variable is introduced to the goal achievement function with the objective of minimization.

Then, these functions are transformed into membership goals by assigning the highest membership value and introducing under- and over-deviational variables to each. In the proposed approach, multi-interval weights that enable fuzzy goals to achieve their aspired levels based on their relative importance are considered in an uncertain environment of the problem. This novel contribution will certainly enrich the literature of multi-criteria method.

1.13.2 Practical Contribution: Decision Makers

In terms of practical benefit, this research has several advantages to practitioners, who are working directly with the agricultural sector. Firstly, the main benefit is that the FGP and GP models concentrates on the use of all elements that contribute to the increase in the production of crops and this helps increase a farmer's profit. This research provides invaluable information concerning resources (i.e. water irrigation, fertilizer requirements, pesticides requirements, and crops) to the decision makers to improve the geographic information use.

Secondly, this research suggests that decision makers could implement some changes in the cropping pattern so that they will be able to get more income and also conserve the environment. The farming operations contribute in various ways to the broader environmental problems. Multiple administrative practices and the sensitivity of the local landscape can affect whether or not a given farm might pose a threat to the environmental quality.

Thirdly, this research provides practical insight into the processes of rural development and the required information to design effective agricultural plans for farmers. This research provides information on choosing the right crops in the arable land and the best solutions to use water, which may lead to quality crops, the best use of resources, and reduce money spent on the agricultural processes. The use of modern methods of irrigation, such as sprinkler irrigation and drip irrigation, which depends on the pipes under the surface, and magnetized water in the irrigation technology have been shown to be highly efficient in improving the water specifications and, hence, accelerating the process of plant growth. These modern methods provide double production capacity.

Finally, the proposed approach is advantageous in that better results in terms of better results can be obtained when the main interval is divided into two sub-intervals. In this case, our method does not focus on the two values (min, max) of the response as the previous methods in the literature.

1.13.3 Practical Contribution: Policy Maker

Several suggestions can be offered to the agricultural management and farmers. Firstly, the results of this study suggest that the self-sufficiency of the food basket can be secured through the provision of basic necessities and optimal use of natural, financial, and human resources, coupled with the use of modern technology and investment of expertise in each zone.

It is recommended for the authorities to compile accurate data on strategic crops production in the whole country to facilitate researchers to carry out scientific studies. Due to low capital, choosing the crops resistant to drought and salinity with the use of the modern techniques of irrigation can help reduce imports of the strategic crops.

Agricultural policies revolve around the main goals of increasing productivity and income growth, especially in farm zones, enhancing food security and equity, emphasizing irrigation to introduce stability in the agricultural output, commercializing and intensifying the production especially among farmers, and enhancing environmental sustainability. The key areas of policy concern, therefore, include an increase in agricultural productivity and income, especially in farm zones, emphasis on irrigation to reduce over-reliance on rain-fed agriculture in the face of the limited potential agricultural land, and the diversification into non-traditional agricultural commodities.

Finally, the government has to promote and encourage a better understanding and appreciation of the natural environment and how social and economic development affects farmers.

1.14 Outline of Thesis

This thesis is organized into six chapters. The first chapter includes introduction of the research study and background on the agricultural situation especially in Iraq along with challenges to production and methods for maximizing agricultural production. Also, the chapter includes the problem statement, research objectives, research scope, and significance of the research.

Chapter Two presents three main subjects: firstly, an overview of the agricultural sector and agricultural planning in Iraq; secondly, multiple criteria decision making approach, and, finally, the optimization techniques in agricultural production.

Chapter Three is divided into four major sections. Firstly, it presents a background of fuzzy technique and its advantages. It also includes a discussion on the definition of fuzzy set theory. The second section shows multi-objective optimization techniques. Finally, it presents about interval weights.

Chapter Four describes research methodology, research design, and research activities. It also illustrates the database, data requirement, and data collection. It then discusses the technical approach and develops the methodology and empirical models.

Chapter Five presents the results of the new alternative method which introduces the multi-interval weights in solving a GP problem in a fuzzy manner, solutions under any opinion or decision, and crop pattern recommendations.

The optimal cropping production is determined after running the fuzzy model and comparing it with the current condition. Discussion on the results, conclusions, limitations of the study, and necessary future work related to the area of this research are covered in Chapter Six.

CHAPTER TWO
AN OVERVIEW OF AGRICULTURAL PROBLEMS

This chapter highlights issues concerning agricultural problems in Iraq including an overview of the background of Iraq that covers the agricultural policy, criteria used in the agricultural sector problems, evaluation of the criteria, objective functions, optimized techniques for agriculture production, linear programming (LP), goal programming (GP) fuzzy goal programming (FGP), other optimized techniques for agriculture production, evaluation techniques, and other techniques. A summary of the chapter is provided in the final section.

2.1 Agricultural Production in Iraq

The land of Iraq is reported to be one of the oldest civilizations in the world. It consists of varieties of cultural lineage and racial groups, hosting Arabs, Kurds, Assyrian, Turkmen and many other minorities (Kadhim, 2010; Le Billon, 2008).

The agricultural activity is distinguished by the high sensitivity of natural circumstances, the seasonal and biological nature of the activity, the privacy of agricultural management, the importance of this activity in satisfying basic human needs, and the national food security. All of these influence the policies adopted by the state. In Iraq, all agricultural strategies and policies are undertaken since the middle of the last century aimed at achieving high percentages of food saving, a goal that was never reached. However, better food security was achieved during the 1950s and 1960s compared to later decades due to war and economic sanctions. The post-2003 war period has witnessed a negative shift away from this aim as a result of the deterioration in the quality of in-use fields and livestock pastures (Ministry of Planning, 2009a).

The agriculture sector in Iraq has been declining in terms of production and productivity since 2002 until now. However, the sector remains the second largest contributor to Iraqi GDP after oil revenues and has the potential to play a key role in reducing poverty and unemployment in Iraq (Gibson, 2012). Approximately 27 percent (11.1 million hectares) of the total land area in Iraq (43.3 million hectares) is considered suitable for cultivation to a varying degree: 4.4 million hectares are highly suitable, 4.7 million hectares moderately suitable, and 2 million hectares less than suitable. Also, around 50 percent of the land suitable for cultivation is irrigable and the rest is rain-fed, of which around half may be farmed every year depending on the rainfall and fallowing patterns. The Tigris and Euphrates rivers supply the major share of the water irrigation for agricultural production in the country, at 77 billion m^3 in good years and 44 billion m^3 in drought years (Schnepf, 2004).

2.1.1 Land Characteristics

Iraq is located in the Middle East, more specifically in west Asia. Iraq is bordered by Turkey to the north, the Republic of Iran to the east, the Arab Gulf to the southeast, Saudi Arabia and Kuwait to the south, and Jordan and the Syrian Arab Republic to the west. A very small sliver of the Arab Gulf (58 kilometres, or 36.04 miles) abuts Iraq on its southeast border. The total area of Iraq is 435,052 km^2 (168,753 square miles) and it is rated in the world as the 58th biggest country. Iraq's capital city, Baghdad, is located in the center of the country. Iraq lies between latitudes 33.3333°

N and longitudes 44.4333° E. Average yearly rainfall is estimated at 216 mm, but it ranges from 1200 mm in the northeast to less than 100 mm over 60 present of the country in the south.

The land of Iraq encapsulates four zones based on the division of topography. Total land area of Iraq is 435,052 km^2, which 39.2 percent is desert land, 30.2 percent plain land, 21 percent mountains, and 9.6 percent undulating land (Ministry of Planning, 2011b; National Investment Commission, 2013). The Iraqi climate is characterized as being primarily continental, sub-tropical, and semi-arid with the north and north-eastern mountainous regions displaying a Mediterranean-like climate. The rainy season takes place from December to February, with the exception of the north and northeast parts of the country where rainfall normally takes place from November to April. The recorded average annual rainfall is approximately 216 mm, although it differs from 1200 mm in the northeast to lower than 100 mm over 60 percent of the southern parts of the country.

During winter, the temperature varies from cool to cold, with a day temperature of around 16°C and a night temperature of 2°C with some instances of frost. On the other hand, summer is very hot with a temperature higher than 43°C in the summer months of July and August, although summer nights have been recorded to reach as low as 26°C. Iraq can be categorized into four agro-ecological parts (FAO, 2003; Frenken, 2009).

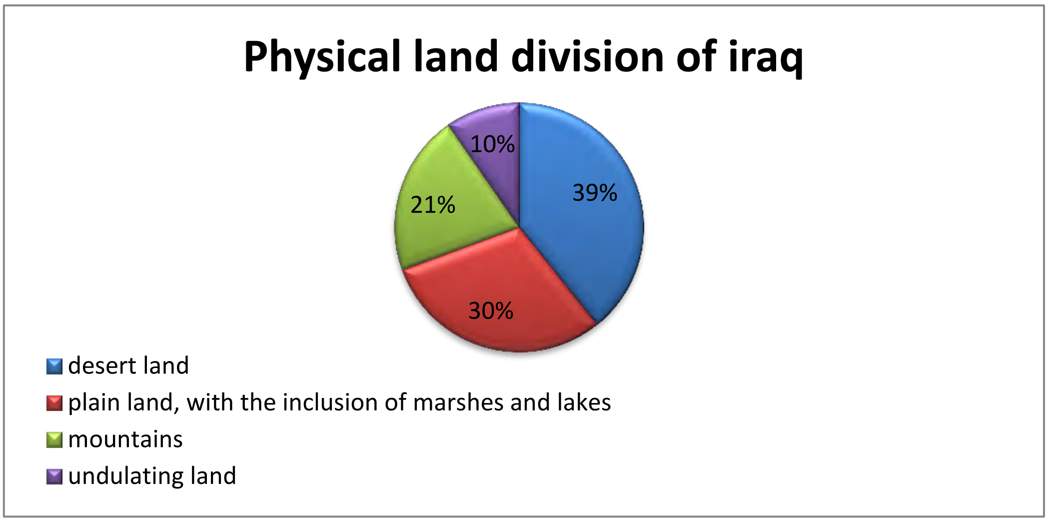


Figure 2.1. Physical land division of Iraq

(Source: Directorate General of Horticulture, Forest and Rangelands (Ministry of Planning, 2011b; National Investment Commission, 2013)).

The topography of Iraq is akin to a basin that comprises the Great Mesopotamian alluvial plain of the Tigris and the Euphrates rivers (the name Mesopotamia literally translates to the land between two rivers). The plain is within a circle of mountains in the north and east side that reaches an altitude of 3550 m above sea level and desert arid land to its south and west, accounting for more than 40 percent of the land area. Regarding the different environmental data Iraq is divided into five various physiographic zones among themselves, which makes the country a good model for the study of the environmental division-agricultural and prepare to consider appropriate for the study of various important crops (Al-Hakim, 2014; Hassan, 2013; Ministry of Planning, 2011a).

For administrative purposes the country is categorized into 18 governorates, including the three governorates comprising the autonomous region in the north of

Iraq that are Arbil, Dahuk, and Al- Sulaymaniyah. The remaining 15 governorates are located in the northern, western, central and southern zones of the country. According to the analytical estimation, around 11.5 million hectare, or 26 percent of the country's total area can be used for agriculture.

2.1.2 Population and Manpower

According to Statistical Centre of Iraq (Ministry of Planning, 2011a), the population size of Iraq increased from approximately 13.7 million in 1980 to approximately 31 million in 2010, of which one third resides in rural areas and depends upon agriculture for their livelihoods. Population growth rate is about 3 per cent at the national level. The poor performance of the agricultural sector and lack of employment drive migration to the urban areas, generating pressure on service delivery and increasing urban poverty. The major cities are a destination both for people seeking economic opportunities and for displaced families (FAO, 2012). Iraq's gross domestic product (GDP) per capita was estimated at US$6,305 in 2012, putting it in the category of middle-income countries(World Bank, 2014).

2.1.3 Gross Domestic Product

The contribution of the agriculture sector to the GDP in Iraq has been showing a steady decline since the early years of the 1980s although the government has been trying its best to encourage agriculture production under the premise that the sector is a vital contributor to the country's economy as it constitutes the largest employer (25 percent of the total country workforce) and the second largest GDP contributor.

In Iraq, agriculture constitutes 10 percent of the GDP, where the biggest contributors are the cereals sub-sector, the fruits and vegetables sector, and the livestock. Additionally, the food processing sector is significantly linked to the agricultural sector and constitutes 0.3 percent of the GDP. These statistics were reported by (Al-Haboby et al., 2014; The Ministry of Planning and Development Cooperation, 2009).

Currently, the Iraqi crop yields are relatively lower than the international crop yields (FAO, 2012) and this may be linked to different reasons, among them being the influence of the ongoing strife in the country, civil wars, sanctions, droughts, and the damaged infrastructure that bars input production, research, and expansion of services (World Bank, 2014). To this end, the GDP per capita in the country was at \$2438.79 in the year 2014. Iraq's GDP per capita is equal to 19 percent of the recorded world average. Specifically, the GDP per capita in Iraq was recorded to average \$1644.73 from 1960 to 2014, where the average annual GDP or growth per capita was reported at \$102.9 (Trading Economics, 2015).

2.1.4 Land Resources

In Iraq, over half of the country's total area is covered with mountains and highlands while other land types like forests, arable lands and others constitute 7.5 percent, 30.9 percent, and 26 percent of the total cultivatable areas, respectively. More specifically, the agricultural land is estimated to cover an area of 8 million ha, which is approximately 93 percent of the cultivatable land. Owing to adverse factors, such as soil salinity, fallow practices, and unstable political climate, only 3-5 million ha are yearly cultivated. In the year 1993 alone, the cultivated area was reported to be around 3.73 million ha, from which 3.46 million were occupied by annual crops and 0.27 million ha were used for permanent crops. Iraq has over 50 percent desert area with most of the pasture areas being susceptible to erosion owing to decreased vegetation cover, Ministry of Planning, (2009b).

Moreover, a large portion of the cropland is increasingly becoming barren because of the adverse agricultural practices. Such loss of the cultivatable areas is mostly prominent in the urban areas, where the established agricultural land is lost due to practices of urbanization, industrialization, and development of transport infrastructure. Compounding the matter further is the desert overgrazing, which leads to plant cover loss, especially in the semi-desert areas. To tackle this issue, land is being reclaimed for production. However, reclaimed land productivity is low and in many cases only some parts of the old and new land is brought into production (Ministry of Planning, 2011a).

2.1.5 Water Management

The Ministry of Water Resources in Iraq is in charge of all public water planning. Other central institutions implicated in the water policies comprise the Ministry of Agriculture, Ministry of Municipalities and Public Works, Ministry of Environment, and some local governorates concerned with economic and human resources (Ministry of Planning, 2011a). In Iraq, water resource limitation in the agricultural sector is currently severe. The Twin Rivers of Tigris and Euphrates control the water resources in the country with both originating from the water source in Turkey. More specifically, the Euphrates flows for around 1000 km while the Tigris for around

1300 km within the land area of Iraq. Added to the two, the Shatt Al-Arab is a river formed by the confluence of both rivers that flows into the Arab Gulf after 190 km. Owing to this confluence, the country can be primarily considered as divided into three river basins, namely, the Tigris, the Euphrates, and the Shatt Al-Arab (Jaradat, 2003).

Around 85 percent of the irrigated agricultural sector in Iraq comes from water sources, making Iraq the pioneer among its Arab neighboring countries to be irrigated for agriculture. However, in the current times, a decrease in the water flowing to Iraq from the Tigris and Euphrates has been noted at 1.5 percent. In the years from 1991 to 1998 alone, the amount of water coming from the Tigris was recorded to decrease by 3.2 percent, while the water coming from the Euphrates was recorded to decrease by 1.3 percent owing primarily to the increase in salt in both rivers. Moreover, the rate of the receptor agricultural water in this period was recorded at 47.35 milliard cubic meter annually, whereas the water requirements for agriculture was recorded at 29.88 milliard cubic meter annually.

As for the rate of water lost, in the same period (1990-2008), it was documented at 17.47 milliard cubic meter annually, indicating that the primary reason behind the scarcity of water in the irrigated agricultural sector in the country is the outdated irrigation classical methods as opposed to the decreasing receptor water rate. On that basis, it becomes a necessity to concentrate on water quotes for crops and minimize water loss through the employment of modern irrigation methods, whereby the irrigation systems had a ratio space of 97.2 percent and the modern irrigation system on a small scale has a ratio space of 2.8 percent (Al-Badri, 2010).

The government passed water legislations with the objective of rationalizing water consumption and promoting water users and other forms of farmers' unions. Additionally, fees for water users were introduced by the Ministry of Water Resources by the same year, making the cost for farmers around 500-2500 ID for one donum, based on the irrigation type. From 2004-2005, the government tried to set up a fixed ratio but the actual cost was lower than the government cost by half (50%). Since then, the taxation process has not been successfully enacted (Al-Badri, 2010; Jaradat, 2003) as shown in Table 2.1.

The Central Statistical Organization in the Ministry of Planning (2011a) reported the average water supply from the Tigris and Euphrates rivers and tributaries for the time period of 1990 until 2009 was 60.41 billion cubic meters. However, during the year 2009-2010 there is low water supply of only 32.11 billion m^3 as shown in Table 2.1. In addition, Figure 2.2 shows the statistics of annual agricultural water supply during the period of 1990-2009 (Ministry of Planning, 2011a), which there is a decrease of water supply for 2009-2010.

Table 2.1

Summary of the annual statistics agricultural water supply from the Tigris and Euphrates during the period (1990-2009).

Years	**Tigris River (in billion m^3)**	**Euphrates River (in billion m^3)**	**Total water supply (in billion m^3)**
1990 - 1991	30.87	12.4	43.27
1991 - 1992	62.72	12.15	74.87
1992 - 1993	66.36	12.37	78.73
1993 - 1994	44.85	15.33	60.18
1994 - 1995	65.63	23.9	89.53
1995 - 1996	38.85	30	68.85
1996 - 1997	42.66	27.64	70.3
1997 - 1998	49.9	28.91	78.81
1998 - 1999	18.8	18.61	37.41
1999 - 2000	18.85	17.23	36.08
2000 - 2001	21.13	9.56	30.69
2001 - 2002	43	10.95	53.95
2002 - 2003	49.48	27.4	76.88
2003 - 2004	45.51	20.54	66.05
2004 - 2005	38.1	17.57	55.67
2005 - 2006	44.6	20.6	65.2
2006 - 2007	39.86	19.33	59.19
2007 - 2008	20.37	14.7	35.07
2008 - 2009	47.69	19.32	67.01
2009 - 2010	9.3	22.81	32.11

(Source: Ministry of Planning (2011a)

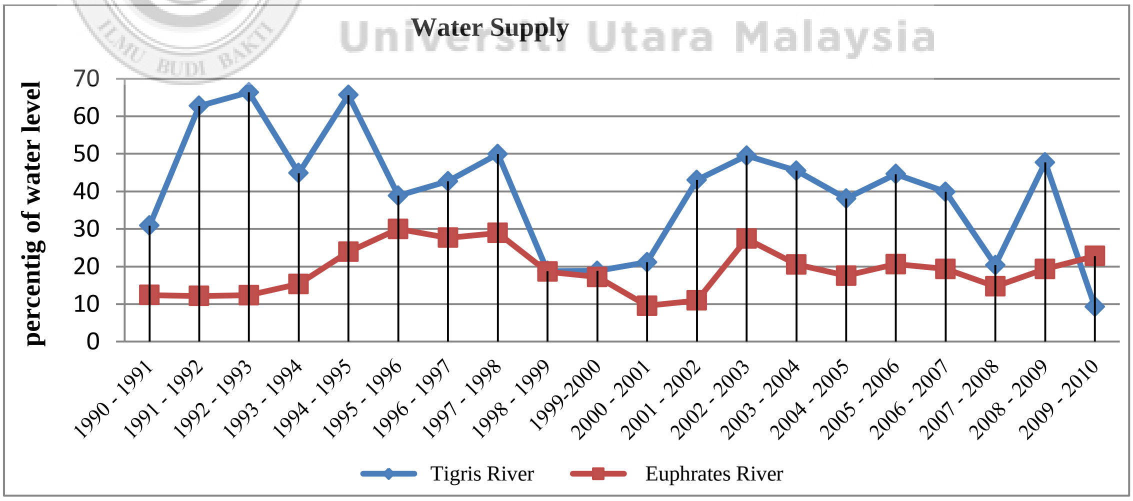


Figure 2.2. Water supply from the Tigris and Euphrates in Iraq for the period 1990 - 2009 billion m^3

2.1.6 Types of Crops Grown in Iraq

As suggested by the Ministry of Planning (2011b), there are 22 type crops representing the relevant variables of cultivable crops in five different regions in Iraq. The crops include wheat, barley, onions, potatoes, lettuce, carrot, tomatoes, mash, pepper, green beans, rice, string beans, garlic, squash, cucumber, millet, sugar beet, sugar cane, corn, sunflower, cotton, and sesame seeds plant. It should be noted that the crops become strategic when they are planned to be grown by the local government (Al Jawaheri & Al Shammari, 2009; Al Sarhan, 2011; Ministry of Planning, 2011b).

The main cereals grown in Iraq are wheat (71% of the total cereals) and barley (20%) as shown in Figure 2.3. To a smaller extent, corn and rice are also grown. Cereals are grown in both rain-fed and irrigated conditions. The annual production is highly varied, depending mainly on water and moisture conditions but also factors, such as input availability, access to the markets, and security situation.

Despite having markedly low productivity levels even when compared to the regional yield standards for major crops, the Iraqi agricultural products have further declined since 2002 (Ministry of Planning, 2011a).

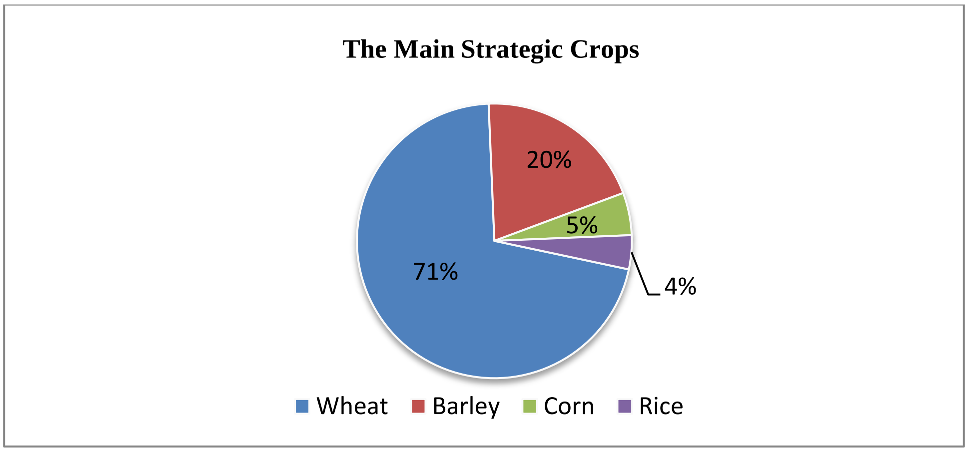


Figure 2.3. The main strategic crops production in Iraq

2.2 Agricultural Policy in Iraq

For two decades, the Iraqi agricultural sector has had limited access to productivity-increasing agricultural technologies, whether imported or generated in-country. An exception is the largely misguided importation by Iraq during the 1970s and 1980s of large scale "high-tech" industrial-type production and processing technologies in the form of turnkey labour-saving, capital-intensive machinery, equipment, facilities, and operating systems. To continue to operate, these agribusinesses depend on heavy government input subsidies and guaranteed output markets. To achieve the national economic development, Iraq must accelerate the agricultural output growth to be responsive to the growing domestic foodstuff markets that now are being supplied by the imports. Imports have increasingly supplied these markets as the Iraqi agricultural economy (for multiple reasons) stagnated and then collapsed. Stagnation began in the early 1990s, economic collapse occurred in 2003, and in 2010, the agricultural economy was still struggling to recover (Al Jawaheri & Al Shammari, 2009; Al Sarhan, 2011; Ministry of Planning, 2011b).

In sum, the Iraqi agricultural competitiveness currently suffers from 20 years of isolation from advances in technologies that stimulate productivity gains.

In contrast, the regional exporters to the Iraqi domestic market have enjoyed ready access to these technology advances and consequent efficiency gains. When combined with considerable subsidies, this has contributed to the ability of the neighbouring producers to crowd out the Iraqi producers in the Iraqi markets, which continue to misguide the government in terms of the agribusiness operations and subsidies that ignored (and continue to ignore) the Iraqi competitive advantages. As a result, the economic efficiency of the agribusiness operations throughout the agricultural value chain is undermined. An extended period of political and economic instabilities and violence and lack of timely maintenance of the infrastructure have also resulted in wide-spread deterioration. In addition, the financial support for the agriculture sector is very weak; for example, the general financial arbitrage in Iraq was 70 billion dollars in 2010, whereas the amount specified to support the agricultural production did not exceed 350 million dollars, i.e. less than 0.005 percent of the total general financial arbitrage Ministry of Planning (2011b).

2.3 Criteria for Agricultural Production

This section provides the definitions and explains the criteria related to the agricultural sector. The criteria are agricultural benefit of production, water irrigation, fertilizer usage, pesticides usage, agricultural labour, agricultural equipment, agricultural seeds, and others. The following sub-sections discuss these criteria.

2.3.1 Agricultural Benefit of Production

The benefit of production in agriculture is the revenues that are gained from the agricultural land according to the strategy crop in a year. Agricultural benefits are brought about by the development of strategies to enhance the agricultural viability as part of the economic development. Communities enjoy the benefits of agriculture, particularly those that are well-planned and managed (Phumiphan, Kangrang, & Sa-Ngiamvibool, 2011; Sivanpheng, Kangrang, & Lamom, 2009; Tzimopoulos, Balioti, Evangelides, & Yannopoulos, 2011). This points out to many important human benefits besides increasing their economic well-being and improved social stability (Asís, 2007).

2.3.2 Water Resources and Irrigation

Irrigation refers to the water application in an artificial manner to the land/soil, with the aim of assisting the growing of agricultural crops, landscapes maintenance, and disturbed soils re-vegetation in dry land and during the periods of insufficient rainfall. Also, irrigation has other uses in terms of the production of crops. These include safeguarding plants from frost (Snyder & Melo-Abreu, 2005), controlling the growth of weeds in grain fields (Williams, Roberts, Hill, Scardaci, & Tibbits, 1990), and safeguarding against consolidation of soil. Contrastingly, agriculture depends solely on direct rainfall, in what is referred to as rain-fed or dry land agriculture

(Erkossa, Haileslassie, & MacAlister, 2014). The systems of irrigation are also useful for the purpose of suppression of dust, sewage disposal, and mining.

Irrigation is often examined with drainage (natural/artificial surface or sub-surface water removal), which has been the focus of agriculture since its inception and is the core of the economy and society of many countries in the Asian region (Bos, Kselik, Allen, & Molden, 2008; Bos, Murray-Rust, Merrey, Johnson, & Snellen, 1993). Irrigation is defined as the supply of land water that is needed for the growth of plants. In addition, the irrigation of water is to achieve several aims, among which are to supply the needed moisture for the growth of plants, to protect plants against drought and heat, to provide wetness to soil and vegetation in order to bring about productive climatic plant growth conditions, to wash off salt concentrations in soil, to bring about ground service operations for the purpose of plowing and other activities relating to agriculture, and lastly, to heighten the capacity of plants to absorb nutrients (Roldán-Cañas, Chipana, Moreno-Pérez, & Chipana, 2015).

Artificial irrigation systems are important to the robust production of plants in dry climates, although it is also carried out in humid and sub-humid climates for crops protection in drought periods and in all environments to heighten the production of crops. Water for irrigation should be supplied in a way that guarantees the efficient employment and distribution of water, lessens runoff, and soil erosion (Ökmen, 2015). The irrigation method used hinges on the crop type, the topography, and the soil type. Several systems can be utilized when they are effectively designed and operated. Three fundamental methods of irrigation exist, namely, surface, sprinkler, and drip irrigation (Almusaed, 2011). The factors that are attributed to the selection of the suitable method of irrigation are the scope of land, water intake, and the soil rate (Al-Omran, Al-Harbi, Wahb-Allah, Mahmoud, & Al-Eter, 2010). The types of irrigation are described as follows.

2.3.2.1 Surface Water Irrigation

This refers to a set of application methods whereby water is distributed over the surface of soil with the help of gravity (Ökmen, 2015). This method is the most extensive form of irrigation so far and has been practiced all over the world over thousands of years. This type of irrigation is also known as flood irrigation, indicating that the distribution of water is not controlled, and, in essence, not efficient. Realistically speaking, some practices of irrigation are covered under this type of irrigation and they entail considerable management control (e.g. surge irrigation), (Roldán-Cañas et al., 2015).

2.3.2.2 Sprinkler Irrigation

A sprinkler irrigation is a planned irrigation system where the entire facilities are set up for the water application that is efficient – this is done through perforated pipes or nozzles that operate under pressure (Mansour, El-Hagarey, Abdelgawad, Ibrahim, & Bralts, 2015). Examples of this kind of irrigation are furrows, borders, contour levees, contour ditches, sub-surface irrigation (Afrakhteh, Armand, & Bozayeh, 2015).

2.3.2.3 Drip Irrigation

A drip irrigation technique is where all the required facilities are employed to apply water to the plants' roots directly through the use of orifices, emitters, porous tubing, or perforated pipe that are slow pressurized (Lalehzari, Samani, & Boroomand-nasab, 2015; Li, Shi, Šimůnek, Gong, & Peng, 2015).

2.3.3 Fertilizer Usage

Fertilizers are the organic/inorganic materials made up of natural or synthetic elements that are mixed with soil to supply plant nutrients crucial for plant growth. For several centuries, organic fertilizers have been utilized prior to the development of chemically synthesized inorganic fertilizers during the industrial revolution. These inorganic fertilizers are nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and Sulphur (S) (Handoussa, Nishimizu, & Page, 1986; McCauley, Jones, & Jacobsen, 2009). The organic farming claims to have the ability to provide benefits in terms of environmental protection, conservation of non-renewable resources, improved food quality, reduction in output of surplus products, and reorientation of agriculture towards areas of market demand (Bhatta, Doppler & KC, 2009). Although there is a discussion as to the environmental benefit of maintaining a particular farming system, we have to pay attention to the fact that agricultural practices may have negative effects on the environment. A serious example is water pollution, such as the nitrate issue caused by chemical fertilizers and manure. This is a common problem observed worldwide, despite the fact that agriculture is not the only source of the contamination (Acs, Berentsen, & Huirne, 2005; Pretty, 2008; Zebarth, Drury, Tremblay, & Cambouris, 2009).

2.3.4 Pesticides Usage

Pesticides comprise a group of chemicals that are employed in agriculture to protect plants from vector-borne diseases like malaria, and filariasis, among others. Pesticides have been defined in different ways. According to several researchers (Brouwer & Heibloem, 1986; Brouwer, Prins, & Heibloem, 1989) a pesticide is any substance or a combination of substances that are used to prevent, destroy, or control pests, with the inclusion of human or animal disease, undesirable species of plants/animals that affect the food production, processing, storage, or marketing and that affect agricultural commodities, wood and wood products, or animal food. Pesticides may also be used on animals to control insects, arachnids, or other pests (Aktar, Sengupta, & Chowdhury, 2009).

The use of pesticides worldwide is aimed at promoting plant growth although its effects on the environment are undeniable (Costantini, 2015). Additionally, pesticides may also negatively affect human respiration and cause other health risks (Bertolote et al., 2010; Bertolote & Fleischmann, 2002; Hoppin, Umbach, London, Alavanja, & Sandler, 2002). The intensive use of pesticides and fertilizer could also affect the top water contamination sources through irrigated agriculture (Zalidis, Stamatiadis, Takavakoglou, Eskridge, & Misopolinos, 2002). The European Environment Agency report (1999) stated that irrigated agriculture is one of the primary causes of nitrates contamination.

2.3.5 Agricultural Labour

Labour is deemed to be the most significant agricultural resource. It includes the management and the operators of the agricultural business activities (labour schedules, resource operation for agriculture, such as machinery, and repair of machinery). In other words, they may cover scientists, technologists, and engineers who come up with innovations in agriculture. As such, labour has to have good training, regularly monitored, and encouraged to sustain the agriculture and the natural surroundings. Based on the reported statistics, Arab firms working towards the development of agriculture in the year 2010 numbered around 343,771, constituting 44.2 percent of the total population distributed unevenly among the states (Peart & Shoup, 2004).

The population in the rural area comprise mostly of aged and aging citizens that lead to the graying of society in farms that show ever-changing agricultural labour market. Owing to the migration of citizens, social problems have also compounded the issue (Bishop-Sambrook, 2003; Kasimis, Papadopoulos, & Zacopoulou, 2003). In this context, agricultural policies pertaining to the maintenance of the economic vitality of the rural societies, specifically in areas having less advantages within which the low income opportunities, should be implemented (Manos, Bournaris, & Chatzinikolaou, 2011). In the context of Iraq, the lack of skilled labour in the rural areas should be addressed in order for them to operate the machinery. With regards to the machinery, care should be given to make the agriculture machineries user-friendly.

2.3.6 Agricultural Equipment

The employment of modern agricultural technologies in the processes of production, such as agricultural equipment, agricultural machinery and mechanization of different types to achieve the agricultural operations is referred to as the integrated production lines. Such production line is initiated from ground ploughing or preparation and planting and culminates in harvesting (Srivastava, Goering, Rohrbach, & Buckmaster, 1993). The introduction of agricultural equipment and its extensive use has contributed to minimizing human manual agricultural work, increased productivity, enhanced agricultural timeliness in both planting and harvesting, and minimized peak labour demands (Bagheri & Moazzen, 2009).

Farm work is characterized as a physically demanding work with harsh working conditions. However, with the introduction of machineries, farm work is lessened; for instance, driving a tractor is much better than tilling soil with a spade and a tractor ploughing cultivates a greater area compared to the human manual use of spade, and hence, farming machinery has contributed greatly to the productivity and timeliness in agriculture as both are pertinent in the field, (Asoegwu & Asoegwu, 2007; Kassas, 2008; Khalaf, 2011).

The achievement of specific farming operations like planting and harvesting in an expedient and timely way contributes to the profitability and crop yields. Agricultural operations depend on seasons and, in this regard, labour demand differs from one season to the next. To expound this statement further, more labour is required during planting and harvesting compared to other periods of farming. As such, labour fluctuation leads to issues of labour management. This issue is handled through mechanization where it becomes possible to lessen the peak labour demand and help maintain stability in farm labour (Nik, Khademolhosseini, Abbaspour-Fard, Mahdinia, & Alami-Saied, 2009).

2.3.7 Agricultural Seeds

Agricultural seed is a material employed for planting or for the purpose of regeneration and a propagating material for agriculture, silviculture and horticulture in the sowing/planting process. Seed is considered to be the vital input in crop production. Planting quality seed increases productivity without adding appreciably to the land area under cultivation (Agannathan, Mohamed, & Kremer, 2009; Khalaf, 2011). Several research has been used the agricultural seed type in mathematical mode such as LP and GP as a constraints (Ibrahim, 2007).

2.3.8 Other Criteria

In addition to the criteria mentioned earlier, other criteria may need to be considered. They include room for expansion, construction costs, accessibility to multiple modes of transportation, cost of shuffling people and materials between plants, and agricultural processing. Applicable facilities include wineries, cheese production, olive oil extraction and similar processing insurance cost, competition from other firms for the workforce, local, ordinances (such as pollution or noise control regulations, polders and a flood-control), community attitudes, climate, and culture (Duerden, 2004), among others. Consequently, a need has emerged for confronting problems with a more comprehensive approach, taking into account the whole range of impacts caused by agriculture (Andreoli & Tellarini, 2000). All or some of the criteria aforementioned can be embedded either as part of the objective function (s) or as constraints in the model. Added to this are many facilities to be chosen and many criteria to be evaluated to select the best criteria. The criteria should be evaluated by the decision maker (s) to select the best solution.

2.4 Evaluation of the Criteria

Several methods have been brought forward to assess the weights of criteria and to aggregate criterion-specific priority scores in an explicit manner. Such methods can be categorized into subjective and objective methods, based on the available information (Eshlaghy & Farokhi, 2011; Kong & Liu, 2005; Ma, Fan, & Huang, 1999; Xu, 2004). More specifically, the subjective methods choose weights according to the preferred information regarding the decision matrix (M) provided attributes, whereas the objective methods identify the weights according to the objective information (Ma et al., 1999).

Moreover weights that are determined by the subjective-method provide the decision maker's (DM) subjective judgment, where the analytical outcomes that are based on the weights are susceptible to the effects of the DM's lack of expertise, intuition, previous data, experience, knowledge and other facts. Literature has provided several subjective methods including the ratio method, the rating method, the trade-off analysis, the swing method, the ranking method, and the pairwise comparison method (Munier, 2004).

Meanwhile, objective methods are often used to determine weights by solving mathematical models that overlook the DM preference (Sen & Yang, 1998).

Examples of objective method are such as LP and GP, which are discussed further in section 2.5. Subjective methods are also important in evaluating the criteria and are described in the following sub-sections. These methods include ranking method, pairwise comparison method and other related methods of determining weights.

2.4.1 Ranking Method

In comparison to other human judgments methods, ranking methods is deemed to be reliable, easy to use and involves simple assignation of weights (Eckenrode, 1965; Johnson & Huber, 1977; Sen & Yang, 1998). In decision making, the requirement is that the factors levels have to be in preference order from the most preferred factors to the least ones, or the pairing of the most preferred factor level selected. In regards to this, (Barron & Barrett, 1996) listed three common weighting formulas in preferred ranking and they are Reciprocal of the Ranks (RR), Rank Order Centroid (ROC), and Rank Sum (RS). Each rank-based method supposes that n criteria exist to be evaluated. For instance, let w_i denote the criterion weight that is ranked in the i^{th} position. Thus, the formula (RS) method is represented in the following.

$$w_i(RS) = \frac{2(n+1-r_i)}{2(n+1)} \quad , i = 1,2,\dots,n \tag{2.1}$$

In the above equation, w_i is the weight of criterion i, n is the number of criteria, and r_i is the rank of criterion i. Equation 2.2 represents the RR formula;

$$w_i(RR) = \frac{\frac{1}{r_i}}{\sum_{i=1}^{n} \frac{1}{r_i}} \quad , i = 1,2,\dots,n \tag{2.2}$$

Moving on to the rank-order centroid (ROC), the approach generates weight estimation that mitigates the maximum error of each individual weight through the identification of the centroid of all the potential weights, while maintaining their order of objective importance by rank (Roszkowska, 2013). In Barron and Barrett (1996) study, the authors found that weights achieved in this manner are characterized by their stability, and if the rank order of the true weight is known, but no other quantitative information about them exist, then it may be assumed that the weights distribution is uniform on the simplex of rank-order weight, with the ROC method equation presented as follows.

$$w_i(ROC) = \frac{1}{n}\sum_{i=1}^{n}\frac{1}{r_i}\ , i = 1,2, \dots , n \tag{2.3}$$

Barron and Barrett (1996) added that ROC is more accurate compared to other rank formulae, as the form makes generalizations to include both information forms (about attribute weights and partial rank order). Also, ROC based analysis is simple, straightforward and efficacious, considering its provision of an implementation tool. Moreover, the technique is referred to as ROC as the weights show the centroid of the simplex described by the criteria ranking; in other words, with greater criteria, the error for ranked criteria will be lower (Roszkowska, 2013).

2.4.2 Pairwise Comparison Method

This method is utilized to compute of relative priorities of criteria/alternatives, and it is described as the comparison of candidates in pairs to identify which in the pair is appropriate. Each of the candidate is compared to individual others, and is given a point for one-on-one win, and a half a point if a tie is revealed. By logic, the candidate that receives the greatest points is declared the winner (Sen & Yang, 1998) referred to the comparison as the Pairwise Matrix development.

Nevertheless, the estimation of criteria weights depends on the subject and as such, this differs throughout decision makers (DM) (E. Triantaphyllou, 2000). For this limitation, the pairwise comparison matrix is employed, generated from repetitive pairwise comparison of DM's estimation criteria or alternative objectives. In this regard, an extensively used multiple-criteria decision making (MCDM) technique that utilizes pairwise comparison matrix is the Analytic Hierarchy Process (AHP) developed by Saaty in 1970s. The origin can be traced back to the 1970s when Saaty brought forward pairwise comparison that has been generally used in resolving issues concerning multi attribute decision maker (MADM) at that time (Eshlaghy & Farokhi, 2011; Yeh, Willis, Deng, & Pan, 1999). Consequently, a structurally-based pairwise comparison matrix with subjective scale that ranges from 1 to 9 became to be known as the Saaty rating scale. In relation to this method, the effort that is needed to conduct a comparison of each criterion with the next increases rapidly, particularly in terms of several classes; for instance, with n criteria, there are $n\,(n-1)/2$ comparisons.

However, this technique is not effective when the number of pairwise comparisons to be made turns into very large and doubles the tasks. In other words, the AHP (Saaty & Vargas, 2012; Saaty, 1990, 2008) and Analytical Network Process (ANP) (Bayazit, 2006; Percin, 2008; Saaty & Vargas, 2006) are among the techniques that use pairwise comparison. The weights for AHP are determined through an eigenvector method and measurement of its consistency, which are briefly discussed below.

2.4.2.1 Eigenvector Method

In pairwise comparison method, weights can also be determined through computations of a complex mathematical formulation to achieve eigenvalues and eigenvectors. The mathematical representation can be expressed in a matrix form as follows.

$$A = \begin{bmatrix} w_1/w_1 & w_1/w_1 & \dots & w_1/w_n \\ w_2/w_1 & w_2/w_1 & \dots & w_2/w_n \\ \dots & \dots & \dots & \dots \\ w_n/w_1 & w_n/w_1 & \dots & w_n/w_n \end{bmatrix}$$

If the vector of weights $(w_1, w_2, \dots, w_n)$ is to be determined, given the ratios, the matrix product of the matrix A, with the vector w can be obtained as follows.

$$\underbrace{\begin{bmatrix} w_1/w_1 & w_1/w_1 & \dots & w_1/w_n \\ w_2/w_1 & w_2/w_1 & \dots & w_2/w_n \\ \dots & \dots & \dots & \dots \\ w_n/w_1 & w_n/w_1 & \dots & w_n/w_n \end{bmatrix}}_{A} \underbrace{\begin{bmatrix} w_1 \\ w_2 \\ \dots \\ w_n \end{bmatrix}}_{\vec{w}} = \underbrace{n \begin{bmatrix} w_1 \\ w_2 \\ \dots \\ w_n \end{bmatrix}}_{n\vec{w}}$$

$$A\vec{\mathrm{w}} = n\vec{w} \tag{2.4}$$

In the above equation, $\vec{w}$ represents the vector of the priorities n, with dimension of the matrix A, and if A is known, w can be determined. The problem of finding the solution for a nonzero solution to the set of equations is a general representation (Grzybowski, 2010).

In this particular case, the priority of vector w can be determined by determining the solution of the eigenvector in equation (2.4). More specifically, for a consistent matrix A, the n represents the principal eigenvalue of A, which is the largest solution of the characteristic equation $(A - \lambda I) = 0$. It is the non-zero eigenvalue in this instance – according to Saaty, the matrix A is assumed to employ the normalized right eigenvector related to the largest eigenvalue as an approximate of the true priority vector (Forman & Selly, 2001). In order to conduct the estimation, the general eigenvector equation has to be solved.

$$AW = \lambda_{max} w \tag{2.5}$$

In the above equation, λ_{max} represents the principal eigenvalue, and for an arbitrary positive reciprocal A, the λ_{max} value is real, distinct and greater than n.

2.4.2.2 Measurement of Consistency

Priorities are meaningful when they are derived from consistent or near-consistent matrices and thus, a consistency confirmation is important. According to Saaty's (1977) recommendation, a consistency index (*CI*) linked to the eigenvalue technique represented by the following equation.

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{2.6}$$

where, λ_{max} represents the maximum eigenvalue.

Moreover, the consistency ratio (ratio between *CI* and *RI*) is written in the following equation.

$$CR = \frac{CI}{RI} \quad (2.7)$$

In equation (2.7), *RI* denotes the random index. In the case where *CR* is lower than 10%, then the matrix may be deemed as possessing acceptable consistency. The *RIs* were provided by Saaty (1977) with the average random consistency index matrices as listed in Table 2.2.

Table 2.2
Random Consistency Index

N	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
R.I	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

If CI is sufficiently small, the decision maker's comparisons are probably consistent enough to give useful estimates of the weights for his or her objective function. If $\frac{CI}{RI} < 10$, the degree of consistency is satisfactory, but if $\frac{CI}{RI} > 10$, serious inconsistencies may exist, and the AHP may not yield meaningful results. The pairwise comparison matrix does not exhibit any serious inconsistencies (Winston & Goldberg, 2004).

2.4.3 Other Rank Methods of Determining the Weight

Besides the recommendations mentioned in Section 2.4.2, there are many other Additive aggregation operators are functions which aggregate local scores of an alternative with the presumption that attributes are independent to each other

(Detyniecki, 2001; Torra & Narukawa, 2007). In following sections, to express the mathematical model of each additive operator $x_j = (x_1, x_2, \dots, x_n)$ is used to represent the local scores of an alternative with respect to n attributes and $w_j = (w_1, w_2, \dots, w_n)$to denote the set of attributes' weights. In this section, we present an overview of the existing mathematical operator and we explain their main properties and particularities. By start by presenting some of most often used aggregation operators. We find the Arithmetic Mean, as well as some classical generalizations like the Quasi- Arithmetic Means, Simple Weighted Average, Median and Ordered Weighted Average. As explained as follows.

2.4.3.1 Arithmetic Mean

Arithmetic mean, commonly known as the average, is the simplest approach for aggregation (Vavríková, 2011) hence it merely combines the local score with the absence of attributes' weights (w_j).

$$Arithmetic\ mean(x_1, x_2, \dots, x_n) = \frac{1}{n}\sum_{j=1}^{n} x_j \tag{2.11}$$

2.4.3.2 Quasi- Arithmetic Means

There are various types of means, namely, geometric mean, harmonic mean, quadratic mean, root-power mean, and exponential mean, which can be assembled into the family of quasi-arithmetic (Liu, 2006). These means are actually the derivation of a simple arithmetic mean. The mathematical models of some quasi-arithmetic means are as follows (Smolikova & Wachowiak, 2002).

$$\text{Geometric mean}(x_1, x_2, \dots, x_n) = \left(\prod_{j=1}^{n} x_j\right)^{\frac{1}{n}} \quad (2.12)$$

$$\text{Harmonic mean}(x_1, x_2, \dots, x_n) = \frac{n}{\frac{1}{x_1} + \frac{1}{x_2} + \cdots + \frac{1}{x_n}} \quad (2.13)$$

2.4.3.3 Simple Weighted Average

Simple weighted average (SWA), which is rooted from arithmetic means, permits positioning of weights on the attributes. It is commonly preferred by decision makers since it stands out as the simplest weight-based aggregator (Krishnan, Mat Kasim, & Engku Abu Bakar, 2011; Ramli et al., 2013) Mathematically, it can be expressed via formula (2.11).

$$SWA(x_1, x_2, \dots, x_n) = \sum_{j=1}^{n} (w_j . x_j) \quad (2.14)$$

where, $w_j \geq 0$ and $\sum_{j=1}^{n} w_j = 1$.

2.4.3.4 Median

Median is an operator that engages to the idea of acquiring "a middle value". The median is a typical ordinal operator, taking into account the ordering of the local scores. Then, the median value can be identified using formula (2.12)

$$Median(x_1, x_2, \dots x_n) = \begin{cases} x_{\left(\frac{(n+1)}{2}\right)} & if\ n\ is\ odd \\ \frac{1}{2}\left(x_{\left(\frac{n}{2}\right)} + x_{\left(\left(\frac{n}{2}\right)+1\right)}\right) & if\ n\ is\ even \end{cases} \quad (2.15)$$

where, parentheses around the index show that the scores are arranged in ascending order such that $x_{(1)} \leq x_{(2)} \leq \cdots x_{(n)}$. Order statistics are operators which function similarly to median but they produce the k^{th} value of the ordered scores as the final output (Domingo-Ferrer & Torra, 2003).

2.4.3.5 Ordered Weighted Average

Ordered Weighted Average (OWA) is a generalization of minimum, maximum and arithmetic mean operator (Yager, Kacprzyk, & Beliakov, 2011), proposed by (Yager, 1988). The application of OWA operator can be summarized in three basic steps (Xu, 2015). Firstly, the local scores are reordered in descending manner. Then, the weights associated with the OWA models are estimated. Finally, the local scores and weights are precisely substituted into OWA model to obtain the single score (2.13) (Grabisch, Marichal, Mesiar, & Pap, 2011).

$$OWA(x_1, x_2, \dots, x_n) = \sum_{j=1}^{n} w_j x_{(j)} \quad (2.16)$$

where, parentheses around the index show that the scores are arranged in ascending order such that $x_{(1)} \leq x_{(2)} \leq \cdots x_{(n)}$, $w_j \geq 0$, and $\sum_{j=1}^{n} w_j = 1$.

2.5 Optimization Techniques for Agriculture Production

In operations research (OR), optimization techniques are efficient method to solve complex problems arising in the management of large systems of men, machines, materials, money, businesses, and defence (Ravindran, 2009). The distinctive approach is to develop a scientific model of the system (Kirby, 2003), incorporating measurements of factors, such as chance and risk, with which to predict and compare the outcome of alternative decisions, strategies, or controls. The purpose is to help the management determine its policy and actions scientifically.

In sum, OR is the discipline of applying advanced analytical methods to help make better decisions. The optimization techniques in OR involve finding an alternative with the most cost effective or the highest achievable performance under the given constraints, by maximizing the desired factors and minimizing the undesired ones. Optimization techniques seek to find values of the decision variables that optimize (maximize or minimize) an objective function among the set of all values for the decision variables that satisfy the given constraints (Winston & Goldberg, 2004). Based on the nature of the agriculture problem, the mathematical programming techniques employed are LP (Alabdulkader, Al-Amoud, & Awad, 2012; Haouari & Azaiez, 2001; Scarpari & de Beauclair, 2010; Sivanpheng et al., 2009), integer programming (IP) (Estrella et al., 2016; Recio et al., 2003), mixed-integer programming (MIP) (Jena & Poggi, 2013; Sharifi & Rodriguez, 2002), goal programming (GP) (Jafari, Koshteli, & Khabiri, 2008a; Sharma, Hada, Bansal, & Bafna, 2010) and fuzzy goal programming (FGP) (Mirkarimi, Joolaie, Eshraghi, &

Abadi, 2013; Žgajnar & Kavčič, 2011) which could be used to find the best possible solution.

The optimization models were initially applied to agriculture problems in the early 1950s. It was Waugh (1951) who first proposed the use of LP to establish the least-cost combinations of feeding stuffs and livestock rations. LPs were the first OR models in agricultural problems after which many other techniques have been widely used in farming over the last sixty years, such as multi objective linear programming (MOLP) (Glen, 1987; Heady, 1954) and goal programming (GP) (Asís, 2007; Jafari et al., 2008a; D Latinopoulos & Mylopoulos, 2005). Furthermore, MOFLP and FGP models have been applied to optimize resource allocation problems in agriculture (Kahraman, 2008; Keramatzadeh et al., 2011; Sani, Kushwaha, Abubakar, & Ayoola, 2011; Sarker & Ray, 2009; Žgajnar & Kavčič, 2011). Moreover, Glen (1987) gave one of the first reviews of literature applying mathematical models for farm planning.

Based on the literature, many complex agriculture problems were successfully solved through these various optimization techniques. This has given us a strong motivation to review these techniques further and identify the best suitable technique for a highly constrained agricultural production problem.

2.5.1 Linear Programming Model

Linear programming is a powerful mathematical modelling technique. It can be traced back to the 1940s. It was proposed by George Dantzig, who published his first work in 1947 (Dantzig & Thapa, 2003). Linear optimization is a mathematical method for determining a way to achieve the best outcome, such as the maximum profit or the lowest cost in a given mathematical model for some lists of requirements represented as linear relationships (Ravindran, 2009). The LP model is widely accepted for its ability to model management decision problems that are significant and complex, and its ability to produce solutions expediently (Bazaraa, Jarvis, & Sherali, 2010).

LP is a specific case of mathematical programming (mathematical optimization) heavily used in microeconomics and company management, such as planning, production, transportation, technology, and other issues. Although the modern management issues are ever-changing, most companies would like to maximize profits or minimize costs with limited resources (Winston & Goldberg, 2004) (Nicola, 2000). Therefore, many issues that can be characterized as linear programming problems hinge on the circumstances or the decision maker's (Dantzig & Thapa, 1997, 2003; Karloff, 2009).

Linear programming has its basis on four mathematical assumptions. An assumption refers to a simplification in the system for the purpose of rendering the model mathematically solvable (Bazaraa et al., 2010). Assumption one to three is based on the basic LP principle; the first assumption is proportionality where the effect of a decision variable in any of the equations is proportional to a fixed quantity. The second assumption is additivity, where the combined impact of the decision variables in a single equation is the total algebraic sum of the individual weighted effects (weighing is according to the proportionality constants). Divisibility is the third assumption where the decision variables are deemed to take on fractional values that are non-integers. Lastly, the fourth assumption is certainty where all model parameters are considered to be constants (Dantzig & Thapa, 2003; Nicola, 2000). Concerning, the LP, the primary assumption of any constrained optimization issue are as follows.

1. Variables/decision variables – the variables' values are unknown at the onset of the problem and such variables are often representatives of the things that are adjustable or controllable (e.g., the rate of items manufacturing). The aim is to determine the variable's values by providing the most optimum value of the objective function (Luenberger & Ye, 2008).

2. Objective function – this refers to a mathematical expression that is a combination of the variables for a goal expression (e.g., profit representation). It may be required to maximize or minimize the objective function.

3. Constraints – they are mathematical expressions that can use a combination of variables to present limitations of potential solutions; for instance, they may present the notion that the number of available workers to work a specific machine is limited or that only a specific amount of steel is available daily (Nicola, 2000).

4. Variable bounds – on rare occasions, the optimization problem variables are permitted to obtain any value from minus infinity to plus infinity. However, the variables often have limits; for instance, zero thousand might be limited to the rate of widgets production on a specific machine (Chinneck, 2008).

The main strength of the LP model is its simplicity for modelling and the efficient algorithms that exist to solve optimization problems; however, its primary weakness is that most of the real world problems are not really linear and sometimes the linear approximation of the problem is too simplistic.

In general, many studies have been dedicated to examining the improvement of agricultural production output and agricultural planning. The LP minimizes the cost of the blend, while some specified level of nutritional requirements represents the model's constraints. Heady (1954) proposed the use of LP for determining optimum crop rotations on a farm. In this case, the objective function represents the gross margin associated with the cropping pattern, while the constraints relate to the availability of resources, such as land, labour, equipment, and working capital. Table 2.3 shows a summary of LP models in agriculture.

Table 2.3

Summary of LP Models in Agriculture

Source	Location	Factors involved (Constraints)	Objective Function
Singh et al. (2001)	India	Land, Irrigation Requirement of Crop	Maximize net return
Ibrahim (2007)	Nigeria	Gross Returns, Land, Labour, Seed , Fertilizer, Insecticide	Maximize returns product term
Agbonlahor et al (2009)	Nigeria	Costs, Profit, Child Farm Labour, Seeds, Tractor, Fertilizer	Maximize economic returns, Minimize child farm
Mohammad & Said (2011)	Malaysia	Expected Revenue, Cultivation Cost, Seedlings, Fertilizer, Machinery, Farmland Water	Maximize total returns
Al Shazly et al.(2009)	Egypt	Land, Capital, Irrigation Water, Agricultural Employment, Equipment Chemical Fertilizer, Organic Fertilizer, Pesticides, Seeds	Minimize total gross margin, Maximize technical requirements
Ibrahim, Bello & Ibrahim (2009)	Nigeria	Gross Return, Land, Labour, Fertilizer, Seeds, Insecticides	Maximize gross return
Tanko, Baba & Adenji (2011)	Nigeria	Gross Margin, Human Labour, Bullock Labour, Tractor, Capital	Maximize gross margin
Haouari & Azaiez (2001)	Saudi Arabia	Balance Constraints Land, Irrigation Level	Maximize total profit
Sivanpheng, Kangrang & Lamom (2009)	Thailand	Gross Returns, Land, Water Fertilizer, Soil, Manpower	Maximize benefit
Scarpari & Beauclair (2010)	Brazil	Profit, Costs, Trucks	Maximize profits
Al-Abdulkader et al (2012)	Saudi Arabia	Water, Cereals, Costs, Net National Import	Maximize net return

Research on farm management involves three successive stages: (i) analysis of the present position of the farm business, (ii) interpretation of the present position for indication of possible improvements, and (iii) preparation of an acceptable course of action for improvement of the farm business (Bjørndal et al., 2012; Tajuddin, Talukder, & Alam, 1994; Ibrahim, 2007). In this regard, several researchers (Singh, Jaiswal, Reddy, Singh, & Bhandarkar, 2001) suggested a linear programming model to optimize the cropping pattern that can give the maximum net return at different water availability levels. The objective function of the model was subject to the total available water and land during different seasons. The results provided an optimal cropping pattern for a command area with different crops. Some studies (Agbonlahor, Adeyemo, Bamire, & Williams, 2009). Mohamad and Said (2011) proposed a linear programming crop mix model for a defined planning horizon. The model was developed and transformed into a multi-period linear programming problem owing to the constraints in resources in the studies. The primary goal was to optimize the total returns towards the end of the planning horizon. The model was employed to choose single-harvest crops through a linear programming package, such as land restriction, labour, seed, fertilizer, insecticide, costs, machinery, water, expected revenue, and cultivation cost. The findings revealed that the model contributed positively to the total returns of the planning horizon.

On the other hand, some studies suggested a linear programming model to achieve the optimum installation of crops and the best possible profit margin in the agricultural land available, with the consumption of irrigation water, the maximization of the use of labour, and the minimization of the economic risk in the agricultural sector, while recommending strong financial support, farm advisory services, and the provision of sufficient supply of modern inputs at competitive prices to smaller farmers (e.g. (El-Shazly et al., 2009; Ibrahim, Bello, & Ibrahim, 2009; Tanko, Baba, & Adeniji, 2011).

In the context of reservoir management for optimal cropping patterns, a large number of linear programming models have been developed for optimal agricultural cropping patterns in the dry season. The objective of the models was to maximize total profit and total benefit (Alabdulkader et al., 2012; Haouari & Azaiez, 2001; Scarpari & de Beauclair, 2010; Sivampheng, Kangrang, & Alonghfd, 2009).

2.5.2 Integer Programming Model

An integer programming (IP) technique is a mathematical optimization in which all of the variables are restricted to be integers (Kaufmann, Arnold , Henry-Labordere, Arnaud & Sneyd, 1975). Integer programming produces an optimum plus one or more sub-optimum solutions to choose from, and IP is a complex one and not particularly easy to operate. It is necessary to write a control program in order to select parts of the main package which are required to solve the particular problem (Forman & Selly, 2001).

Butterworth (1985) proposed the application of integer programming as a maximizing technique in farm planning. Recio, Rubio and Criado (2003) applied IP to the production process considering irrigation, fertilization and cost or benefit. On the other hand, Cid-Garcia, Albornoz, Rios-Solis, and Ortega (2013) studied a new zoning method that optimally delineates rectangular homogeneous management zones, which relied on an IP model using spatial variability of soil properties as one of the main impairments to the productivity and agriculture crop quality. In another study, Estrella, Cattrysse and Van Orshoven (2016) determined how a set of land use types distributed over space and time using IP to optimize the multi-dimensional land performance.

Since IP requires only integer-valued variables, therefore it is not suitable for agricultural production problems that involve constraints or goals which are vague. Moreover, if there is many constraints involved in an agricultural production problem, the IP may lead to an infeasible solution.

2.5.3 Mixed Integer Programming Model

A mixed-integer programming (MIP) technique is similar to IP, but some of the decision variables are constrained to be integer values and real values to obtain the optimal solution. MIP was used to formulate an agriculture production problem (Wolsey & Nemhauser, 2014). Glen and Tipper (2001) developed a MIP technique to improve cultivation systems in a semi-subsistence farm that aims at solving the harvest planning problems arising in the production. Other researchers (Higgins, 1999; Jena & Poggi, 2013; Morrison, Kingwell, Pannell, & Ewing, 1986) also presented a MIP model for strategic and tactical harvest planning. The model was also applied to explore regional planning options for a more integrated harvesting and transport system (Higgins, 2006; Jena & Arag, 2009; Paiva & Morabito, 2009). Some studies have focused on the farm planning decisions in an integrated crop-livestock-farm context. More specifically, Visagie, De Kock,and Ghebretsadik (2004) developed a MIP technique to determine the optimal mix of agricultural crops and the number of animals. In the environmental system, Sharifi and Rodriguez

(2002) presented a planning support system based on the frame introduced to planning.

The MIP requires integer and real valued variables, which is suitable for an agricultural production problem. However, similar to IP which if there is many constraints involved in a complex agricultural production problem, the MIP may lead to an infeasible solution.

2.5.4 Goal Programming Model

Goal programming (GP) was first used by Charnes et al. (1955) and Charnes and Cooper (1961) as an application for single objective linear programming. From the works of Lee (1972), however, it gained widespread popularity from the 1960s and 1970s. In the present time, GP is a critical area of multiple criteria optimization with the main objective of establishing a level of goal achievement for every criterion. GP is a solution technique that minimizes the set of deviations, which are considered simultaneously but are weighted according to their relative importance (Gero, 2012). Moreover, GP is a branch of multi-objective optimization, which in turns is a branch of multi-criteria decision analysis (MCDA), also known as multiple-criteria decision making (MCDM) (Romero, 2014). It can be thought of as an extension or generalization of linear programming to handle multiple and normally conflicting objective measures. Each of these measures is given a goal or target value to be achieved. Unwanted deviations from this set of target values are then minimized in an achievement function. The GP is normally used to perform three types of analysis:

a. Determine the required resources to achieve a desired set of objectives.

b. Determine the degree of attainment of the goals with the available resources.

c. Provide the best satisfying solution under varying amount of resources and priorities of the goals, where the goals are specific values or levels, defined in terms of attributes and objectives, determined through a priori by decision makers (Barichard, Ehrgott, Gandibleux, & T'Kindt, 2009).

Wheeler and Russell (1977) (as cited in Romero (2014)) were the pioneers in using the GP in the agricultural problem sector. The applications of GP are best suitable when there are many goals to consider and prioritization needs to be done to improve the crops production planning process. GP has played an important role in the analysis and decision making of natural resources, specifically in agriculture, in their attempt to develop, employ, and analyse the farmers' welfare and income maximization. The summary of GP models in agriculture is shown in Table 2.4.

Table 2.4

Summary of GP Models in Agriculture

Source	Location	Factors involved (Constraints)	Objective Function
Latinopoulos & Mylopoulos (2005)	Greece	Profit, Labour, Risk, Irrigation water, fertilizers	Maximize profit Minimize labour requirements, risk income, irrigation water, nitrogen input
Abdul Aziz (2007)	Egyptian	Irrigation, water, Workers, Azotic units, Potassium, Total changeable costs, Seed	Maximize net profit Minimize irrigation water, workers, and azotic units
Jafari et al.(2008)	Iran	Gross benefit, production cost, water produced paddy, Urea Fertilizer, Triple Fertilizer, Potash Fertilizer, Pesticide, human force	Maximize income Minimize water, fertilizer, chemical poison, cost of produce, paddy, human force
Latinopoulos (2009)	Greece	Gross margin, labour, irrigation water, fertilizer	Maximize gross margin, human labour, labour efficiency, and irrigation water consumed use efficiency Minimize of risk on farmer's income, investment costs on new perennial crops, water availability, and fertilizer
Wheeler &Russell (1977)	UK	Labour force, water requirement, and gross income	Minimize benefit, cost and labour Maximize total gross
Wei, Liu, Liu, & Zhao (2009)	China	Economic benefit, water irrigation, fertilizer, seeds	Maximize net revenue and production of crops Minimize cost of cultivation.
Zhao et al. (2009)	China	Economic benefit, water irrigation, fertilizer, seeds	Minimize benefit Maximize total annual net revenue
Asadpoor et al. (2009)	Iran	Production, price, circulating capital, labour force, water requirement, Gross income	Minimize land, production, water, labour, circulating capital and gross income
Boustani et al. (2010)	Iran	Land, water, labour, capital, crop rotation and risk	Minimize risk income
Adeyemo & Otieno (2010)	South Africa	Total planting area, irrigation water, and monthly irrigation water	Maximize total agricultural output and total net benefit Minimize total irrigation water
Pal, Kumar & Sen (2010)	India	Land utilization , machine hours, Manpower, water, fertilizer, cash expenditure, production achievement	Maximize machine-hour, manpower requirement, water consumption, fertilizer requirement, production ratio and profit
Ibrahim & Omotisho (2011)	Nigeria	Land, labour, urea fertilizer, N.P.K fertilizer, onion seeds, tomato seeds Pepper seeds (Hot) Pepper seeds (Sweet)	Maximize yield of tomato, onion, and pepper Minimize environmental impacts

Zgajnar & Kavcic (2011)	Slovenia	Agriculture area, crop rotation, constraints regarding grass gathering, livestock, nutrition balancing constraints, labour, infrastructure capacity and balance constraints	Maximize expected income Minimize expected income
Sani et al. (2011)	Nigeria	Land, income, employment, Fertilizer, groundwater use, seed	Maximize income and employment, Minimize fertilizer and water use
Keramatzadeh,Chizari & Moore (2011)	Iran	Land area, summer crops, labour requirement, water requirements , Fertilizer and pesticide, Machinery	Maximize total net and employment Minimize chemical fertilizer and pesticides
Sarker, & Ray (1012)	Nigeria	Demand, Land Capital, Contingent constraint	Maximize total gross, Minimize total working capital
Sharma et al. (2010)	India	Environmental risk, production	Maximize production Minimize damages
Karbasi et al. (2012)	Iran	Fertilizer, total cost, lower limit of nutrient, upper limit of nutrient	Minimize cost of fertilizer and limit of nutrient combination Maximize limit of nutrient combination Maximize yield Maximize utilized of fertilizer
Prišenk, et al. (2014)	Slovenia	Land, labour, urea fertilizer	Minimize production cost

The studies listed in Table 2.4 summarized that GP models are important technique of operations research with extensive applications in agricultural problem through the improvement of significant social economic and environmental objectives, such as maximum net profit, income, benefit, and labour efficiency, and minimum irrigation water, risk on farmers, investment costs, labour input, nitrogen input, and use of fertilizer. These goals are subject to limitations, such as labour input, risk, irrigation water, workers, total changeable costs, seeds, production cost, urea units, triple potassium, fertilizer, and pesticide (Asís, 2007; Hajkowicz & Collins, 2007; Jafari et al., 2008; Latinopoulos & Mylopoulos, 2005; Dionysis Latinopoulos, 2007; Sharma, Hada, Bansal, & Bafna, 2010).

However, to determine the optimum pattern of agricultural irrigation needed for dry and semi-arid areas with limited water resources, a need was found to trade-off between the reduction of water use and the reduction of risk to get the total gross margin, crops production level, and profit. Also the sustainable use of resources is impacted by the market production (Boustani & Mohammadi, 2010; Pal et al., 2010).

Most of the applications in agricultural planning correspond to the problem of determining an optimum cropping pattern with multiple goals. The GP technique have been successfully used for these purposes (Romero, 1991). Wheeler and Russell (1977) used GP to set goals for gross margin, seasonal cash exposure, and labour utilization, and smoothing for the case of farm planting in the UK. Meanwhile, Ghosh, Pal, and Basu (1993) and Prišenk et al. (2014) presented the use of penalty functions in the GP model for land allocation problems for optimal production of seasonal crops. Wei, Liu, Hu, and Zhao (2009) carried out a study to investigate how multi-objectives programing can be effectively used for modelling and solving the problems of crop planning, maximizing the net revenue from cultivated land, and minimizing the cost of cultivation. Other studies were conducted to determine a superior production resource allocation including water, labour force, and land (Adeyemo, Bux, & Otieno, 2010; Asadpoor, Alipour, Shabestani, & Paeenafrakoti, 2009; Ibrahim & Omotesho, 2011; Zhao, Zhang, Tang, Wang, & Zheng, 2009). The findings showed that minimizing water, labour, circulating capital and increasing the cultivation area and gross income lead to the maximization of the total net benefit.

Other studies dedicated to the topic highlighted the impact of multi-objectives programming methods. For instance, Al-Zahrani, Musa, and Chowdhury (2015) studied the optimal sources of agricultural sector for reduction of water consumption, reduction of fertilizer use, reduction of ground water use, and maximization of income and employment. Other studies revealed trade-offs among reduced water use, reduced risk, obtaining gross margin, and increasing the farmers' net returns, in addition to sustainable resources use (Boustani & Mohammadi, 2010; Karbasi, Sardehaee, Geshniyan, & Rezaei, 2012; Keramatzadeh et al., 2011; Sani et al., 2011).

2.5.5 Fuzzy Goal Programming

A decision maker faces difficulties when making a decision, especially if this decision has multiple objectives that need to be simultaneously achieved. This problem becomes more complicated when the nature of the objectives is conflicting and vague. GP is a suitable technique to solve such problems; however, its applications may be faced with some difficulties, including expressing the decision maker's vague goals and/or constraints mathematically and the need to optimize all goals simultaneously. In such cases, the use of Zadeh's (1965) fuzzy set theory (FST) is quite useful. Another alternative approach to handle vagueness in gaols is to establish a level of importance or weights objectives (Makui, Fathi, & Narenji, 2010).

In a fuzzy goal programming (FGP), inaccurate or fuzzy objectives and constraints, known as fuzzy goals, are represented by associated membership functions. Thus, the lower or upper tolerance limit must be defined for each one depending on the fuzzy restriction given to a fuzzy goal of the problem (Biswas & Pal, 2005). Zimmermann (1978) and Mohamed (1997) discussed the relationship between GP and fuzzy programming and introduced the FGP approach to solving the multiple objective problems. The FGP approach has been applied to a number of problems related to agriculture (Barough, 2011; Zimmermann, 1985).

In the agricultural sector, the nature of most production planning problems is multi-objective. Issues of risk resources sustainability and conservation, social aspects of farming systems, and environmental quality are as important as economic efficiency. It is not possible to expand a single objective that satisfies all interests, adversities, and political and social viewpoints (Gupta, Harboe, & Tabucanon, 2000). However, much of decision making in the real-world takes place in an agricultural environment where the objectives, constraints, weights or parameters are often imprecisely defined (Sen & Pal, 2013).

Therefore, the decision making based on the vague data is fuzzy rather than precise and is often inaccurate by nature (Amini, 2015). In order to reflect this uncertainty, the problem model is often constructed with fuzzy data. Consistent with Gupta et al. (2000) and Gupta and Bhatia (2001), the fuzziness in goals and constraints is regarded as fuzzy criteria in the agricultural crop planning problems and the allocation of production resources. This leads us to keep in mind all the conflicting environmental and socio-economic components of the farming sector (Biswas & Pal, 2005).

Other studies on the FGP techniques have pointed out that, recently, the use of fuzzy approach to farm planning problems, such as the productive resources management, the uncertainty in crop planning, and the analysis of water use in agriculture (Amini, 2015; Silva & Marins, 2014; Mirkarimi, Joolaie, Eshraghi, & Abadi, 2013), the water supply planning (Slowinski, 1986), and the farm structure optimization problem (Czyżak, 1990). Comparing GP and FGP, it can be suggested that FGP is the most appropriate approach when the problems involve vagueness or fuzzy objectives in level of importance.

2.6 Discussion and Summary

This chapter provides considerable reviews concerning agricultural problems, including the background and agricultural policy. It also describes about the criteria used in agricultural sector problems, objective functions and related techniques for agriculture problems.

The mathematical programming such as the GP and FGP are the most favourable techniques among all the techniques being reviewed in the agricultural production sector, when the problem involves prioritization of goals, uncertainty elements and level of importance.

In the real-world problem, the input data or parameters such as water, fertilizer and other resources available, among others, are often imprecise (fuzzy) because of in-complete or non-obtainable information. Therefore, the fuzzy goal programming has been identified to solve this type, of which is discussed in detail in Chapter Four.

CHAPTER THREE
GOAL PROGRAMMING AND FUZZY CONCEPTS

This Chapter Three discusses fundamentals and concepts relevant to goal programming (GP) and fuzzy elements to support the methodology employed in this research. This chapter is divided into the following sections: Multi-criteria decision making (MCDM) concept, multi-objective decision making (MODM) technique, theoretical framework for goal programming concept (GP) and fuzzy goal concept (FGP) with the definition of fuzzy programming, fuzzy set theory, membership function concept, construction of membership goals, interval weights, definition of interval arithmetic, and determination of errors. A summary of the chapter is provided at the end.

3.1 Multi-Criteria Decision Making Concept

Multiple criteria decision making (MCDM) is defined as a sub-disciplinary operational study that takes into account conditions in the environment of decision making. It involves decision making in the face of several contrasting and often conflicting conditions and the decision is selected from several different alternatives, with the preferred optimum alternative chosen among many choices (Romero & Rehman, 2003). In this context, it is pertinent for the decision maker to be privy to the task and to judge the performance of the available alternatives and to weight the relative importance of the condition, so as to reach a global judgment. This judgment should take into account the existence of several conditions that partially contradict each other and are frequently non-commensurable, and thus, the MCDM came into existence (Lazarevska, Fischer, Haarstrick, & Münnich, 2009).

In the majority of disciplines, MCDM has been noted as the fastest developing area in the scientific fields. The core issue of MCDM is how to conduct an evaluation of a set of alternatives in light of a number of conditions (Coello, Van Veldhuizen, & Lamont, 2002; Triantaphyllou, Kovalerchuk, Mann, & Knapp, 1997). Several authors with the inclusion of Zimmermann (1996) have categorized MCDM into two, namely, multi-objective decision making (MODM) and multi-attribute decision making (MADM). The two classes of models are often used synonymously (Kahraman, 2008; Lee, 1972). Studies dedicated to MODM decision problems are characterized by continuous decision space; for instance, mathematical programming issues having multiple objective functions (Romero & Rehman, 2003).

3.2 Multi-Objective Decision Making Technique

The MODM is also commonly known as the multi-objective optimization (MOO). It is a technique defined as a mathematical procedure that determines alternatives to the most cost-effective performance under limitations by the maximization of desired factors and the minimization of negative ones. Maximization here refers to the attempt to achieve the highest outcome notwithstanding the cost or expense (Kahraman, 2008).

In the past few years, many researchers have come to realize that a variety of real-world problems, which have been previously solved by LP techniques, have, in fact, become more complicated. Frequently, these problems have multiple goals or objectives to be optimized rather than having a single objective as in the LP. In an LP, a single objective is selected and the other objectives are consigned to be constraints. With the advent of MOO these problems can now be modelled more realistically (Chinneck, 2008; Hannan, 1981).

MOO is an extension to the mathematical programming theory that involves decisions, which depends on the maximization or minimization of multiple objective functions, that need to be optimized subject to a set of constraints (Deb, 2014; Doumpos & Zopounidis, 2002; Lu, Zhang, Ruan, & Wu, 2007). The standard form of MOO model as defined by Doumpos and Zopounidis (2002) is as follows.

$$Maximize\ or\ Minimize\ \{f_1(x),\ \ f_1(x), \ldots, f_n(x)\} \tag{3.1}$$

Subject to

$$x\ \in B$$

where, x is the vector of the decision variables, $f_1(x), f_1(x), \ldots, f_n(x)$ are the objective functions (linear or non-linear) to be optimized, and B is the set of all feasible solutions.

Many decision making problems can be formulated as an MOO. Usually, there hardly exists a feasible solution that optimizes all objective functions in the MOO, when considering candidates for a final decision-making solution (Murty, 2010). Due to that, the concept of Pareto optimal solution was introduced. It is an issue on how decision makers decide the final solution from the set of Pareto optimal solutions (Konak, Coit, & Smith, 2006; Lu et al., 2007).

In general, for a MOO problem what is optimal for one of the objectives is usually non-optimal for the remaining objectives. The predominant concept of defining such optimal solution is that of Pareto (Jones, Tamiz, & Ries, 2009) which defines that if no other feasible solution exists that yield an improvement in one objective without causing detriment to at least one other objective, then such optimal solution is acceptable. Hence, the term optimizing means finding a solution that would analyse the trade-offs and give the values of all the objective functions acceptable to the decision maker (Deb & Saxena, 2006). Implicit from the concept is that there is no single global solution for an MOO problem and mathematically, all the Pareto optimal points are equally acceptable solutions for the MOO problem. However, it is desirable for the decision maker to select a satisfactory solution from a set of Pareto optimal solutions based on his or her judgment and value system, or specifically, preferences.

The MOO technique that can handle the multiple objectives or goals problems is the GP, which is able to prioritize these goals accordingly. The concepts of GP are discussed in the following sections.

3.3 Goal Programming Concept

Goal Programming is a branch of MODM, which in turn is a branch of MCDM. It can be thought of as an extension of an LP to handle multiple, normally conflicting objective measures. Each of these measures is given a goal or target value to be achieved. Unwanted deviations from this set of target values are then minimized in an achievement function. GP is a well-known modification of LP.

The LP deals with only one single objective to be minimized or maximized, and subject to some constraints; therefore, it has limitations in solving a problem with multiple objectives or goals. GP, instead, can be used as an effective approach to handle a decision concerning multiple and conflicting goals. Further, the objective function of a GP model may consist of non-homogeneous units of measure (Romero, 2014).

The computational procedure in a GP is to select a set of solutions, which satisfies the environmental constraints and provide a satisfactory goal, ranked in priority order. Low ordered goals are considered only after the higher ordered goals are satisfied. If ordinal rankings of the goals can be provided in terms of importance or contributions and all goal constraints are linear in nature, the solution of the portion can be obtained through the GP (Hillier & Lieberman, 2001; Jones & Tamiz, 2010; Jones et al., 2009). In the solution of GP models, the objective is used to minimize the deviation of the determined target according to priority and weight coefficients defined by the decision maker. However, the GP is not only a technique to minimize the sum of all deviations, but it is also a technique to minimize priority deviations as much as possible (Gero, 2012). The results of an MOO problem are affected by the decision maker. Therefore, when there is a concession between goals, there will be deviations according to the decisions made. The direction and extent of these deviations play important roles in this type of problem (Hillier & Lieberman, 2001; Jones & Tamiz, 2010).

Some authors (e.g., Barichard et al., 2009; Jones & Tamiz, 2010) considered GP as one of the stronger technique available due to its close correspondence with decision-making in practice. Furthermore, it has some attractive technical properties as described in Section 2.5.1. In practice, decision makers aim at various goals, formulated as aspiration levels. The intensity with which the goals are strived for may vary from goal to goal; in other words, different weights may be assigned to different goals (Romero, 2014).

There are two basic aspects to solve a problem through a GP technique, which are weighted and pre-emptive aspects. In both aspects, there is a method converts the multiple goals into a single and objective confliction (Steuer, 1986). First, in the weight method, the single objective function is the weighted sum of the conflictions that represent the goals of the problems; that is, it considers all goals simultaneously within a composite objective confliction, comprising the sum of all respective deviations of the goals from their aspiration levels (Hillier & Lieberman, 2001). The deviations are then weighted according to the relative importance of each goal. To avoid the possible bias effect of the solution to different measurement unit goals, normalization takes place (i.e., the model minimizes the sum of the deviations from the target) (Lee, 1972).

Second, the pre-emptive method starts by prioritizing the goals in order of importance. According to Jones and Tamiz (2010) the pre-emptive method is based on the logic that in some decision-making spectrums, some goals seem to prevail. The procedures begin with comparing all the alternatives with respect to the higher priority goals and continue with the next priorities until only one alternative is left. The mode is then optimized using one goal at a time such that the optimum value of a higher priority goal is never deemed by a lower priority goal (Jones & Tamiz, 2010; Romero, 2014).

The two methods do not generally produce the same solution and neither is one method is superior to the other because each method is designed to satisfy certain decision makers' preferences.

Subsequently, the following subsections present the underlying philosophy of the GP, and then by one-of-a-kind strategies of GP with a specific emphasis on three principal classes: weighted GP, Lexicographic GP, and min-max (Chebyshev) GP.

3.3.1 Philosophy of Goal Programming

In the GP, the term goal usually means a criterion and a numerical level known as the target level which the decision maker sets to achieve the criterion. There can be three principal types of goal in GP models (Romero, 2014).

- Type 1- Maximizing goal: This needs to be achieved at the highest target level.
- Type 2- Minimizing goal: This needs to be achieved at the lowest target level.
- Type 3- Equalizing goal: This needs to be achieved exactly at the target level (Jones et al., 2009).

Applying the GP in any field requires a deep understanding of the underlying philosophy. This will ensure that the right choices of variables and corresponding parameters are set.

One of the primary underlying philosophies in the GP is satisficing. A target level is set and an attempt to reach that target as close as possible is embarked upon. This is an alternative of the optimizing philosophy. It assumes that human behaviour is more related to satisficing rather than optimizing as people are more interested and are able to reach goals than optimizing each outcome of a decision problem (Hillier & Lieberman, 2001; Jones & Tamiz, 2010).

On the other hand, the optimizing philosophy in GP can become important in three different situations: First, for optimistic goals that have been set up to their ideal values, the dominant philosophy would be optimizing rather than satisficing. Second, the optimizing and satisficing philosophy will coincide for two-sided goals. Third, for Pareto optimality detection and restoration, the dominant philosophy is the combination of both satisficing and optimizing (Ishizaka & Nemery, 2013; Romero, 2014). The basic definitions and concepts of GP that are used throughout this research are addressed. These concepts are discussed in order to highlight awareness on the utilization of the GP.

Definition 3.1: Decision Variable

A decision variable is defined as a factor over which the decision maker has control (Hillier & Lieberman, 2001). For example, in the agriculture production planning the types of crops is the decision variables. The set of decision variables fully describe the problem and form the decision to be made (Romero & Rehman, 2003). The purpose of the GP technique can be viewed as a search of all the possible combinations of decision variable values (known as decision space) to determine the point which best satisfies the decision maker's goals and constraints (Gero, 2012; Jones & Tamiz, 2010).

Definition 3.2 Criterion

A criterion is a single measure by which the goodness of any solution to a decision problem can be measured (Jones & Tamiz, 2010). There are many possible criteria arising from different fields of application, but some of the most commonly arising relate at the highest level to cost, profit, benefit, time, distance, performance of a system, company or organization strategy, environmental risk, personal preferences of the decision maker(s), and safety considerations (Romero & Rehman, 2003). A decision problem, which has more than one criterion, is, therefore, referred to as an MCDM problem. The space formed by the set of criteria is known as criteria space (Hillier & Lieberman, 2001; Ishizaka & Nemery, 2013).

Definition 3.3 Objective Function

An objective function is referred to as a criterion with the additional information of the direction (maximize or minimize) in which the decision maker(s) prefers the criterion scale (Hillier & Lieberman, 2001; Tamiz, 1996). For example, minimizing the cost or maximizing the performance of a system. In practice, the objectives may be conflicting in a sense that they cannot reach their optimal values simultaneously. If they could, then the model can be solved as a single-objective problem for any of the objectives. If they could not a decision problem with a set of objectives is referred to as a MOO. The space formed by the values of the set of objectives is known as objective space (Ehrgott & Wiecek, 2005).

The objectives should not only reflect the current decision-making behaviour. It is quite significant that they are properly selected to constitute the optimization targets to any policy scenario that is going to be implemented in modelling activities in each sector (Taleizadeh, Akhavan Niaki, & Hoseini, 2009).

Definition 3.4 Constraints

A constraint is a restriction upon the decision variables must be satisfied for the solution to be implementable in practice (Ehrgott & Wiecek, 2005). This is distinct from the concept of a goal whose non-achievement does not automatically make the solution non-implementable. A constraint is normally a function of several decision variables and can be equality or an inequality and integer constraints. The set of candidate solutions that satisfy all constraints is called the feasible set (Ishizaka & Nemery, 2013). For example, in the agricultural sector, the resources on the farm consist of agricultural lands, exploitation of water irrigation, fertilizer, pesticides, labour, equipment, and seeds (Tamiz, Jones, & El-Darzi, 1995). The availabilities of these resources work serve as constraints within which the feasible planning needs to be optimized (Romero & Rehman, 2003).

Definition 3.5 Feasible Region

The set of solutions in decision space that satisfies all constraints and sign restrictions in a GP form the feasible region (Romero, 2014). Any solution that falls within the feasible region is deemed to be implementable in practice (Tamiz, 1996).

3.3.2 Types of Goal Programming Technique

Three basic techniques have been developed to optimize a multi objective model with possibly conflicting goals. The techniques are weighted GP, pre-emptive GP or Lexicographic GP (LGP) and min-max (Chebyshev) GP (Ishizaka & Nemery, 2013; Jones et al., 2009). The weighted GP technique was first presented by Charnes and Cooper (1961), the objective is to find a solution that minimizes the weighted sum of the goal deviations. In this case all the unwanted deviations are multiplied by weights, reflecting their relative importance, and then added together as a single sum in order to minimize the weighted sum of the goal deviations (Jones & Tamiz, 2010).

The second GP technique is the LGP presented by Ignizio (1976) as an algorithm to show how can be solved as a series of LP. The initial GP formulations ordered the unwanted deviations into a number of priority levels, with the minimization of a deviation in a higher priority level being of infinitely more importance than any deviations in lower priority levels. The LGP should be used when a clear priority ordering exists amongst the goals to be achieved. Objective functions are ordered according to their importance (Jones & Tamiz, 2010).

The third technique introduced by Flavell (1976) known as min-max (Chebyshev) GP, which seeks the solution that minimizes the worst unwanted deviation from any single goal. For decision-makers more interested in obtaining a balance between the competing objectives rather than ruthless optimization, min-max GP, which is considered as a specific form of a weighted GP technique, should be used. However, this technique is not extensively used in practice as much as the weighted GP and LGP techniques (Jones & Tamiz, 2010).

In short, weighted GP technique considers the relative importance of the goals that is dealt with using their relative weights, while in LGP the absolute goals are handled by their rankings. Next sub-section presented the weighted GP technique definition and formulation in detail.

3.3.2.1 Weighted Goal Programming

This technique involves identifying objectives, setting goals (target value for each objective), assigning weights to each goal, and then developing a normalized single objective function. Each goal, i, has its achievement value F_i which is equal to the target T_i. The satisficing philosophy allows under-achievement or over-achievement of each of the goals. Deviational variables d_i^- (for under-achievement) and d_i^+ (for over-achievement) are introduced:

$$F_i + d_i^- - d_i^+ = T_i \qquad (3.2)$$

$$d_i^-, d_i^+ \geq 0$$

If under-achievement is desirable then d_i^+ is minimized, while d_i^- can take any positive value. In case of over-achievement is desirable, d_i^- is minimized while d_i^+ can have any positive value. Steuer (1986) presented the GP problem with, for instance, one of each type of goal criterion as

$$\left.\begin{array}{l} \text{Goal } \{ c^1 x = z_1\} \ (z_1 \geq t_1) \\ \text{Goal } \{ c^2 x = z_2\} \ (z_2 = t_2) \\ \text{Goal } \{ c^3 x = z_3\} \ (z_3 \in [t_3^l, t_3^u) \\ \text{Subject to} \\ \qquad X \in S \end{array}\right\} \tag{3.3}$$

The weighted GP formulation of the above GP is

$$\left.\begin{array}{l} Min \{ w_1^- d_1^- + w_2^+ d_2^+ + w_2^- d_2^- + w_3^- d_3^- + w_3^+ d_3^+ \} \\ \quad \text{Subject to} \\ \qquad c^1 x - d_1^+ + d_1^- = t_1 \\ \qquad c^2 x - d_2^+ + d_2^- = t_2 \\ \qquad c^3 x - d_3^+ + d_3^- = t_3^l \\ \qquad c^3 x - d_3^+ + d_3^- = t_3^u \\ \qquad x \in s \\ \qquad \text{all } d's \geq 0 \end{array}\right\} \tag{3.4a}$$

The characteristics of weighted GP are as follows:

1. The objective function weights are considered positive penalty weights.
2. Every goal leads to a goal limitation with the exception of range goals that give rise to two.
3. The devotional variables are the only variables related to undesirable deviations required to be applied in the formulation.
4. The objective function is the weighted-sum of the undesirable deviational variances.

5. Solutions can be reached with the use of conventional LP software.

As a summary the weighted GP model is suitable to solve a MOO problem in case, if the decision-maker is more interested in direct comparisons of the objectives then weighted GP should be used.

3.3.2.2 Lexicographic Goal Programming

Lexicographic or pre-emptive GP (LGP) is the existence of a number of priority levels. Each priority level contains a number of unwanted deviations to be minimized (Jones & Tamiz, 2010).

The LGP technique aims at minimizing the deviational variables for a higher priority level and considers them to be more important than that of the deviational variables placed in the lower priority level (Min & Storbeck, 1991). This is done by following a sequential optimization process, where in each step the feasible region will be reduced as the minimization of the higher priority goals is maintained (Jones & Tamiz, 2010). According to Romero (2014), the pre-emptive priority factors first developed by Ijiri (1965) and Lee (1972) were a way of ordering goals in the objective function in the GP models.

To formulate a generic LGP algebraically, we define the number of priority levels as L with corresponding index $l = 1, \ldots, L$. Each priority level is now a function of a subset of unwanted deviational variables which we define as $h_l(d_l^-, d_l^+)$. This leads to the following formulation.

$$\left.\begin{array}{l} \text{Min } a = \{h_1\,(d_1^-,\ d_1^+), h_2\,(d_2^-,\ d_2^+), \dots, h_L\,(d_l^-,\ d_l^+)\,\} \\ \quad \text{subject to} \\ \qquad h_l(\underline{x}) +\ d_1^- -\ d_1^+\ = b_q \qquad q = 1, \dots, Q \\ \qquad \underline{x} \in F \\ \qquad d_1^-,\ d_1^+ \geq 0 \qquad q = 1, \dots, Q \end{array}\right\} \quad (3.4b)$$

Or alternatively,

$$\text{Min } a = [a_1, a_2, \dots, a_l]$$

Where, each $a_l = h_l(d_l^-,\ d_l^+)$ is a function of the deviational variables. The exact nature of $h_l(d_l^-,\ d_l^+)$ depends on the nature of the goal programme to be formulated, but if we assume that it is linear and separable then it will assume the form

$$\text{Min } Z = [Q_1 h_1\,(d_1^-,\ d_1^+) +\ Q_2\ h_2\,(d_2^-,\ d_2^+) + \dots + Q_l h_l\,(d_l^-,\ d_l^+)]$$

where, Q_1 denotes the first priority with an infinitely larger weight than Q_2.

3.3.2.3 Min-Max (Chebyshev) Goal Programming

Min-Max GP was first introduced by Flavell (1976) to minimize the worst or the maximum unwanted goal deviations. This is very similar to weighted GP with the only exception being that the objective function is to minimize the maximum deviational variables. When the decision maker desires to achieve a balance between different goals rather than prioritizing one goal over another or weighting different goals, Mini-Max GP gives a better result. Also, it can identify optimal solutions for linear models that are not located at extreme points in the decision space (Jones & Tamiz, 2010). It also indicates that the balancing philosophy is dominant in Mini-

Max GP. However, this technique is not extensively used in practice as much as the weighted GP and LGP techniques.

If we let λ be the maximal deviation from amongst the set of goals then the Chebyshev goal programming has the following formulation.

$$\left.\begin{array}{ll} Min\ a = \lambda & \\ \text{subject to} & \\ f_q(\underline{x}) + d_1^- - d_1^+ = b_q & q = 1, \dots, Q \\ \dfrac{u_{q,}^l\, d_l^-}{k_q} + \dfrac{v_{q,}^l\ d_1^+}{k_q} \leq \lambda & q = 1, \dots, Q \\ \underline{x} \in F & \\ d_1^-,\ d_1^+ \geq 0 & q = 1, \dots, Q \end{array}\right\} \qquad (3.4c)$$

Provided all objective functions $f_q(\underline{x})$ are linear, this shares the advantage along with the other two major GP variants.

3.4 Fuzzy Goal Programming Concept

Fuzzy GP (FGP) utilizes fuzzy set theory (Zadeh, 1965) to deal with a level of imprecision in the GP technique. FGP is defined as an extension of conventional GP, where aspiration level of each objective is taken as a unity concerning the achievement of the highest degree of fuzzy goals of a problem (Hannan, 1981; Narasimhan, 1980; Tiwari et al., 1987; da Silva & Marins, 2014; Loganathan & Bhattacharya, 1990).

3.4.1 Fuzzy Sets Theory

A classical (crisp) set is normally defined as a collection of elements or objects which can be finite, countable, or over countable (Zimmermann, 2001). Each single element can either belong or not belong to a set. The fuzzy set theory fundamentals were pioneered by Zadeh (1965). The following definitions are related to fuzzy sets.

Definition 3.6 Fuzzy Subset Membership

Let x be a universal set. Then, we define the fuzzy subset $\tilde{A}$ of x by its membership function $\mu_{\tilde{A}} : X \rightarrow [0, 1]$ which assigns to each element, $x \in X$ a real number $\mu_{\tilde{A}}(x)$ in the interval $[0, 1]$, where the function value of $\mu_{\tilde{A}}(x)$ represents the grade of membership of x in $\tilde{A}$.

A fuzzy set $\tilde{A}$ is written as $\tilde{A} = \{(x, \mu_{\tilde{A}}(x)), x \in X, \mu_{\tilde{A}}(x) \in [0, 1]\}$.

Definition 3.7 Normal Fuzzy Set

Let $\tilde{A}$ be a fuzzy set, defined on the set of $R, \tilde{A}$ is called normal fuzzy set if there exist $x \in R$ such that $\mu_{\tilde{A}} = 1$.

Definition 3.8 Left and Right

Left and Right (L-R) is a representation of fuzzy numbers (Dubois & Prade, 1978).The idea of constructing the concept of L-R fuzzy number is referred to as Dubois and Prade, to avoid the previous operations of fuzzy numbers and to make the computational formulation easier and quicker.

A fuzzy number $\tilde{m}$ is called an L-R fuzzy number,

$$\mu_{\tilde{m}}(x) = \begin{cases} L\left(\frac{m-x}{\alpha}\right) \; if \;\; x \le m \;\; , \;\; \alpha > 0 \\ R\left(\frac{x-m}{\beta}\right) \; if \;\; m \le x \; , \;\; \beta > 0 \end{cases} \tag{3.5}$$

where, m, α and $\beta \in R$. The function $L(x)$ is called a left shape function if the following holds:

(1) $L(x) = L(-x)$,

(2) $L(0) = 1,\ L(1) = 0$,

(3) L is non-increasing on $[0, \infty]$

The functions R and L are called the right and left shape functions, m symbolizes the mean value of $\tilde{m}$, while α and β are left and right spreads, respectively, i.e. α and β are the coefficients of "fuzziness". As the spreads increase, $\tilde{m}$ become fuzzier and fuzzier. It is symbolically written as $\tilde{m} = (m, \alpha, \beta)_{LR}$.

Clearly, $\tilde{m} = (m, \alpha, \beta)_{LR}$ is positive, if and only if $m - \alpha > 0$ (Note that, $L(0) = 1$).

Definition 3.9 Triangular Fuzzy Number

Among the several shapes of fuzzy numbers, the most common one used is the triangular fuzzy number (TFN), and is a special type of L − R fuzzy number. A TFN is a L − R fuzzy number,

where, $L = R = max\ (0, 1 - x)$, consequently its membership function is given by

$$\mu_{\tilde{A}}(x) = \begin{cases} 1 - \dfrac{m-x}{\alpha}, & m-\alpha \le x < m \;\;, \; \alpha > 0 \\ 1 - \dfrac{x-m}{\beta}, & m \le x < m+\beta \;\;, \; \beta > 0 \\ 0 & \text{otherwise} \end{cases} \tag{3.6}$$

In addition, a set of all TFN is denoted by $F(R)$. The TFN can be represented as three real numbers, $\widetilde{m} = (m, \alpha, \beta)$. Fuzzy membership function is explained in the following example.

The membership function of the TFN, $\widetilde{m} = (3, 5, 4)$ is

$$\mu_{\widetilde{m}}(x) = \begin{cases} 0 & x < -2 \\ \dfrac{2+x}{5} & -2 \le x \le 3 \\ \dfrac{7-x}{4} & 3 \le x \le 7 \\ 0 & \text{otherwise} \end{cases} \tag{3.7}$$

as shown in Figure 3.1.

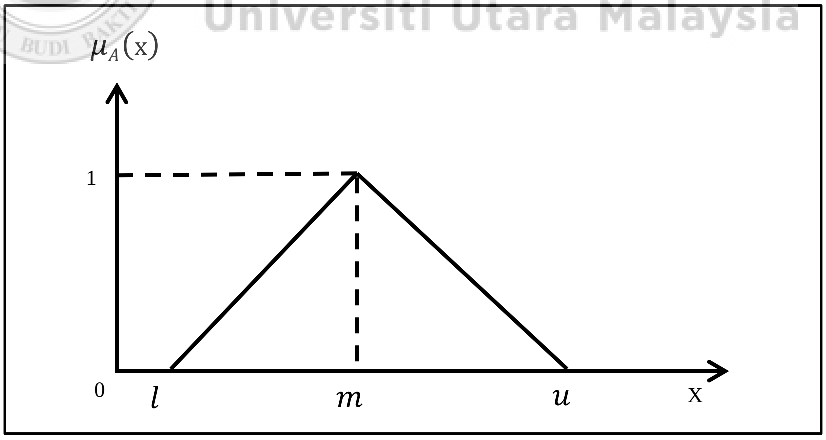


Figure 3.1. Triangular fuzzy number (m, l, u)

There is another very advantageous form for a TFN, $\widetilde{m} = (m, \alpha, \beta)$. It is so if we suppose $a_1 = m - \alpha$ and $a_2 = m$ and $a_3 = m + \beta$. In which case, it is symbolically written as $\tilde{a} = (a_1, a_2, a_3)$. Then the membership function of this form is

$$\mu_{\tilde{A}}(x) = \begin{cases} \dfrac{x - a_1}{a_2 - a_1} & a_1 \leq x \leq a_2 \\ \dfrac{a_3 - x}{a_3 - a_2} & a_2 \leq x \leq a_3 \\ 0 & \text{otherwise} \end{cases} \quad (3.8)$$

3.4.2 Membership Function Concept

In 1965, Zadeh formalized the fuzzy set theory at the University of California. He introduced a shift in paradigm and its effective use has guaranteed its employment throughout the globe. A paradigm refers to a set of rules and regulations that describes boundaries and indicates how to successfully solve issues within limitations (Kahraman, 2008). A membership function (MF) is described as a curve describing the way every input space point is mapped to a membership value or the level of membership (from 0 to 1). The most basic MF is developed via straight lines, and among them, the triangular membership function is the most basic and it is merely a gathering of three points that form a triangle.

3.4.3 Construction of Membership Goals

The multi-objective problem be formulated as $Z_1(x),\ Z_2(x), \ldots,\ Z_g(x)$ which are the objectives to be optimized, subject to given constraints as

$$\left.\begin{array}{ll} Z_k(X) \gtrsim b_k\ , & k = 1,2,\ldots,K \\ Z_k(X) \lesssim b_k\ , & k = (K+1),(K+2),..,g \\ \text{Subject to} & \\ X \in S^* = \left\{X \in R^n \middle| \begin{Bmatrix} AX \geq C \\ AX \leq C \end{Bmatrix}, X \geq 0, C \in R^m \right\} & \end{array}\right\} \quad (3.9)$$

b_k be the imprecise aspiration level of the kth goal, $Z_k(X)$ $(k = 1,2,\ldots,g)$. The fuzzy goals take the form of either $Z_k(X) \gtrsim b_k$ or $Z_k(X) \lesssim b_k$, depending on whether the objectives should be maximised or minimised, where X is the vector of the decision variables and $\gtrsim$ and $\lesssim$ represent the fuzziness of $\geq$ and $\leq$ restrictions, respectively (Zimmermann, 1978). By using the concept of fuzzy sets theory, the linear membership functions shown in Figure 3.2 can be defined based on the following steps (Baky, 2010; Ehrgott & Gandibleux, 2003; Lachhwani, 2013; Zangiabadi & Maleki, 2013).

Step 1: Solve the multi-objective problem as a single objective problem, taking each time only one objective as objective function and ignoring all others.

Step 2: Compute the value of each objective function at each solution derived in Step 1.

Step 3: From Step 2, find for each objective the best (L_k) and the worst (U_k) values corresponding to the set of solutions. Recall that L_k and U_k are the aspired level of achievement and the highest acceptable level of achievement for the k^{th} goal, respectively (Zangiabadi & Maleki, 2007).

Step 4: Define a membership functions μ_k for the k^{th} goal.

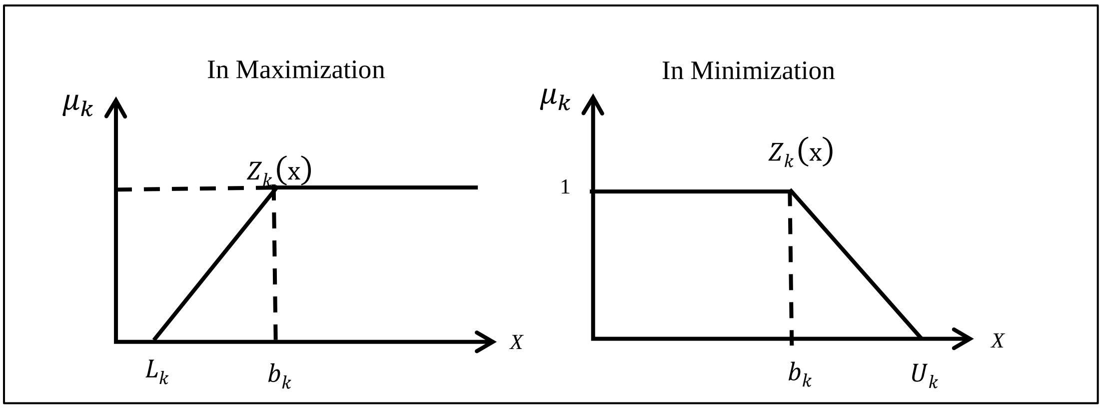


Figure 3.2. Linear membership function

In a decision-making situation, fuzzy goals are characterised by their respective membership functions. The membership function is $Z_k(X) \gtrsim b_k$; thus, the following membership function, which correspond to each objective function are introduced algebraically as,

$$\mu_k\big(Z_k(x)\big) = \begin{cases} 1 & Z_k(x) \geq b_k \\ \dfrac{Z_k(x) - L_k}{b_k - L_k} & L_k \leq Z_k(x) \leq b_k\,, \quad k = 1,2,\dots,K \\ 0 & Z_k(x) < L_k \end{cases} \quad (3.10)$$

On the other hand, the membership function μ_k for the k^{th} fuzzy goal for minimizing $Z_k(x)$ can be defined as,

$$\mu_k\big(Z_k(x)\big) = \begin{cases} 1 & Z_k(x) \leq b_k \\ \frac{U_k - Z_k(x)}{U_k - b_k}\,, & b_k < Z_k(x) \leq U_k\,,\ k = (K+1),(K+2),\dots,g \\ 0 & Z_k(x) \geq U_k \end{cases} \quad (3.11)$$

where, L_k and U_k are the aspired level of achievement and the highest acceptable level of achievement for the kth goal, respectively; μ_k is the membership function of the k^{th} goal, Z_k.

In decision making situation, the aim of each decision maker (DM) is to achieve the highest membership value (unity) of the associated fuzzy goal in order to obtain the absolute satisfactory solution. However, in real practice, achievement of all membership values to the highest degree (unity) is not possible due to conflicting objectives. Therefore, decision policy for minimizing the regrets of the DMs for all the objectives should be taken into consideration. Then each DM should try to maximize his or her membership function by making them as close as possible to unity by minimizing its negative deviational variables. Therefore, in effect, we are simultaneously optimizing all the objective functions. So, for the defined membership functions in (3.10) and (3.11), the flexible membership goals having the aspired level unity can be represented as follows:

$$\frac{Z_k(x) - L_k}{b_k - L_k} + \rho_k^- - \rho_k^+ = 1 \qquad k = 1,2, \ldots, K \tag{3.12}$$

$$\frac{U_k - Z_k(x)}{U_k - b_k} + \rho_k^- - \rho_k^+ = 1 \qquad k = (K+1), (K+2), .., g \tag{3.13}$$

where, ρ_k^- and ρ_k^+ are under- and over-deviational variables concerned with achieving the aspired level of the k^{th} membership goal.

In conventional GP, the under- and or over-deviational variables are included in the achievement function for minimizing them and that depends upon the type of objective functions to be optimized.

3.5 Interval Weights

Interval programming is one of the approaches to tackle uncertainty in mathematical programming models, which possesses some interesting characteristics because it does not require the specification or the assumption of probabilistic distributions (as in stochastic programming) or possibilistic distributions (as in fuzzy programming) (Oliveira & Antunes, 2007) Interval programming just assumes that information about the range of variation of some (or all) of the parameters is available, which allows to specify a model with interval coefficients. Furthermore, it has been used to tackle specific issues in MOLP. In this sense, some algorithms only deal with uncertainty in the objective functions (Oliveira & Antunes, 2007), others deal with uncertainty in all the coefficients of the model (Makui et al., 2010), others handle the interval comparison matrix (Wang & Elhag, 2007), and others handle uncertainty in weights (Sen & Pal, 2013)

In the case of uncertainty in weights, the interval weights or known as a single interval weight (SIW) method is a popular tool for tackling such uncertain weight structure. In this method, weights associated with unwanted deviational variables in goal achievement function have been taken as in an interval form. Moore (1979) introduced a method based on interval arithmetic with applied numerical mathematics methods and a relevant tool to address the intrinsic uncertainty in models of real-world problems as cited by Moore, Kearfortt, and Cloud (2009). But, the SIW method was introduced in the GP area by Inuiguchi and Kume (1991) which is known as a general method to handle the uncertainty of weights under the concept of interval programming (Oliveira & Antunes, 2007; Pal, Moitra, & Sen, 2011; Sen

& Pal, 2013). Investigate the effect of uncertainty in judgment on the stability of the rank order of alternatives and used paired comparisons to derive a scale of relative importance for alternatives in weight structure by Saaty and Vargas (1987). While, the priorities determined from a pairwise interval comparison matrix were suggested by Sugihara, Ishii, and Tanaka (2004). SIW has been determined from the interval comparison matrix, as presented by Wang and Elhag (2007).

The following description presents the structure of SIW method for solving the MOO problems. First, the target achievement function is presented as the weighted summation of unwanted deviational variables. Weights (in interval form) are regulated by using a pairwise interval judgment matrix via the GP methodology (Pal & Sen, 2008). Interval goals are modified into standard goals by using the SIWGP approach (Wang & Elhag, 2007). Then the sum of unwanted deviations associated with their respective goals is considered to achieve the goal values within the specified range and construct the regret function of the final executable model. Finally, the problem is resolved through the standard GP methodology.

Similarly, several researchers (Makui, Fathi, & Narenji, 2010; Sen & Pal, 2013; Wang, Wang, & Li, 2009) introduced a new approach in SIWGP to resolve fuzzy MOO problems with SIW related to the goal accomplishment function. The membership functions of determined fuzzy targets are set in an indeterminate environment according to the defined aspiration levels and low tolerance range. The main benefit of this method is that the right weights for attaining goals can be apportioned in the approximate decision environment based on their importance. However, this method used only one interval with upper and lower values. In other words, SIW method focuses on the two extreme values of weight that are min and max which is not covered by all responses from DMs. Furthermore, the research on SIW associated with unwanted deviational variables in the weighted GP or fuzzy weighted GP area remains lacking. To discuss such an uncertain weight structure, the weights associated with unwanted deviational variables in the goal achievement function are considered a new insight of interval programming as a multi-interval weights (MIW) form which is described in Chapter Four.

3.5.1 Definition of Interval Concepts

An interval A can be defined as an ordered pair. A closed interval A (called an interval number) is defined by $A = [a^L, a^U] = \{a: a^L \leq a \leq a^U, a \in \Re\}$ where a^L, a^U are the left and right limits, respectively, of the interval A on the real line $\Re$. For a particular case, $A = [a, a]$ represents only the real number a. Now, for intervals $A_1 = [a_1^L, a_1^U]$ and $A_2 = [a_2^L, a_2^U]$ the different interval arithmetic operations are defined based on Sen and Pal, (2013) as follows:

1) The binary operation addition between two interval numbers A_1 and A_2 is defined as, $A_1 + A_2 = [a_1^L + a_2^L, a_1^U + a_2^U]$.
2) The multiplication of two interval numbers, A_1 and A_2 is defined as:

$$A_1 * A_2 = [min(a_1^L a_2^L, a_1^L a_2^U, a_1^U a_2^L, a_1^U a_2^U), max(a_1^L a_2^L, a_1^L a_2^U, a_1^U a_2^L, a_1^U a_2^U)]$$

3) The division of two interval numbers A_1 and A_2, is defined as:

$$\frac{A_1}{A_2} = \left[min\left(\frac{a_1^L}{a_2^L}, \frac{a_1^L}{a_2^U}, \frac{a_1^U}{a_2^L}, \frac{a_1^U}{a_2^U}\right), max\left(\frac{a_1^L}{a_2^L}, \frac{a_1^L}{a_2^U}, \frac{a_1^U}{a_2^L}, \frac{a_1^U}{a_2^U}\right)\right], a_2^L, a_2^U \neq 0$$

For a particular case, when $(a_1^L, a_1^U, a_2^L, a_2^U) > 0$ then, $\frac{A_1}{A_2} = [\frac{a_1^L}{a_2^U}, \frac{a_1^U}{a_2^L}]$.

3.5.2 Single Interval Weights

SIW is a way to compute the weights in the presence of uncertainty in decision-making techniques. The SIW is derived from a pairwise interval judgment matrix. Most real world decision problems involve multiple criteria that are often in conflict and it is, therefore, sometimes necessary to conduct a trade-off analysis in MCDM. As such, the estimation of the relative weights of criteria plays an important role in the MCDM process. Among many frameworks developed for weight estimation, pairwise comparison matrices provide a natural framework to elicit preferences from DMs and have been used in several weight generation methods such as SIW method (Sen & Pal, 2013).

3.5.2.1 Determination of Interval Weights

Weights of the importance of unwanted deviational variables are used to represent the relative importance of the respective criteria. It is more realistic to measure the relative importance in the interval form rather than in the deterministic values Sen and Pal (2013). If W_1^L, W_1^U where $W_1^L, W_1^U > 0$ is the IW of importance of the objective Z_i and also the pairwise judgments are precise, then the interval comparison matrix (Makui et al., 2010) A can be presented as follows:

$$A = \begin{pmatrix} 1 & \left[\frac{w_1^L, w_1^U}{w_2^L, w_2^U}\right] & \dots & \left[\frac{w_1^L, w_1^U}{w_g^L, w_g^U}\right] \\ \left[\frac{w_2^L, w_2^U}{w_1^L, w_1^U}\right] & 1 & \dots & \left[\frac{w_2^L, w_2^U}{w_g^L, w_g^U}\right] \\ \dots & \dots & \dots & \dots \\ \left[\frac{w_g^L, w_g^U}{w_1^L, w_1^U}\right] & \left[\frac{w_g^L, w_g^U}{w_2^L, w_2^U}\right] & \dots & 1 \end{pmatrix} \quad (3.14)$$

where, $\frac{[W_{k_0}^L \;,\; W_{k_0}^U]}{[W_k^L \;,\; W_k^U]}$ represents the relative importance Z_{k_0} over Z_k. Using the interval arithmetic defined in the Section 3.3.1 the interval comparison matrix can be expressed as:

$$A = \begin{pmatrix} 1 & \left[\frac{w_1^L}{w_2^U}, \frac{w_1^U}{w_2^L}\right] & \dots & \left[\frac{w_1^L}{w_g^U}, \frac{w_1^U}{w_g^L}\right] \\ \left[\frac{w_2^L}{w_1^U}, \frac{w_2^U}{w_1^L}\right] & 1 & \dots & \left[\frac{w_2^L}{w_g^U}, \frac{w_2^U}{w_g^L}\right] \\ \dots & \dots & \dots & \dots \\ \left[\frac{w_g^L}{w_1^U}, \frac{w_g^U}{w_1^L}\right] & \left[\frac{w_g^L}{w_2^L}, \frac{w_g^U}{w_2^U}\right] & \dots & 1 \end{pmatrix} \quad (3.15)$$

If $(k_0, k)^{th}$ the element of the matrix defined in (3.15), is designated by $[l_{k_0\,k}, u_{k_0\,k}]$

then $l_{k_0 k} = \frac{w_{k_0}^L}{w_k^U}$ and $u_{k_0\,k} = \frac{w_{k_0}^U}{w_k^L}$. Obviously,

$$l_{k_0\,k} \times u_{k_0\,k} = 1 \qquad k_0, k = 1,2, \dots, g \quad (3.16)$$

Still, the two relations

$$A^L \; W^U = W^U + (g-1)W^L \quad (3.17)$$

and

$$A^U \; W^L = W^L + (g-1)W^U \quad (3.18)$$

are satisfied where

$$A^L = \begin{pmatrix} 1 & \frac{w_1^L}{w_2^U} & \dots & \frac{w_1^L}{w_g^U} \\ \frac{w_2^L}{w_1^U} & 1 & \dots & \frac{w_2^L}{w_g^U} \\ \dots & \dots & \dots & \dots \\ \frac{w_g^L}{w_1^U} & \frac{w_g^L}{w_2^U} & \dots & 1 \end{pmatrix}, \text{and}$$

$$A^U = \begin{pmatrix} 1 & \frac{w_1^U}{w_2^L} & \dots & \frac{w_1^U}{w_g^L} \\ \frac{w_2^U}{w_1^L} & 1 & \dots & \frac{w_1^U}{w_g^L} \\ \dots & \dots & \dots & \dots \\ \frac{w_g^U}{w_1^L} & \frac{w_g^U}{w_2^L} & \dots & 1 \end{pmatrix} \quad (3.19)$$

W^L and W^U represent the lower and upper weight vector defined as $W^L = [w_1^L, w_2^L, \dots, w_g^L]^T$ and $W^U = [w_1^U, w_2^U, \dots, w_g^U]^T$ Sen and Pal (2013). But in practical situation, a pairwise comparison judgment is not 100% correct and obviously the relation (3.16) is not satisfied. Consequently, the relations between (3.17) and (3.18) are also not satisfied.

There are some errors occurred. If E_1, E_2 be error occurred in satisfying the relations (3.17) and (3.18) then the error can be expressed as

$$E_1 = (A^L - I)\, W^U - (g-1)\, W^L$$

and

$$E_2 = (A^U - I)\, W^L - (g-1)\, W^U$$

3.5.2.2 Determination of Errors

In practical cases, a pairwise comparison judgment is not 100% correct and obviously the relation (3.16) is not satisfied. Several errors occur where E_1 and E_2 are the errors that occur in satisfying relations (3.17) and (3.18) then the goal is to achieve the weights W^L and W^U and in such a way that error is to be zero. Then considering the target values as zero, the goal expression can be written as.

$$(A^L - I)\, W^U - \,(g-1)\, W^L + \, d_1^- \, - \, d_1^+ \quad = 0 \qquad (3.20)$$

and

$$(A^U - I)\, W^L - \,(g-1)\, W^U + \, d_2^- \, - \, d_2^+ \quad = 0 \qquad (3.21)$$

where, d_e^- and d_e^+ with $e = 1, 2$ represent the vectors of the deviational variables of the dimension (i.e. $[W^L, W^U]$. Since we have the target is to achieve the exact value zero, sum of the both under- and over-deviational variables associated with the respective goals have to be minimized. The executable GP model can be expressed according to Makui et al. (2010), Sen and Pal (2013), and Wang and Elhag (2007).

$$\text{Min } Z = \sum_{e=1}^{e_0} \sum_{k=1}^{g} \,(\, d_{ek}^- + \, d_{ek}^+ \,)$$

Thus, to satisfy the goal equations in (3.20) and (3.21) the following goals should be satisfied.

$$
\left.\begin{aligned}
w_{k_0}^L + \sum_{\substack{k=1 \\ k\neq k_0}}^{g} w_k^U \ \geq 1 \quad k_0 = 1,2,\dots,g \\
w_{k_0}^U + \sum_{\substack{k=1 \\ k\neq k_0}}^{g} w_k^L \ \leq 1 \quad k_0 = 1,2,\dots,g \\
W^U - W^L \ \geq 0 \\
W^L, W^U \geq 0
\end{aligned}\right\} \tag{3.22}
$$

where, the d_{ek}^- and d_{ek}^+ represent the vectors of the deviational variables and the SIW method treats the weights, W_k of criteria as decision variables which is captured, respectively the lower and upper bounds w_k^L and w_k^U of the interval weights of each goal, Z_k.

Using the SIW determined from the relations in (3.22), the goal achievement function associated with the fuzzy goals is defined in (3.12) and (3.13). In weighted GP scenarios, the goals are transformed into objectives by incorporating aspiration levels and inserting under- and over-deviational variables into each of them. In the proposed problem, the objectives or goals can be constructed from the expression, following previous researchers (Makui et al., 2010; Sen & Pal, 2013).

We are proposing a new alternative method that employs interval weights to provide a better solution to GP problems. Stated clearly, this study contributes by proposing multi-interval weights to determine solutions for MO problems. A detailed will be discussed in Chapter Four.

3.6 Discussion and Summary

This chapter provided some basic concepts about the MCDM, GP, fuzzy GP, fuzzy set theory, in relation to decision making, and interval weights approach. At the end, it put light on the interval arithmetic operations.

In the real-world, the input data or parameters such as water, prices of input and output, resources available, among others, are often imprecise (fuzzy) because of incomplete or non-obtainable information. The FGP has been developed to solve these problems. Moreover, there are several conflicting objectives in FGP and GP such as economic, social and environmental issues in agricultural production planning. These objectives create problems that constantly affect public officials, who are responsible for agricultural production planning. Therefore, these decision makers should consider multi objective models.

The weighted GP technique considers the relative importance of the goals that is dealt with using their relative weights, while in GP; the absolute goals are handled by their rankings. The WGP model is suitable to solve a MOO problem. Weighted GP should be used when the decision-maker is more interested in direct comparisons of the objectives.

Furthermore, under the concept of interval, the interval programming presented to handle uncertainty in weights is used as a general method, known as SIW. Based on this method, a new insight of SIW will be presented in the next chapter. This modification on the SIW method and its formulation, research methodology and models development is addressed in detail in Chapter Four.

CHAPTER FOUR
RESEARCH METHODOLOGY

The major problem of the agricultural production sector, especially in the strategic crop production, was identified in the previous chapter. Systematically, three successive stages in farm management as suggested by Bjørndal et al. (2012), Tajuddin et al. (1994) and Ibrahim (2007). The main goal is to maximize the strategic crops production for the benefits of farmers. To do so, a promising technique has been identified. A model with multiple objectives is proposed as a solution technique, which uses the fuzzy weighted GP concept with new multi-interval weights. Hence, this chapter describes in detail the methodology used to achieve the objectives of developing the FGP model. The details designed to accomplish the objectives are illustrated in 4.1 Research Design, 4.2 Research Activities, 4.3 Research Framework, 4.4 Data Collection, 4.5 Model development, 4.6 Development of the proposed Fuzzy Goal Programming Model, 4.7 Development of the proposed Goal Programming Model, 4.8 Evaluation of the proposed models and 4.9 Summary and Discussion.

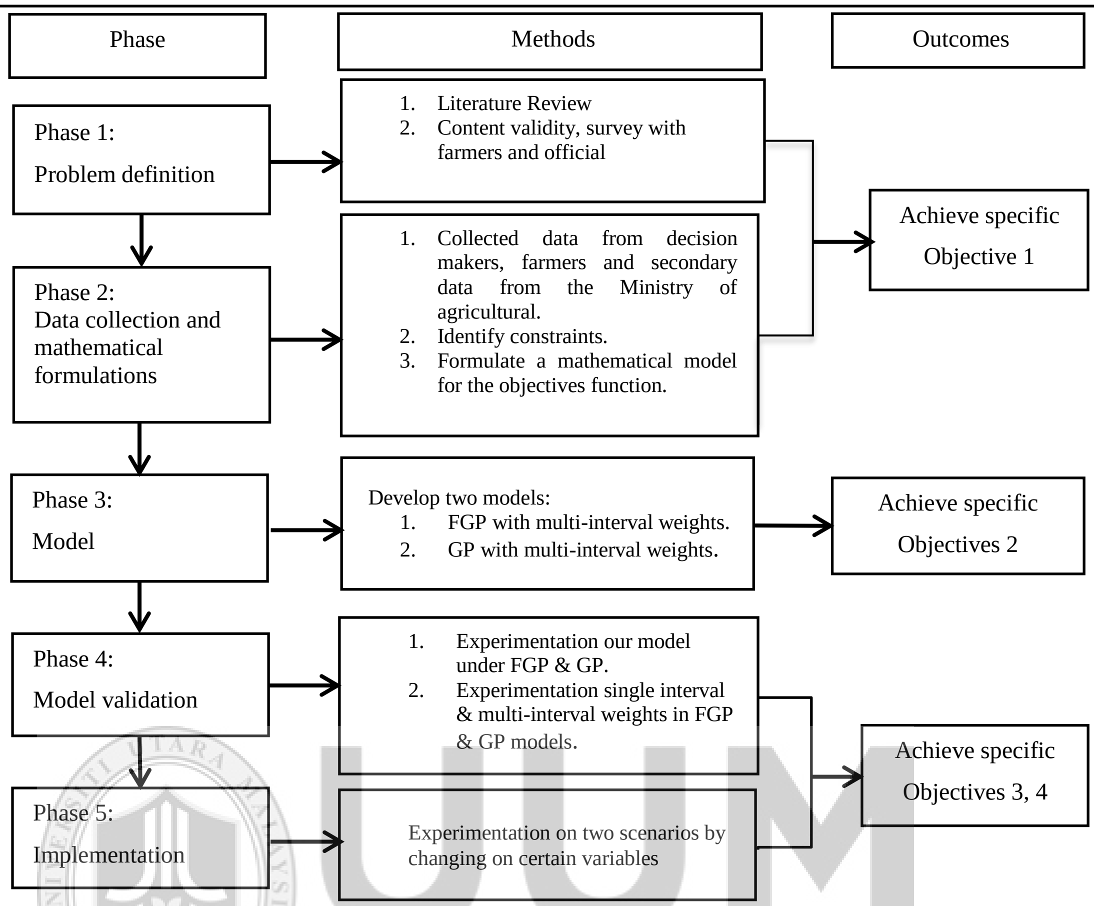
4.1 Research Design

To achieve the main goal of this research, the FGP model is deemed necessary to be developed with an embedded new multi-interval weight. The proposed FGP model is to solve a multi-objective problem using goal programming (GP) and fuzzy goal concepts (FGP). This research focuses on model developments, where two types of quantitative data are utilized. They are primary and secondary data.

The quantitative data was the primary data collected from decision makers and farmers in the agricultural sector. In addition, some decision makers with expertise in the areas of field crops, food industry, plant protection, biological techniques, garden design, agricultural engineering, biological chemistry, and agricultural economy were also approached. Some of the quantitative data is quantifiable for a quantitative analysis. On the other hand, the secondary quantitative data was obtained from reports in the agricultural sector. The FGP model was then developed using the enhanced multi-interval weights (MIW) method, which is used in the deviations of agricultural benefits as the variables in the FGP. For evaluation purposes, a GP was also developed embedding the new MIW, which the results were compared to that of the FGP. Experimentation and analyses were carried out to validate the two models. The combination of the two types of interval weights of the criteria, i.e., the single interval weights (SIW) and multi-interval weights (MIW) with the FGP and GP formed four models known as the SIWFGP, SIWGP, MIWFGP and MIWGP models. Several comparison analyses were done among these four models.

4.2 Research Activities

The research activities are detailed in Figure 4.1. This section discusses how to define the problem and determine the variables, collect data and formulate the mathematical model, and develop the FGP model.



OBJECTIVES

The main objective of this research is to develop a mathematical model to improve crops production, while considering sustainable agricultural development. The specific objectives are as follows:

1. To determine the main resources which affect the crop production in an attempt to improve the benefit of an agricultural production.

2. To develop a mathematical model that integrates the FGP and GP with measurement of weights

3. To identify the performance of goals which are resources such as water, fertilizer and pesticides on the environment in improving crops production in different geographical zones.

4. To compare the proposed multi-interval weights FGP and GP models with the existing single-interval weights models.

Figure 4.1. Phases of research and its activities

4.3 Research Framework

The following sub-sections details the research framework and discusses how the problem was defined, the variables determined, the data collected, and the FGP and GP models with interval weights were developed. Figure 4.2 describes the process.

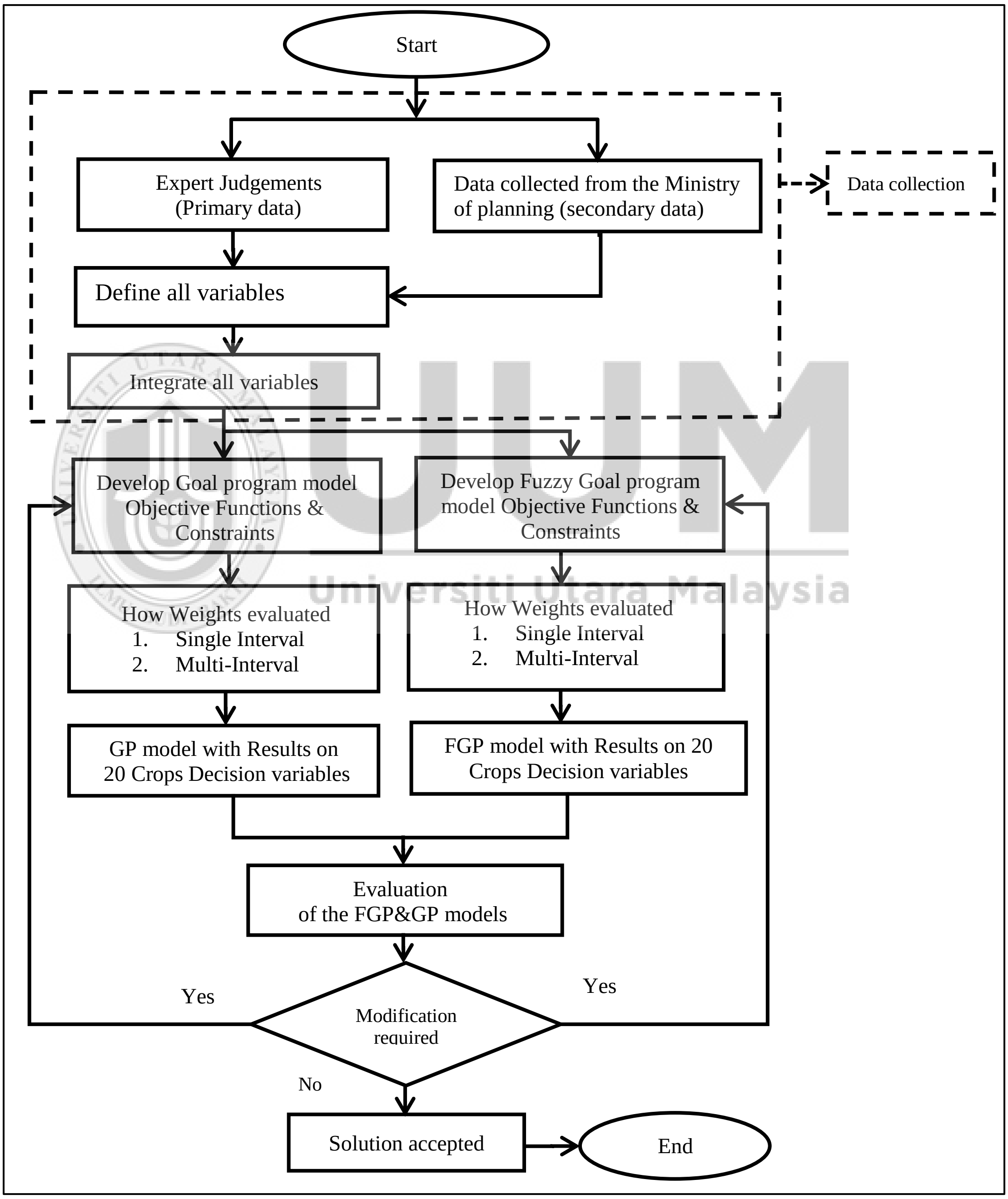


Figure 4.2. Research framework of the FGP and GP models

The proposed framework includes a number of key elements for the research theme using the GP and FGP technologies in the agricultural sector. We also explain the problem in a number of phases, such as data collection. We defined the variables and integrated the information gathered to develop, validate, and analyse the model as follows.

4.3.1 Data collection

Data collection is one of the most important components of research since data is needed to verify whether the proposed model can be accepted or not. This research considered two important types of collecting data they are primary data and secondary data. In this phase, we defined the types of crops to be produced as the variables. Twenty strategic crops were identified after two crops were not considered due to missing data. Then we integrated the information of these variables from the secondary data, such as the amount of water, fertilizer, pesticides, land use, the need for each tonne, etc. The primary data was collected through a set of questionnaire. The weight of each objective was provided by the agricultural decision makers who responded to the questionnaire.

4.3.2 Development of FGP and GP Models

In this phase, the model formulation began with the process of identifying the mathematical formulation problem to solve the crops production problem through the proposed method. We follow the analysis as suggested by Wheeler and Russel (1977) and Keramatzadeh et al. (2011) in performing the GP. However, we did not determine the degree of attainment of the goals in this research since all objectives have the same priority levels. In addition, this development phase is to enhance the agricultural production through the use of the FGP and GP models to improve the strategic crops production and exploitation of water irrigation, fertilizer, and pesticides. For the FGP, we adapt the Sen and Pal (2013) FGP model as it was proven that the FGP gives better results than that of the GP. However, Sen and Pal (2013) used SIW in the coefficients of the deviations. Four goals for the FGP were developed based on agricultural benefit, water irrigation, fertilizer, and pesticides. These goals are achieved by using a newly modified interval method to find weights in the objective functions of the FGP. Furthermore, these goals are subjected to new constraints that are first time addressed in this problem. We discussed in detail the model formulation developed in Section 4.5.

4.3.3 Evaluation of FGP and GP Models

In this research we proposed two models, which are MIWFGP and MIWGP. Several experimentations, analyses and evaluation are carried out to support the performance of the proposed the MIWFGP and MIWGP models.

4.4 Data Collection and Data Types

Data collection is the process of gathering and measuring information on the variables of interest. It is carried out in an established systematic fashion that enables one to answer the stated research questions, test the hypotheses, and evaluate the outcomes. The different types of data required for a needs assessment are most easily understood using the descriptive terms.

This research considered two important types of collecting data; they are primary data and secondary data. First, the secondary data was gathered from different official records and reports of the Manual of Agricultural Statistical Indicators for the period of 2002-2010 on the strategic crops cultivation and production in the Republic of Iraq (Ministry of Planning, 2011a, 2011b). On the other hand, the primary data was collected via questionnaire, which was distributed to decision makers and farmers in five different agricultural zones. The methods of collecting the quantitative data hinge on random sampling and the structured data collection instruments that accommodate various experiences with predetermined response types. The quantitative data generates results that are easy to summarize, compare, and generalize. Besides reviewing the literature, the selection criteria of possible zones was also determined through the administration of the questionnaire. The investigation of the selection criteria of possible zones, the source of data and data collection as well as the data analysis techniques are further discussed in the following subsections.

4.4.1 Sample Frame and Size

This research involves the employee's population in the public agricultural sector in Iraq. After the type of respondents was decided, the number of public employees and farmers in Iraq was determined based on the statistics from the Ministry of Planning in Iraq (2011a). The researcher visited the Department of Statistics and Informatics in the Ministry of Agriculture and the Ministry of Planning to confirm that the total number of farmers and agricultural employees was 125,048 in 2010, distributed across 15 governorates as shown in Table 4.1.

Table 4.1

Number of Farmers and Agricultural Employees in Iraq

No.	Governorate	Number of farmers and employees
1	Ninevah	1012
2	Kirkuk	1563
3	Diala	10655
4	Al-Anbar	20369
5	Baghdad	2322
6	Babylon	8344
7	Kerbela	15724
8	Wasit	15351
9	Salah Al-Deen	8994
10	Al-Najaf	3283
11	Al-Qadisiya	4418
12	Al-Muthanna	4607
13	Thi Qar	17026
14	Maysan	987
15	Basrah	10393
Total		125048

Data of the present study was collected by distributing a questionnaire to the Iraqi farmers and the agricultural officers. The respondents were selected among the employees and farmers who are identified as decision makers in each governorate. As description in Section 2.1, Iraq is categorized into five zones based on their geographic and environmental characteristics that are the Northern, Western, Middle, Eastern and Southern zones. In this research the data was collected from the selected governorates in each zone that are Nineveh, Al-Anbar, Baghdad, Al-Qadisiya, and Maysan, respectively. The approval process was obtained from the whole hierarchy of several governmental bodies in each governorate. Then, the general managers sent out official letters, together with data and permission for conducting interviews, to the local farmers, local council managers, managers of irrigation and agriculture in each governorate, and the peasant assembly officers.

The total number of farmers and those employees for the five governorates is 29108 and the sample size is 470. The stratified sampling was applied to determine the number of sample employees to be selected within the selected zones, as shown in Table 4.2. From the Western zone Al-Anbar has a total number of 20369 farmers and employees, and it has the highest number in comparison to all the other governorates with the percentage equal to 70% (20369 out 29108) and sample of 333 employees. Following Al-Anbar is the Maysan governorate in the Southern zone, which has a total number of 10393 farmers and employees. The Eastern zone is represented by the Al-Qadisiya governorate with a total number of 4418 farmers and employees. The governorates with the least total number of farmers and employees are in the Middle and Northern zones that are Baghdad with 2322 and Ninevah with 1012.

Table 4.2
Distribution of Sample Farmers and Employees in Each Selected Governorate

Zone	Name of governorate	Number of farmers and employees	Sample size of farmers and employees
Northern	Ninevah	1012	15
Western	Al-Anbar	20369	333
Middle	Baghdad	2322	33
Eastern	Al-Qadisiya	4418	73
Southern	Maysan	987	16
Total		29108	470

For example, in the Northern zone Nineveh, 15 questionnaires were distributed while in the Western zone Al-Anbar, 333 questionnaires were distributed. In the middle zone Baghdad, 33 questionnaires were distributed, than in the Eastern zone Al-Qadisiya, 73 questionnaires were distributed, and finally, in the Southern zone 16 questionnaires were distributed in Maysan.

4.4.2 The Primary Data

Data was collected from farmers and employees in five different agricultural zones via the questionnaire. The stratified sampling was used to choose these five of the15 governorates. The 470 questionnaires were distributed to the five governorates and 246 were returned but only 231 were found useable for the analysis.

4.4.3 The Secondary Data

The secondary data of this research is related to the amount of crops and the requirements of water irrigation, fertilizer, pesticides, labour, equipment and seeds as shown in Appendix B. These data were obtained from the relevant literature in journal articles, electronic sources, and reports.

This research considered the amounts of 22 types of crops that were reported in the Manual of Agricultural Statistical Indicators for the period of 2002-2010. Due to the incomplete data for certain years during that period, but fortunately data for 2002 and 2010 are complete with all the information needed to solve the problem in this research, therefore, these two years data are chosen to test the models.

4.4.4 Criteria Identification

Based on the collected data, the decision makers in the agricultural sector in all zones identified the selection criteria. The identified criteria can be expressed as agricultural benefit (in Iraqi Dinar, ID), water resources (m^3 per donum), fertilizer resources (tonne per donum), and pesticides resources (kg per donum). Donum is a measurement for Iraqi acre. The agricultural benefit which is measured in ID is the representative of the agricultural profit. These criteria were ranked based on the pairwise comparison matrix as suggested by Saaty (1980), and further adapted it to obtain the interval weights as recommended by Wang and Elhag (2007). The purpose of this section is to identify the most appropriate criteria to be used in the proposed models. Firstly, a group of respondents were asked to determine the level of importance of each criterion suggested and rank each criterion by using a pairwise comparison judgment. In addition, we considered 22 strategic crops as suggested by the Iraq Ministry of Planning (2011b). However, in this research, we considered only 20 crops that are wheat, barley, onions, potatoes, lettuce, carrot, tomatoes, mash, pepper, green beans, rice, string bean, garlic, squash, cucumber, millet, corn, sunflower, cotton, and sesame seeds plant. Two crops, i.e. sugar beet and sugar cane were omitted because of missing data.

4.4.5 Data Collection Instruments

The main data collection instrument is the questionnaire, which was used to obtain weights to the selection criteria, the order of criteria, and the performance scores. The questionnaire was divided into four parts as shown in Appendix A. The first part is the demographic profile, the second part consists of descriptions and definitions of criteria involved in the agriculture sector, the third part consists of examples on choosing a judgment of criteria, and the final part is the pairwise judgment with influencing criteria in the agriculture sector to determine the priority of the four criteria chosen. The criteria are agricultural benefit, water irrigation as a resource, fertilizer resources, and pesticide resources. The primary data in the form of order of each criterion based on the respondents' perception and experience obtained through the questionnaires was used for comparison purposes between the criteria.

It took approximately six months to collect the data. The researcher met the respondents in groups in each governorate to avoid inconsistencies in their responses. Meeting them in groups in each zone also enabled the respondents to have a clear understanding of the questionnaire. In the questionnaire, a numerical scale from 1 to 9 was utilized. The respondents were asked to rate the importance of each criterion based on Saaty's 1-9-scale as shown in Table 4.3. Then, the evaluation values were transformed into a pairwise comparison matrix using the approach described in Section 5.1.1.2.

Table 4.3

Saaty's AHP Scale

AHP Scale of Importance for Comparison	Numeric Rating
Equal Importance	1
Equally to Moderately	2
Moderate Importance	3
Moderately to Strong	4
Strong Importance	5
Strongly to to very strong	6
Very strong Importance	7
Very strong to extremely	8
Extreme Importance	9

(Source: Saaty, 1980)

4.5 Models development

In this model development section, a complete description of steps towards establishing the two proposed MIWFGP and MIWGP models is presented. The development is based on the concept of mathematical programming as discussed in Chapter Three. A mathematical modelling for the FGP based on the GP concept related to the crops production is developed to maximize the benefit by increasing the agricultural crops production that can satisfy demands and requirements of the population. Eventually, two models are proposed, which are the FGP and GP. The novel concept of MIW is then incorporated in the proposed models, which are as the MIWFGP and MIWGP. The important modelling stages include defining the decision variables and parameters, formulating the objective function and goals, formulating the constraints and determining the interval weights. In this model, the principle objective function is to minimize the weighted sum of deviations from their respective goals, which are (i) the maximization of agricultural benefit, (ii) the minimization of the exploitation of water irrigation, (iii) the minimization of fertilizer requirement, and (iv) the minimization of pesticides requirement. These goals are subjected to several different constraints which some are new ones.

4.5.1 Decision Variables and Parameters

The decision variables for this agricultural production model is

$$x_{ij} = \begin{cases} 1 & \text{if crop } i \text{ in zone } j \text{ is considered} \\ 0 & \text{if crop } i \text{ in zone } j \text{ is not conidered} \end{cases}$$

These decision variables are the 0-1variables type. The parameters used in the model formulation are as listed in Table 4.4.

Table 4.4

Parameters Used in the MIWFGP and MIWGP Models

Parameter	Description
W_k	the interval weight of k^{th} goal
w_k^L	the lower value of interval weight of k^{th} goal
w_k^{ML}	the middle value of interval weight from left of k^{th} goal
w_k^{MR}	the middle value of interval weight from right of k^{th} goal
w_k^U	the upper value of interval weight of k^{th} goal
$lafc_{ij}$	the land requirement in donum to produce i^{th} yearly food crop in j^{th} zone
$lind_{ij}$	the land requirement in donum to produce i^{th} industrial crop in j^{th} zone
lao_{ij}	the land requirement in donum to produce i^{th} oil crop in j^{th} zone
$ladr_{ij}$	the land requirement in donum to produce i^{th} drought resistant crop in j^{th} zone
$suwi_{ij}$	surface water irrigation requirement in m^3 per donum for i^{th} crop in j^{th} zone
$spwi_j$	sprinkler irrigation requirement in m^3 per donum for i^{th} crop in j^{th} zone
$drwi_{ij}$	drip irrigation requirement in m^3 per donum for i^{th} crop in j^{th} zone
cf_{ij}	the amount of chemical fertilizer requirement in kg per donum for i^{th} crop in j^{th} zone
nf_{ij}	the amount of natural fertilizer requirement in kg per donum for i^{th} crop in j^{th} zone
azf_{ij}	the amount of azotic fertilizer requirement in kg per donum for i^{th} crop in j^{th} zone
la_{ij}	the labour requirement in hour per donum for i^{th} crop in j^{th} zone
pc_{ij}	the amount of pesticide requirement in kg per donum for i^{th} crop in j^{th} zone
eq_{ij}	the equipment requirement in hour per donum for i^{th} crop in j^{th} zone
se_{ij}	the seed requirement in kg per donum for i^{th} crop in j^{th} zone
cp_{ij}	the amount of production in tonne for i^{th} crop in j^{th} zone
$TLAFC_j$	the total available land area in donum for yearly food crop in j^{th} zone
$TLAIND_j$	the total available land area in donum for industrial crop in j^{th} zone
$TLADR_j$	the total available land area in donum for drought resistant crop in j^{th} zone
$TLAO_j$	the total available land area in donum for oil crop in j^{th} zone
$TSUWI_j$	the total surface water irrigation availability in m^3 per donum in j^{th} zone
$TSPWI_j$	the total sprinkler irrigation availability in m^3 per donum in j^{th} zone
$TDRWI_j$	the total drip irrigation availability in m^3 per donum in j^{th} zone
TCF_j	the total available chemical fertilizer in kg per donum used in j^{th} zone
TNF_j	the total available natural fertilizer in kg per donum used in j^{th} zone
$TAZF_j$	the total available azotic fertilizer in kg per donum used in j^{th} zone
TLA_j	the total available labour in hour per donum in j^{th} zone
TPC_j	the total available pesticide in kg per donum used in j^{th} zone
TEQ_j	the total available equipment in hour per donum in j^{th} zone
TSE_j	the total available seed in kg per donum used in j^{th} zone
TD_i	the total amount of demand in tonne for i^{th} crop in all zones
TCP_{ij}	the total amount of demand in tonne for i^{th} crop in j^{th} zone
AB_{ij}	the agricultural benefit in ID for i^{th} crop in j^{th} zone
t_k	the expected target that indicates a realistic value to be reached by k^{th} goal
ρ_k^-	under-deviation for weights of k^{th} goal
ρ_k^+	over-deviation for weights of k^{th} goal
d_{ek}^-	under-deviation for interval weights of k^{th} goal
d_{ek}^+	over-deviation for interval weights of k^{th} goal
Y	the set of crops grown yearly
O	the set of oil crops
R	the set of drought resistant crops
S	the set of crops used sprinkler irrigation
D	the set of crops used drip irrigation

i = 1, 2…, n where n is the number of crops which can be considered for production
j = 1, 2..., m where m is the total number agricultural zones

4.5.2 Objective Functions Formulation

In this section, the general formulation of the proposed FGP and GP was developed to include the strategic crops production requirements. In this research, there are four goals to be achieved, which are maximization of agricultural benefit, minimization of water irrigation, minimization of fertilizer requirement, and minimization of pesticides requirement. These four goals are considered as a fuzzy type objective function. This is due to the nature of agricultural problem, which is dependent on many factors that are not easily quantified and often are not fully controllable. For example, weather condition, land suitability, and fertilizer and pesticides usage (Mishra, B., K., & Singh, 2014; Prakash, 2003; Sher & Amir, 1994).

In the real world, the input data or parameters involving resources such as water, labour, chemical fertilizer and pesticides mostly are imprecise and vague which lead to subjective consideration by decision makers (Biswas & Pal, 2005). These factors often lead to uncertainty. Therefore, the most appropriate technique to cater real world problems with uncertainty is the one that involves fuzzy modelling as implemented by Biswas and Pal (2005), Prakash (2003), Sharma, Jana and Gaur (2007) and Saman, Hadis, Elham and Samira (2014). As a result, the fuzzy concept of modelling is employed in the objective function of the proposed FGP and GP for the agricultural production problem. The objective function used in the models is the minimization of weighted sum of deviations from the targeted goals. The minimization of the weighted sum of deviations from their respective goals is as follows.

$$Minimize \sum_{k=1}^{g} W_k \, (\rho_k^-, \rho_k^+) \qquad (4.1)$$

where, W_k is the interval weight of the k^{th} goal, ρ_k^- and ρ_k^+ are the under- and over-deviation variables of k^{th} goal. The level of importance of unwanted deviational variables are used to represent the relative importance of the respective goals is defined as weight, which are found by using a new insight of interval weight method as introduced in section 4.5.4. The four goals are discussed as follows.

4.5.2.1 Agricultural Benefit

All farmers wish to maximize the agricultural products of their production. The objective function is to achieve the maximum crop production in different zones. After considering the total quantity per year from the agricultural benefit, therefore, to meet the demand of agricultural products in the society, the achievement level of the production of each type of the crops is highly desired. The goal expressions can be presented as:

$$Maximize \sum_{i=1}^{n} \sum_{j=1}^{m} AB_{ij} \, x_{ij} \qquad (4.2a)$$

where, AB_{ij} is the agricultural benefits in ID for i^{th} crop in j^{th} zone. The k^{th} goal has an expected target, t_k that indicates a realistic value to be reached by the k^{th} goal. After combining the goal with deviational values from the target, we obtained a goal. The goal can be considered as a soft constraint that can be violated without producing infeasible solutions. The amount of violation from the expected target expresses the non-reaching overcoming of the expected value of each target. The first goal (k =1) will be

$$t_1 = \sum_{i=1}^{n} \sum_{j=1}^{m} AB_{ij}\, x_{ij} + \rho_1^- - \rho_1^+ \qquad (4.2b)$$

where, ρ_1^- and ρ_1^+ are the under- and over-deviations from the target, t_1.

4.5.2.2 Water Irrigation

This is one of the important constraints to check the mechanism, distribution and consumption of water in various agricultural zones. There are three different types of irrigation techniques that are surface water irrigation, sprinkler irrigation and drip irrigation. However, only the surface water irrigation is used as one of the goals. The others are used as constraints in the model. Therefore, we minimize the exploitation of surface water irrigation as described in the formulation as (4.3a).

$$Minimize \sum_{i=1}^{n} \sum_{j=1}^{m} suwi_{ij}\, x_{ij} \qquad (4.3a)$$

where, $suwi_{ij}$ is the surface water irrigation requirement in m^3 per donum for i^{th} crop in j^{th} zone. The second goal in (4.3a) has an expected target, t_2 that indicates a realistic value to be reached by the second goal. The second goal (k =2) is

$$t_2 = \sum_{i=1}^{n} \sum_{j=1}^{m} suwi_{ij}\, x_{ij} + \rho_2^- - \rho_2^+ \qquad (4.3b)$$

where, ρ_2^- and ρ_2^+ are the under- and over- deviations from the target, t_2.

4.5.2.3 Fertilizer Requirement

The minimization of fertilizer usage is a societal goal. For this reason, it is not taken into account during the decision-making process by the farmers because it is a conflicting goal**.** The minimization of fertilizer usage is the primary way to reduce the deterioration of soil fertility (such as a surplus of nitrogen) that is potentially dangerous for the environment. It is also the main element of agriculture that give impact on the environment, as groundwater quality is affected by the fertilizer usage. Three types of fertilizer are chemical fertilizer, natural fertilizer, and nitrogen (azotic) fertilizer. The misuse of azotic fertilizer could be expressed as a constraint and goal at the same time. The others are only used as constraints in the model. Therefore, we minimize the requirement of azotic fertilizer as described in the formulation (4.4a).

$$Minimize \sum_{i=1}^{n}\sum_{j=1}^{m} azf_{ij}\, x_{ij} \qquad (4.4a)$$

where, azf_{ij} is the amount of azotic fertilizer requirement in kg per donum for i^{th} crop in j^{th} zone. The goal in (4.4a) has an expected target, t_3 that indicates a realistic value to be reached by the third goal. The goal in (4.4a) is considered as the third goal (k = 3) and presented as

$$t_3 = \sum_{i=1}^{n}\sum_{j=1}^{m} azf_{ij}\, x_{ij} + \rho_3^- - \rho_3^+ \qquad (4.4b)$$

where, ρ_3^- and ρ_3^+ are the under and over-deviations from the target, t_3.

4.5.2.4 Pesticides Requirement

In the pesticides requirement, there is only one type of pesticide that was considered in this research. The minimization of chemical in the agricultural pesticide is to reduce the deteriorating rate of land fertility and to trim its side effects, while at the same time to develop a sustainable environment. This can be expressed as a constraint and goal. Therefore, we minimize the requirement of pesticide as described in the formulation (4.5a).

$$Minimize \sum_{i=1}^{n}\sum_{j=1}^{m} pc_{ij}x_{ij} \qquad (4.5a)$$

where, pc_{ij} is the amount of pesticide requirement in kg per donum for i^{th} crop in j^{th} zone. The goal in (4.5a) is considered as the fourth goal (k = 4) and presented as

$$t_4 = \sum_{i=1}^{n}\sum_{j=1}^{m} pc_{ij}x_{ij} + \rho_4^- - \rho_4^+ \qquad (4.5b)$$

where, ρ_4^- and ρ_4^+ are the under- and over-deviations from the target, t_4.

4.5.3 Constraints Formulation

In this section, we construct constraints on individual crops or groups of crops assuming there is independence among these crops. The reasoning behind specifying either absolute or proportional limitations on individual crops or groups is that the input and output data for crops will not change unduly, provided they are grown within certain specified proportions of the arable land. Constraints on individual crops most commonly are concerned on the amount that must not be exceeded, with the occasional insistence on minimum acreages.

Some values are absolute values wherever the arable acreage is fixed. But when there are requirements that vary, the formulation of constraints must take into consideration of proportional values. In either case, the potential flexibility of crops requirements depends on the combined maximal values of individual crops exceeding the arable acreage.

In this model, some of the constraints are newly introduced constraints, which are those related to drought resistant crops, sprinkler irrigation, drip irrigation and natural fertilizer usage. 20 crops in five zones are considered in the formulation of the model. Thus, the net return of the production which is in terms of agricultural benefit for each crop in each zone is expected to be different. So, the model is subjected to 16 constraints, where four are related to the land area, three for water irrigation, three for fertilizer requirements, one for labour requirements, one for pesticides requirements, one for agricultural equipment requirements, one for agricultural seeds requirements, one for demand requirements, and one for individual crops production. These constraints are described in detail in the following subsections.

4.5.3.1 Land Area Constraints

This is one of the important constraints in the agricultural sector; the plots of land for agricultural practice are segmented into four of crop constraints. The first goes to the yearly food crops, followed by the industrial crops, while the third is to the oil crops and the last one is the drought resistant crops.

- **Land Area Constraint for Yearly Food Crops**

The crop production guide aims to provide the latest commercial information relevant to a variety of selection, together with agronomic recommendations, in a format that is easy to use and readily available. This constraint considers 15 types of crop, i.e., wheat, barley, onions, potatoes, lettuce, carrot, tomatoes, mash, pepper, green beans, rice, cowpea, garlic, squash and cucumber which are annually grown. The formulation for this constraint is presented as

$$\sum_{i \in Y} \sum_{j=1}^{m} lafc_{ij} \; x_{ij} \; \leq TLAFC_j \qquad (4.6)$$

where, Y is the set of crops grown yearly, $lafc_{ij}$ is the land requirement in donum to produce i^{th} yearly food crop in j^{th} zone, $TLAFC_j$ is the total available land area in donum for yearly food crops in j^{th} zone, and. x_{ij} is the selected i^{th} yearly food crop in j^{th} zone.

- **Land Area Constraint for Industrial Crops**

Industrial crops are considered as the crops that are grown to produce products to be used in the production sector and food consumption. These crops have impact on the economy since they lessen the need for imports. Therefore, this constraint considers three types of crop, i.e., millet, corn and cotton in the model. The formulation of this constraint is presented as

$$\sum_{i \in D} \sum_{j=1}^{m} lind_{ij} \, x_{ij} \leq TLAIND_j \qquad (4.7)$$

where, D is the set of industrial crops, $lind_{ij}$ is the land requirement to produce i^{th} industrial crop in j^{th} zone, and $TLAIND_j$ is the total available land area in donum for industrial crop in j^{th} zone, and x_{ij} is the selected i^{th} industrial crop in j^{th} zone.

- **Land Area Constraint for Oil Crops**

Vegetable oil has garnered significant importance in the past few decades and this has led to the world oil crop production doubling in the previous two and a half decades. This is evidenced by the increasing oil crops used as raw materials, food, livestock feed, and industrial applications. In addition, the crop plantation has had a key role in reinforcing the economic development. The oil crop plantation is the key factor to produce a higher yield of oil crop production. Therefore, this constraint considers three types of oil crop, i.e., corn, sunflower and sesame seeds plant. The formulation of this constraint is presented as

$$\sum_{i \in O} \sum_{j=1}^{m} lao_{ij}\, x_{ij} \leq TLAO_j \qquad (4.8)$$

where, O is the set of oil crops, lao_{ij} is the land requirement in donum to produce i^{th} oil crop in j^{th} zone, and $TLAO_j$ is the total land area available in donum for oil crop in j^{th} zone, and x_{ij} is the selected i^{th} oil crop in j^{th} zone.

- **Land Area Constraint for Drought Resistant Crops**

The drought conditions experienced by Iraq are resulted from the low levels of water in the Tigris and Euphrates rivers, lack of rain, and high salinity of land. These conditions affect crops cultivation. Consequently, it is very important to look for other crops that are more resistant to salinity and drought, which can give good returns, thus allowing farmers to continue the agriculture activities. This constraint considers four types of crops, i.e. sunflower, corn, sesame seeds plant and mash (Abdullah et al., 2008). The formulation of this constraint is presented as

$$\sum_{i\in R}\sum_{j=1}^{m} ladr_{ij}\, x_{ij} \le TLADR_j \qquad (4.9)$$

where, R is the set of drought resistant crops, $ladr_{ij}$ is the land requirement in donum to produce i^{th} drought resistant crop in j^{th} zone, $TLADR_j$ is the total land area available in donum for drought resistant crop in j^{th} zone, and x_{ij} is the selected i^{th} drought resistant crop in j^{th} zone.

4.5.3.2 Water Irrigation Techniques Constraints

The need for sustainable and efficient water usage is essential in agriculture that plays a fundamental role in economic growth and farming development. In this context, the irrigated agriculture is important to develop a better understanding of alternate irrigation's water allocation strategies along larger emphasis on the most efficient water utilization. There is a need to create adequate water provision for the crops because the need of plants varies from season to season in a year. The water provision also depends on the atmospheric condition of the season in a year. The condition reflects different water availability in different seasons within a year. This is the reason to apply the irrigation system in the farm practice for better output during the harvesting period. It is an obligatory requirement that plants acquire moistures for its germination and development. However, this requirement for moisture absorption also depends on the crop type and development stage of the crops. Therefore, the technique of water irrigation is important for the effective production of crops. Hence, there are three types of water irrigation that are considered in this research, which are surface water irrigation, sprinkler irrigation and drip irrigation.

- **Surface Water Irrigation Constraints**

A surface water or flood irrigation is a technique in which water is pumped or brought to the fields and is allowed to flow along the ground among the crops. This technique is simple and cheap (Darnault, 2008; Ilaco, 2013). Since water consumption depends on the nature of the land and the cropping season, land's water utilization per unit and the supply quantity must be maintained for the production of crops. Thus, the formulation for this constraint is presented as

$$\sum_{i=1}^{n}\sum_{j=1}^{m} suwi_{ij}\, x_{ij} \leq TSUWI_j \tag{4.10}$$

where, $suwi_{ij}$ is surface water irrigation requirement in m^3 per donum for i^{th} crop in j^{th} zone, x_{ij} is the selected i^{th} crop in j^{th} zone, and $TSUWI_j$ is the total surface irrigation water availability in m^3 per donum in j^{th} zone.

- **Sprinkler Irrigation Constraints**

Despite the expansion of sprinkler irrigation system utilization in different parts of the world with high efficiency, the use of it in Iraq is still limited. The sprinkler irrigation system is a technique to add water to the soil in a modern and advanced way. The sprinkler provides moisture for plant growth by the quantities of water added to the soil and controls precisely for the specific zone. The usage of this technique along with fertilizer and pesticides has its advantages to control water and maximize the production of crops in large areas. The formulation for this constraint is presented as

$$\sum_{i \in S} \sum_{j=1}^{m} spwi_{ij} \ x_{ij} \ \leq TSPWI_j \qquad (4.11)$$

where, S is the set of crops that used sprinkler irrigation, x_{ij} is the i^{th} selected crop that used sprinkler irrigation in j^{th} zone, $spwi_{ij}$ is sprinkler irrigation requirement in m^3 per donum for i^{th} crop in j^{th} zone, and $TSPWI_j$ is the total sprinkler water availability in m^3 per donum in j^{th} zone.

- **Drip Irrigation Constraints**

A drip irrigation system is the third technique experimented in this research, normally used for irrigating fruits and vegetables. Water is sent through plastic pipes (with holes on them) that are either laid along the rows of crops or even buried along their root lines (Darnault, 2008).

The use of drip irrigation in the agriculture fields is normally practised in the arid and semi-arid land where water is limited. Consumption of the water through drip irrigation is suitable for sandy soil of the desert areas that have a high permeability for water. It is normally difficult to use other techniques of water irrigation in these areas. Desert regions usually suffer from the problem of water shortage due to the harsh climatic conditions. The formulation for this constraint is presented as

$$\sum_{i \in D} \sum_{j=1}^{m} drwi_{ij} \, x_{ij} \leq TDRWI_j \tag{4.12}$$

where, D is the set of crops that used drip irrigation, $drwi_{ij}$ is the drip irrigation requirement in m^3 per donum for i^{th} crop in j^{th} zone, and $TDRWI_j$ is the total drip irrigation water availability in m^3 per donum in j^{th} zone.

4.5.3.3 Fertilizer Requirements Constraints

It has become crucial to utilize the agricultural plot of lands at the optimal level in order to sustain production. This could be addressed through fertilizer utilization and the application of modern technologies for food consumption. In this research, three types of fertilizer are experimented namely, chemical fertilizer, natural fertilizer and azotic fertilizer which have their basis on the following constraints.

- **Chemical Fertilizer Constraints**

There are various forms of chemical fertilizer. The typical form of fertilizer is the solid fertilizer in granulated or powdered forms or liquid fertilizer (FAO, 1991). The most common fertilizer used is the compound chemical fertilizer in the form of powder (McCauley et al., 2009). The formulation for this constraint is presented as

$$\sum_{i=1}^{n} \sum_{j=1}^{m} cf_{ij} \, x_{ij} \leq TCF_j \tag{4.13}$$

where, cf_{ij} is the amount of chemical fertilizer requirement in kg per donum for i^{th} crop in j^{th} zone, x_{ij} is the i^{th} selected crop that used chemical fertilizer in j^{th} zone and TCF_j is the total amount of chemical fertilizer available in kg per donum in j^{th} zone.

- **Natural Fertilizer Constraints**

The natural fertilizer supports organic farming methods along with scientific knowledge of ecology and modern technology with traditional farming practices based on naturally occurring of biological processes. Organic farming methods are considered in the field of agro-ecology (Acs et al., 2005). The formulation for this constraint is presented as

$$\sum_{i=1}^{n}\sum_{j=1}^{m} nf_{ij}\, x_{ij} \geq TNF_j \qquad (4.14)$$

where, nf_{ij} is the amount of natural fertilizer requirement in kg per donum for i^{th} crop in j^{th} zone, x_{ij} is the i^{th} selected crop that used natural fertilizer in j^{th} zone and TNF_j is the total amount of natural fertilizer available in kg per donum used in j^{th} zone.

- **Azotic Fertilizer Constraints**

All crops require azotic (nitrogen) fertilizer, which is good for crops growth. However the azotic fertilizer, if misuse would lead to environmental issues. Moreover, the risk of excessive use of this fertilizer is mostly regarding the lack of mineral elements. Therefore, the issues in soil and water pollution are caused by the over-application of nitrogenous fertilizers (Pretty, 2008; Zebarth et al., 2009).

However, this type of fertilizer is still suitable to be experimented in this research. The formulation for this constraint is presented as

$$\sum_{i=1}^{n}\sum_{j=1}^{m} azf_{ij}\, x_{ij} \leq TAZF_j \qquad (4.15)$$

where, azf_{ij} is the amount of azotic fertilizer requirement in kg per donum for i^{th} crop in j^{th} zone, x_{ij} is the i^{th} selected crop that used azotic fertilizer in j^{th} zone and $TAZF_j$ is the total amount of azotic fertilizer available in kg per donum used in j^{th} zone.

4.5.3.4 Labour Requirement Constraint

Agriculture is the backbone of the local economy and currently the challenge of addressing labour constraints in rural households has become even more critical in many countries. The past decade has seen a significant reduction in the availability of farm power due to lack of interest in farming among the youth (Bishop-Sambrook, 2003; Kasimis et al., 2003), who are seeking for alternatives employment in other countries. So, labour availability is an important constraint in the modelling of this agricultural production problem. The formulation for this constraint is presented as

$$\sum_{i=1}^{n}\sum_{j=1}^{m} la_{ij}\, x_{ij} \leq TLA_j \qquad (4.16)$$

where, la_{ij} is the labour requirement in hour per donum for i^{th} crop in j^{th} zone, x_{ij} is the i^{th} selected crop that used labour requirement in j^{th} zone and TLA_j is the total available labour in hour per donum in j^{th} zone.

4.5.3.5 Pesticide Requirement Constraint

Pesticides are used to control pests in agriculture, such as insects, mice and fungi, or microorganisms like bacteria and viruses. The issue of pesticide use in some crops and agricultural regions is quite critical. The intensive use of pesticides can cause problems in some regions, such as the contamination of ground water, surface water, and rain water (Zalidis et al., 2002). There are long-term health effects such as reduced fertility (Hoppin et al., 2002). So, a crop protection system is needed to control the use of pesticide in the farming process. Therefore, this mechanism is reflected in the formulation of the constraints as follows.

$$\sum_{i=1}^{n}\sum_{j=1}^{m} pc_{ij}\, x_{ij} \le TPC_j \qquad (4.17)$$

where, pc_{ij} is the amount of pesticide requirement in *kg* per donum for i^{th} crop in j^{th} zone, x_{ij} is the i^{th} selected crop that used pesticides requirement in j^{th} zone and TPC_j is the total available of pesticide in *kg* per donum in j^{th} zone.

4.5.3.6 Agricultural Equipment Constraint

Agricultural equipment and mechanization play a vital role in transforming agriculture in any agrarian economy operations (Asoegwu & Asoegwu, 2007). Mechanization could contribute by increasing power inputs to farming activities, hence putting more land into production. Furthermore, it could reduce drudgery in farming activities, thus enhancement in lifestyles, and improved timeliness and efficiency of farm operations (Asoegwu & Asoegwu, 2007). Mechanization also allows those tasks which are difficult to perform without mechanical aids for accomplishment of work and improve its quality (Pingali, 2007). Therefore, the use of equipment is important to be considered as constraints in this model. The formulation for this constraint is presented as

$$\sum_{i=1}^{n}\sum_{j=1}^{m} eq_{ij}\, x_{ij} \leq TEQ_j \tag{4.18}$$

where, eq_{ij} is the equipment requirement in hour per donum for i^{th} crop in j^{th} zone, x_{ij} is the i^{th} selected crop that used agricultural equipment in j^{th} zone and TEQ_j is the total available equipment usage in hour per donum in j^{th} zone.

4.5.3.7 Agricultural Seeds Constraint

Agricultural seeds are seeds that have been produced and labelled in accordance with the procedures and in compliance with the requirements of an officially recognized certifying agency (Khalaf, 2011; Pretty, 2008). They include the seeds of cereal, corn and vegetables. So, the quality seeds are important for the high production of the respective crops. Thus, the formulation for this constraint is presented as

$$\sum_{i=1}^{n}\sum_{j=1}^{m} se_{ij}\ x_{ij} \leq TSE_j \tag{4.19}$$

where, se_{ij} is the seed requirement in *kg* per donum for i^{th} crop in j^{th} zone, x_{ij} is the i^{th} selected crop that used agricultural seed in j^{th} zone and TSE_{j} is the total available seeds in *kg* per donum in j^{th} zone.

4.5.3.8 Demand Constraint

The total of local production and the imported quantity of crops in a year must be greater than or equal to the total demand in the country (Sarker & Ray, 2009). However, this research considered total demand based on the local agricultural production only.

Therefore, the formulation for the demand constraint is presented as

$$\sum_{j=1}^{m} cp_{ij}x_{ij} \geq TD_i \qquad \forall\, i = 1,2,\ldots,n \qquad (4.20)$$

where, cp_{ij} denotes the amount of production in tonne for i^{th} crop in j^{th} zon, x_{ij} is the i^{th} crop that is considered in j^{th} zone, and TD_i is the total amount of demand in tonne for i^{th} crop.

4.5.3.9 Demand Constraints for each Zone

The requirements of five zones for individual crops are presented as constraints. That means the production of each crop in each zone must be greater than or equal to its respective demand. So, the problem is to determine how many tonnes should be produced from each crop in each zone so that all demands are satisfied at the maximum total production (Sarker & Newton, 2008). The crops included in this research are wheat, barley, onions, potatoes, lettuce, carrot, tomatoes, mash, pepper, green beans, rice, string beans, garlic, squash, cucumber, millet, corn, sunflower, cotton, and sesame seeds plant.

The formulations for this constraint are presented as

$$cp_{i(j=1)}\, x_{i(j=1)} \geq TCP_{i(j=1)} \quad \forall\, i \qquad (4.21)$$

$$cp_{i(j=2)}\, x_{i(j=2)} \geq TCP_{i(j=2)} \quad \forall\, i \qquad (4.22)$$

$$cp_{i(j=3)}\, x_{i(j=3)} \geq TCP_{i(j=3)} \quad \forall\, i \qquad (4.23)$$

$$cp_{i(j=4)}\, x_{i(j=4)} \geq TCP_{i(j=4)} \quad \forall\, i \qquad (4.24)$$

$$cp_{i(j=5)}\, x_{i(j=5)} \geq TCP_{i(j=5)} \quad \forall\, i \qquad (4.25)$$

$$x_{ij} \geq 0 \quad \forall\, i, j$$

where, cp_{ij} denotes the amount of production in tonne for i^{th} crop in j^{th} zone, x_{ij} is the i^{th} crop that is considered in j^{th} zone, and TCP_{ij} is the total amount of demand in tonne for i^{th} crop in j^{th} zone.

4.5.4 Interval Weights Determination

It is more realistic to measure the relative importance of the objective function in equation (4.1) as interval form rather than in deterministic values as recommended by Sen and Pal (2013). In the agricultural production, there is the situation where the production is lower than targeted goals, and similar situation higher than the targeted goals for each crop. These situations are defined as under- and over-deviational variables for respective goals. In this research, a weight of an unwanted deviational variable is used to represent the relative importance for each goal. However, based on Wang and Elhag (2007) the interval weight is more suitable and thus, we adapt the interval weight method in constructing the objective functions for the FGP and GP models. The proposed interval weight method is a novel way of determining the weights embedded in the models. The goals, Z_k in these models are represented by the criteria in decision making process. The maximum and minimum weights for each goal is taken as an interval, $[w_k^L, w_k^U]$ as obtained from Table 4.5.

Table 4.5

Creating Bounds from the Distribution of Weights

Decision Makers	C_1	C_2	...	C_H
DM_1	W_{11}	W_{12}	...	W_{1H}
DM_2	W_{21}	W_{22}	...	W_{2H}
DM_3	W_{31}	W_{32}	...	W_{3H}
⋮	⋮	⋮	⋮	⋮
DM_P	W_{P1}	W_{P2}	...	W_{PH}
Minimum value of weight	W_1^L	W_2^L	...	W_H^L
Maximum value of weight	W_1^U	W_2^U	...	W_H^U
Middle value of weight (mean)	W_1^M	W_2^M	...	W_H^M

h = 1, 2..., H *where* H is the number of criteria which can be considered for decision making process

p = 1, 2..., P *where* P is the number of decision maker

In the Table 4.5, the intervals of the weight of goal, W_k where $k = 1,2, \dots, g$ can be identified as $[w_k^L, w_k^U]$, which is known as a single interval weight (SIW). Based on the SIW, we defined $A = [W^L, W^U]$, where $W^L = [\, w_1^L \,, w_2^L \,, \dots, w_g^L \,]^T$ is the vector of the minimum value of weights for each goal, k and $W^U = [\, w_1^U \,, w_2^U \,, \dots, w_g^U \,]^T$ is the vector of the maximum value of weights for each goal, k.

The proposed interval weight method which is known as multi-interval weight (MIW) is presented by dividing $A = [W^L, W^U]$ into two parts. The first part is a sub interval named as $A_1 = [W^L, W^M]$ and the second part is another sub interval named as $A_2 = [W^M, W^U]$, where the lower value W^L is the minimum weight, and the upper value W^U is the maximum weight, while W^M is the middle value of the weights represented by the geometric mean. Figure 4.3 illustrates the SIW and the sub-intervals of weights.

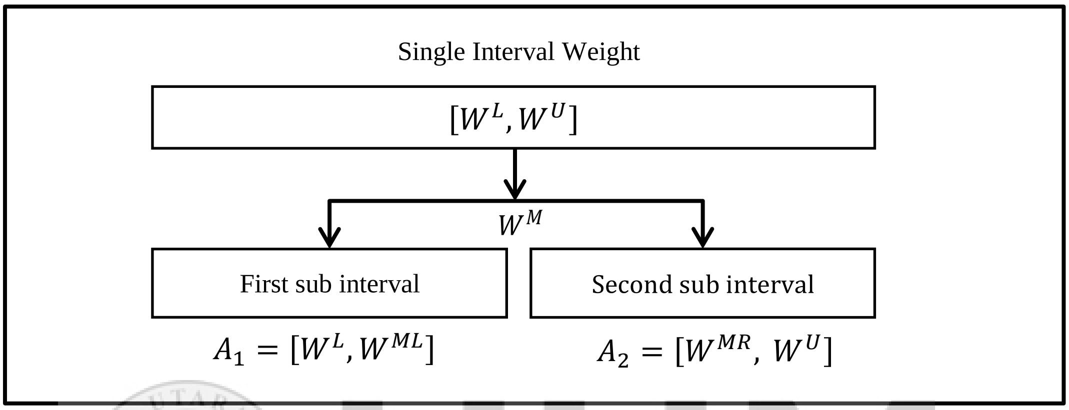


Figure 4.3. The formulation of sub intervals from single interval weights

where, W^{ML} denotes the W^M from the left, and W^{MR} denotes the W^M from the right. In other words, each of W^{ML} and W^{MR} values are equal. Then, based on the interval arithmetic operations as defined in Section 3.5.1, the interval comparison matrices can be expressed as follows.

$$A_1 = \begin{pmatrix} 1 & \left[\frac{W_1^L}{W_2^{ML}}, \frac{W_1^{ML}}{W_2^L}\right] & \cdots & \left[\frac{W_1^L}{W_g^{ML}}, \frac{W_1^{ML}}{W_g^L}\right] \\ \left[\frac{W_2^L}{W_1^{ML}}, \frac{W_2^{ML}}{W_1^L}\right] & 1 & & \left[\frac{W_2^L}{W_g^{ML}}, \frac{W_2^M}{W_g^L}\right] \\ \vdots & \vdots & \vdots & \vdots \\ \left[\frac{W_g^L}{W_1^{ML}}, \frac{W_g^M}{W_1^L}\right] & \left[\frac{W_g^L}{W_2^{ML}}, \frac{W_g^{ML}}{W_2^L}\right] & \cdots & 1 \end{pmatrix} \quad (4.26)$$

$$A_2 = \begin{pmatrix} 1 & \left[\frac{W_1^{MR}}{W_2^U}, \frac{W_1^U}{W_2^{MR}}\right] & \cdots & \left[\frac{W_1^{MR}}{W_g^U}, \frac{W_1^U}{W_g^{MR}}\right] \\ \left[\frac{W_2^{MR}}{W_1^U}, \frac{W_2^U}{W_1^{MR}}\right] & 1 & & \left[\frac{W_2^{MR}}{W_g^U}, \frac{W_2^U}{W_g^{MR}}\right] \\ \vdots & \vdots & \vdots & \vdots \\ \left[\frac{W_g^{MR}}{W_1^U}, \frac{W_g^U}{W_1^{MR}}\right] & \left[\frac{W_g^{MR}}{W_2^U}, \frac{W_g^U}{W_2^{MR}}\right] & \cdots & 1 \end{pmatrix} \quad (4.27)$$

If $(k_0, k)^{th}$ element of the matrix defined in equation (4.26) and equation (4.27) is designated by $[l_{k_0\,k}, m^l_{k_0\,k}]$ and $[m^r_{k_0\,k}, u_{k_0\,k}]$, respectively then $l_{k_0 k} = \frac{w^L_{k_0}}{w^{ML}_k}$, $m^l_{k_0\,k} = \frac{w^{ML}_{k_0}}{w^L_k}$, and $m^r_{k_0\,k} = \frac{w^{MR}_{k_0}}{w^U_k}$, $u_{k_0\,k} = \frac{w^U_{k_0}}{w^{MR}_k}$. Obviously,

$$\left.\begin{aligned} & l_{k_0\,k} \times m^l_{k_0\,k} = 1 \\ & m^r_{k_0\,k} \times u_{k_0\,k} = 1 \\ & for \quad k_0, k = 1,2, \dots, g \end{aligned}\right\} \quad (4.28)$$

Therefore, four new relations can be presented as follows:

$$A^L W^{ML} = W^{ML} + (g-1)W^L \quad (4.29)$$

$$A^{ML} W^L = W^L + (g-1)W^{ML} \quad (4.30)$$

$$A^{MR} W^U = W^U + (g-1)W^{MR} \quad (4.31)$$

and

$$A^U W^{MR} = W^{MR} + (g-1)W^U \quad (4.32)$$

Equations (4.29), (4.30), (4.31), and (4.32) are important links between the lower and upper bounds of the multi-interval weights, which are satisfied as,

$$A^L = \begin{pmatrix} 1 & \frac{W_1^L}{W_2^{ML}} & \cdots & \frac{W_1^L}{W_g^{ML}} \\ \frac{W_2^L}{W_1^{ML}} & 1 & \cdots & \frac{W_2^L}{W_g^{ML}} \\ \vdots & \vdots & \vdots & \vdots \\ \frac{W_g^L}{W_1^{ML}} & \frac{W_g^L}{W_2^{ML}} & \cdots & 1 \end{pmatrix} \text{ and, } \quad A^{ML} = \begin{pmatrix} 1 & \frac{W_1^{ML}}{W_2^L} & \cdots & \frac{W_1^{ML}}{W_g^L} \\ \frac{W_2^{ML}}{W_1^L} & 1 & \cdots & \frac{W_2^{ML}}{W_g^L} \\ \vdots & \vdots & \vdots & \vdots \\ \frac{W_g^{ML}}{W_1^L} & \frac{W_g^{ML}}{W_2^L} & \cdots & 1 \end{pmatrix} \quad (4.33)$$

$$A^{MR} = \begin{pmatrix} 1 & \frac{W_1^{MR}}{W_2^U} & \cdots & \frac{W_1^{MR}}{W_g^U} \\ \frac{W_2^{MR}}{W_1^U} & 1 & \cdots & \frac{W_2^{MR}}{W_g^U} \\ \vdots & \vdots & \vdots & \vdots \\ \frac{W_g^{MR}}{W_1^U} & \frac{W_g^{MR}}{W_2^U} & \cdots & 1 \end{pmatrix} \text{ and, } \quad A^U = \begin{pmatrix} 1 & \frac{W_1^U}{W_2^{MR}} & \cdots & \frac{W_1^U}{W_g^{MR}} \\ \frac{W_2^U}{W_1^{MR}} & 1 & \cdots & \frac{W_2^U}{W_g^{MR}} \\ \vdots & \vdots & \vdots & \vdots \\ \frac{W_g^U}{W_1^{MR}} & \frac{W_g^U}{W_2^{MR}} & \cdots & 1 \end{pmatrix} \quad (4.34)$$

where, $A^L \leq A_1 \leq A^{ML}$ and $A^{MR} \leq A_2 \leq A^U$.

4.5.4.1 Determination of Errors

A pairwise comparison judgment is not 100 percent correct and obviously the equation (4.28) is not satisfied. Also, relations (4.29), (4.30), (4.31), and (4.32) are not satisfied. Several errors occur, where $E_e = E_1, E_2, E_3, E_4$ is the error that occurs in satisfying the relation (4.29), (4.30), (4.31), and (4.32), respectively. These errors can be expressed as follows.

$$E_1 = (A^L - I)\, W^{ML} - (\, g - 1)\, W^L \quad (4.35)$$

$$E_2 = (A^{ML} - I)\, W^L - (\, g - 1)\, W^{ML} \quad (4.36)$$

$$E_3 = (A^{MR} - I)\, W^U - (g - 1)\, W^{MR} \quad (4.37)$$

and

$$E_4 = (A^U - I)\, W^{MR} - (\, g - 1)\, W^U \tag{4.38}$$

where, E_e is the pairwise comparison judgment errors and I is an $g \times g$ unit matrix whose elements on the leading diagonal are 1, and all the other elements are 0. It is most desirable that the absolute values of deviation variables should be kept as small as possible (Wang & Elhag, 2007). If we have SIW, E_e is limited to E_1 and E_2 as derived in Section 3.5.2.2. However, if we have two or more interval weight, for example in case of two, then E_e varies according to E_1, E_2, E_3 and E_4 , as given by equations (4.35), (4.36), (4.37), and (4.38), respectively.

4.5.4.2 Manifestation of New Multi-Interval Weights

In manifesting the new multi-interval weights, the concept of GP is used together with the MIW to solve a hypothetical problem in minimizing errors, as similarly done by Wang and Elhag (2007) with SIW. The first step in the formulation is to achieve the MIW, which are W^L, W^{ML}, W^{RL} and W^U such that the error becomes zero. Considering the target values as zero, the goals in this MIW are to minimize errors, in which the expressions can be written as follows.

$$(A^L - I)\, W^{ML} - (\, g - 1)\, W^L + d_1^- - d_1^+ = 0 \tag{4.39}$$

$$(A^{ML} - I)\, W^L - (\, g - 1)\, W^{ML} + d_2^- - d_2^+ = 0 \tag{4.40}$$

$$(A^{MR} - I)\, W^U - (\, g - 1)\, W^{MR} + d_3^- - d_3^+ = 0 \tag{4.41}$$

and

$$(A^U - I)\, W^{MR} - (g - 1)\, W^U + d_4^- - d_4^+ = 0 \tag{4.42}$$

where, d_e^- and d_e^+ with $e = 1, 2, 3, 4$, represent the vectors of the deviational variables of the dimension (i.e. $[W^L, W^{ML}]$ and $[W^{MR}, W^U]$). Given that our target is to obtain the exact value zero, we have to minimize the sum of both under- and over-deviations associated with their respective goals. The executable GP method can be expressed as follows (Wang & Elhag, 2007).

$$Min\ Z = \sum_{e=1}^{4} \sum_{k=1}^{g} (d_{ek}^- + d_{ek}^+) \tag{4.43}$$

Thus, to satisfy the goal equations in (4.39), (4.40), (4.41), and (4.42), the following relations regarding the MIW should be satisfied.

$$\left.\begin{array}{l}
w_{k_0}^L + \sum_{\substack{k=1 \\ k\neq k_0}}^{g} w_k^{ML} \geq 1, \quad w_{k_0}^{ML} + \sum_{\substack{k=1 \\ k\neq k_0}}^{g} w_k^L \leq 1 \ (k_0 = 1,2,\ldots,g) \\
w_{k_0}^L + \sum_{\substack{k=1 \\ k\neq k_0}}^{g} w_k^{ML} \geq 1, \quad w_{k_0}^{ML} + \sum_{\substack{k=1 \\ k\neq k_0}}^{g} w_k^L \leq 1 \ (k_0 = 1,2,\ldots,g) \\
w_{k_0}^{MR} + \sum_{\substack{k=1 \\ k\neq k_0}}^{g} w_k^U \geq 1, \quad w_{k_0}^U + \sum_{\substack{k=1 \\ k\neq k_0}}^{g} w_k^{MR} \leq 1 \ (k_0 = 1,2,\ldots,g) \\
W^{ML} - W^L \geq 0 \\
W^U - W^{MR} \geq 0 \\
W^{MR}, W^{ML}, W^L, W^U \geq 0
\end{array}\right\} \tag{4.44}$$

where, the d_{ek}^- and d_{ek}^+ represent the vectors of the deviational variables and this method treats the weights of criteria as decision variables which is captured respectively the lower and upper bounds $w_k^L, w_k^{MR}, w_k^{ML}$ and w_k^U of the interval weights of each goal, Z_k.

Up to this point, all steps in the model development for a GP with interval weights are successfully done with the decision variables, goals, constraints and the formulation of the proposed MIW method as described. Subsequently, in the next two sections, the development of the FGP and GP models specifically related to the improvement of the crops production problem are presented.

4.6 Development of the Proposed FGP Model

The development of an FGP model is proposed for the improvement of the crops production problem by embedding the novel method of MIW as described in Section 4.5.4. Therefore, the appropriate steps for developing this FGP are described in the following sub-sections, where the aspiration levels of goals and weights are imprecise due to real world decision making problem. Accordingly, the framework of the model, the membership function formulation of each goal and the proposed FGP follow.

4.6.1 Fuzzy Goal Programming Framework

Based on the crops production problem in this research a more practical decision making model that is the FGP can deal with multiple conflicts and fuzzy goals. The framework for the FGP is as shown in Figure 4.4.

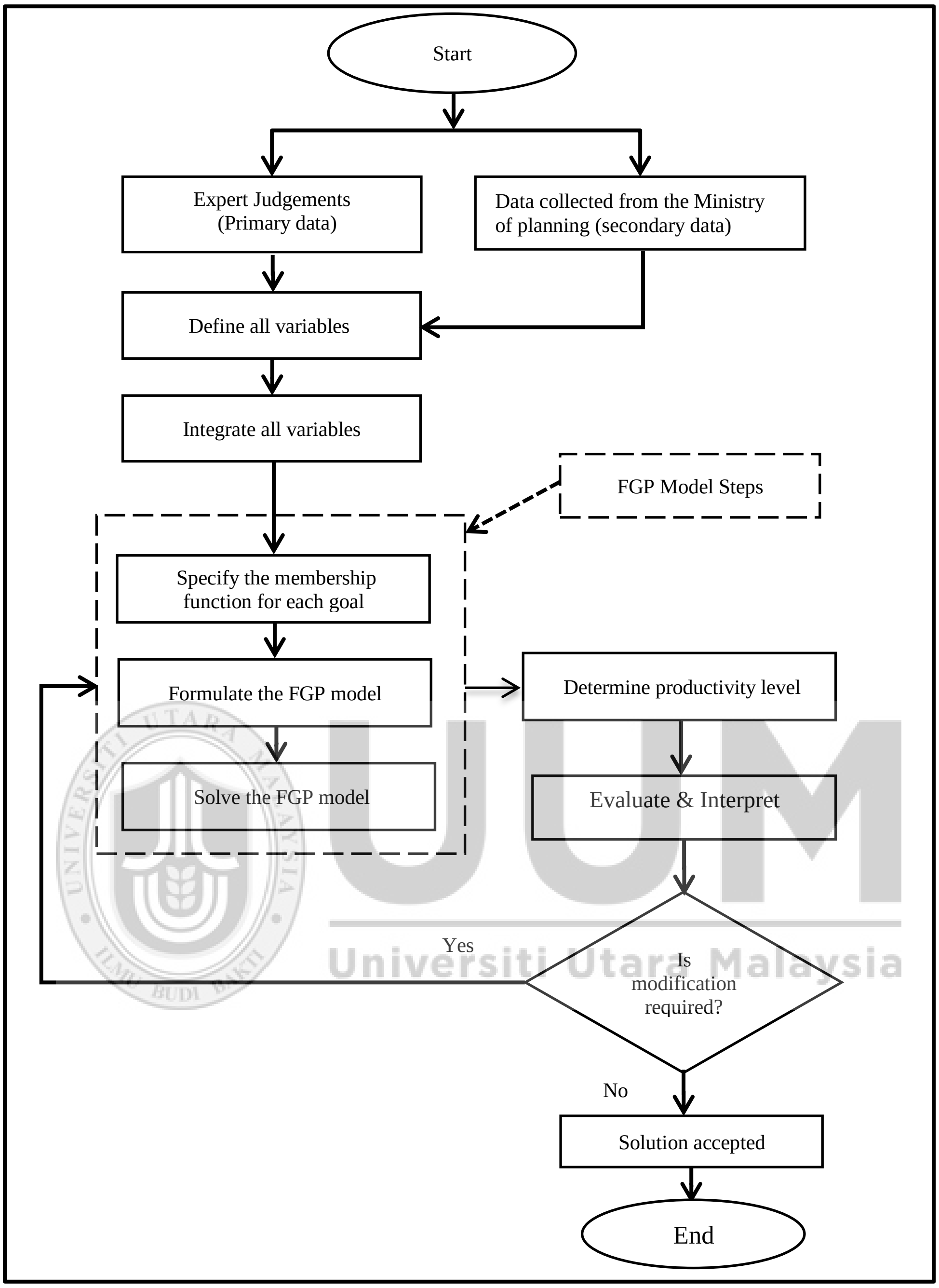


Figure 4.4. Framework of the proposed FGP model

As discussed in Section 3.5, Sen and Pal (2013) proved that the FGP model is suitable and gives better results than that of the GP model under the interval weight concept.

4.6.2 Membership Function Formulation

Prior to constructing the appropriate membership functions, the maximum and minimum values of each goal are determined. These values represent the highest aspired level of achievement and the lowest acceptable level of achievement, respectively. To construct the membership functions, fuzzy goals and their aspiration levels should to determine first. To determine these aspiration levels, the steps presented by Baky (2010) and Ehrgott and Gandibleux (2003) are adapted. However, they could not be determined if without meaningful supporting data. Using the individual best solution, we obtain the maximum and minimum values of each goal and corresponding decision vectors as presented in Section 3.4.3. The steps are as follows.

Step 1: The solution of each single goal problem as a vector is

$$\left.\begin{array}{l} X^1 = \left(x_{11}^1, x_{21}^1, \dots, x_{ij}^1\right) \\ X^2 = \left(X_{11}^2, X_{21}^2, \dots, x_{ij}^2\right) \\ \vdots \qquad \vdots \qquad \vdots \\ X^g = \left(x_{11}^g, x_{21}^g, \dots, x_{ij}^g\right) \end{array}\right\} \tag{4.45}$$

Step 2: The goal values are

$$\left.\begin{array}{l} Z_1(X^1), Z_1(X^2), \dots, Z_1(X^g) \\ Z_2(X^1), Z_2(X^2), \dots, Z_2(X^g) \\ \vdots \qquad \vdots \qquad \vdots \\ Z_g(X^1), Z_g(X^2), \dots, Z_g(X^g) \end{array}\right\} \tag{4.46}$$

Step 3: The upper and lower bounds of each goal can be written as follows.

$$L_1 \leq Z_1 \leq U_1, L_2 \leq Z_2 \leq U_2, \dots, L_g \leq Z_g \leq U_g$$

The membership function, μ_k for the k^{th} goal, $Z_k(x)$ in the maximum case can be expressed as

$$\mu_k(x) = \begin{cases} 1 & Z_k(x) \geq U_k \\ \dfrac{Z_k(x) - L_k}{U_k - L_k} & L_k \leq Z_k(x) \leq U_k, \quad k = 1,2,\dots,K \\ 0 & Z_k(x) < L_k \end{cases} \quad (4.47)$$

On the other hand, the membership function, μ_k for the k^{th} goal, $Z_k(x)$ in the minimum case can be defined as

$$\mu_k(x) = \begin{cases} 1 & Z_k(x) \leq L_k \\ \dfrac{U_k - Z_k(x)}{U_k - L_k}, & L_k < Z_k(x) \leq U_k, k = (K+1),(K+2),\dots,g \\ 0 & Z_k(x) \geq U_k \end{cases} \quad (4.48)$$

where, L_k is the minimum value for the k^{th} goal $Z_k(x)$, U_k is the maximum value for the k^{th} goal $Z_k(x)$. The membership function defined in (4.47) and (4.48) can be illustrated in Figure 4.5.

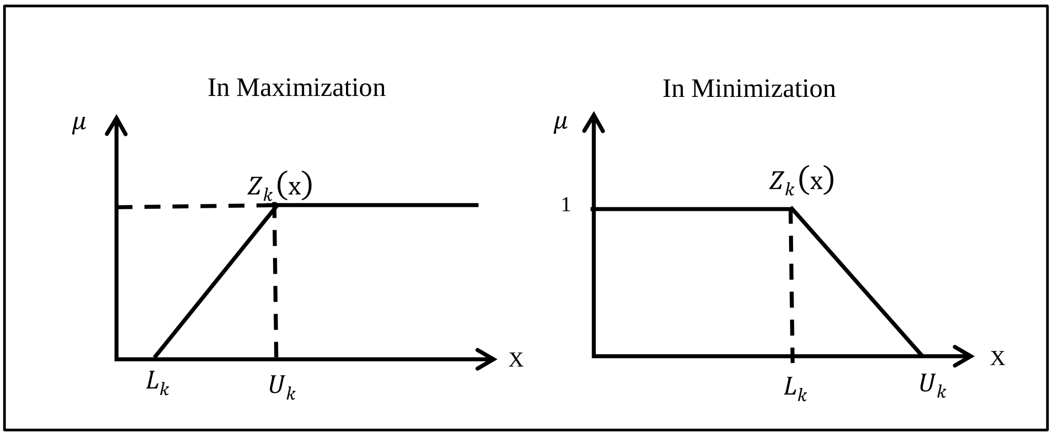


Figure 4.5. Linear membership function for goals

4.6.3 Goals and MIW in the FGP

The membership functions of goals (can be considered as soft constraints) defined with the highest membership value (i.e., unity) are presented as follows.

$$\frac{Z_k(x) - L_k}{U_k - L_k} + \rho_k^- - \rho_k^+ = 1, \qquad k = 1,2, \dots, K \tag{4.49}$$

$$\frac{U_k - Z_k(x)}{U_k - L_k} + \rho_k^- - \rho_k^+ = 1, \qquad k = (K+1), (K+2), \dots, g \tag{4.50}$$

where, ρ_k^- and ρ_k^+ are under- and over-deviational variables concerned with achieving the aspired level of the k^{th} membership goal. The FGP model obtains a solution by calculating the membership function for each goal. It promises the best solution compared to that of GP model (Sen & Pal, 2013).

The proposed FGP model to solve the crops production problem through the different conflicting goals simultaneously is subjected to a set of constraints that can be summarized as follows.

$$Min \sum_{k=1}^{g} W_k \, (\rho_k^-, \rho_k^+) \tag{4.51}$$

$$\left.\begin{aligned}
&subject\ to\\
&\mu_k(x) + \rho_k^- - \rho_k^+ = 1, \quad k = 1,2, \dots, K\\
&\mu_k(x) + \rho_k^- - \rho_k^+ = 1, \quad k = (K+1), (K+2), \dots, g\\
&X \in S^* = \left\{ X \in R^{n\times m} \middle| \begin{cases} AX \geq C \\ AX \leq C \end{cases}, X \geq 0, C, A \in R^{n\times m} \right\}\\
&\rho_k^-, \rho_k^+ \geq 0\\
&X \geq 0
\end{aligned}\right\} \tag{4.52}$$

where, ρ_k^- is expected to be minimized when the kth goal, $Z_k(x)$ is maximized, while ρ_k^+ is expected to be minimized when the kth goal, $Z_k(\mathrm{x})$ need to be minimized. W_k is the interval weight (i.e., MIW) as assessed through the MIW method. X is the $n \times m$ matrix of the decision variables in real values, R. S^* is the set of all feasible solutions, and A and C are the $n \times m$ constant matrix representing the amount of available resource requirements and the total available amounts used for each crop in each zone.

Using the MIW determined from the relations in equations (4.43) and (4.44), the goal achievement function associated with the fuzzy goals, which were defined in equations (4.49) and (4.50) can be presented as follows.

$$Min\ G_q = \sum_{k=1}^{g} ([w_k^L, w_k^{ML}], [w_k^{MR}, w_k^U])\ (\rho_k^-, \rho_k^+)\ , \quad q = 1, 2 \qquad (4.53)$$

where, q is the q^{th} interval.

The MIW determined from the relations in (4.44) is expressed as follows.

$$\left.\begin{aligned} &\mathrm{Min}\ G_1 = \sum_{k=1}^{g} ([w_k^L, w_k^{ML}])\ (\rho_k^-, \rho_k^+) \\ &\mathrm{Min}\ G_2 = \sum_{k=1}^{g} ([w_k^{MR}, w_k^U])\ (\rho_k^-, \rho_k^+) \\ &\text{So,} \\ &\mathrm{Min}\ G_1 \Rightarrow [T_1^L(\rho_k^-, \rho_k^+),\ T_1^{ML}(\rho_k^-, \rho_k^+)] \\ &\mathrm{Min}\ G_2 \Rightarrow [T_2^{MR}(\rho_k^-, \rho_k^+),\ T_2^U(\rho_k^-, \rho_k^+)] \end{aligned}\right\} \qquad (4.54)$$

To determine the target interval, the individual least solution of $T_2^U(\rho_k^-, \rho_k^+)$ should be initially obtained. If $\dot{T}_2^U$ is the minimum value of the function $T_2^U(\rho_k^-, \rho_k^+)$, then, $\dot{T}_2^U = min_{X \in F} T_2^U(\rho_k^-, \rho_k^+)$, where, F is the feasible region satisfying the goal constraint in equations (4.49) and (4.50), as well as the constraints in equation (3.9). Achieving the least value of the target, the feasible interval can be regarded as follows.

$$0 \leq t_1^L \leq t_1^{LR} \leq \dot{T}_1^{LR} \quad \text{and} \quad 0 \leq t_2^{MR} \leq t_2^U \leq \dot{T}_2^U$$

Incorporating the target interval, the interval objective in (4.53) can be represented as follows.

$$[T_1^L(\rho_k^-, \rho_k^+), T_1^{ML}(\rho_k^-, \rho_k^+)], [T_2^{MR}(\rho_k^-, \rho_k^+), T_2^U(\rho_k^-, \rho_k^+)] \\ = [t_1^L, t_1^{ML}], [t_2^{MR}, t_2^U] \quad (4.55)$$

To achieve the goals values in the target intervals $[t_1^L, t_1^{ML}]$ and $[t_2^{MR}, t_2^U]$ the goals can be expressed as

$$\left.\begin{array}{l} T_1^L(\rho_k^-, \rho_k^+) \geq t_1^L \\ T_1^{ML}(\rho_k^-, \rho_k^+) \geq t_1^{ML} \\ \text{and} \\ T_2^{MR}(\rho_k^-, \rho_k^+) \geq t_2^{MR} \\ T_2^{MR}(\rho_k^-, \rho_k^+) \geq t_2^U \end{array}\right\} \quad (4.56)$$

Using under- and over-deviational variables, the goal expressions can be presented as follows.

$$\left.\begin{aligned}
T_1^{L}(\rho^-) + \gamma_{1L}^- - \gamma_{1L}^+ &= t_1^{L} \\
T_1^{ML}(\rho^-) + \gamma_{1ML}^- - \gamma_{1ML}^+ &= t_1^{ML} \\
T_2^{MR}(\rho^-) + \gamma_{2MR}^- - \gamma_{2MR}^+ &= t_2^{MR} \\
T_2^{U}(\rho^-) + \gamma_{2U}^- - \gamma_{2U}^+ &= t_2^{U} \\
\text{where,} & \\
\gamma_{1L}^-, \gamma_{1L}^+ &\geq 0 \\
\gamma_{1ML}^-, \gamma_{1ML}^+ &\geq 0 \\
\gamma_{2MR}^-, \gamma_{2MR}^+ &\geq 0 \\
\gamma_{2U}^-, \gamma_{2U}^+ &\geq 0
\end{aligned}\right\} \quad (4.57)$$

4.6.4 Overall Formulation of the Proposed MIWFGP Model

To achieve the interval goal in the specified interval $[\, t_1^{L}, t_1^{ML}], [\, t_1^{MR}, t_1^{U}]$ the sum of under-deviations (associated with the first and third goal in (4.57)) and over-deviations (associated with the second and fourth goal in (4.57)) should be minimized. Therefore, the overall deviations are combined as the objective function of the FGP as given in $G = \gamma_{1L}^- + \gamma_{1ML}^+ + \gamma_{2MR}^- + \gamma_{2U}^+$.

Finally, the proposed FGP with MIW for the crops production problem can be formulated as follows.

$$
\left.\begin{aligned}
&\text{Min G } = (\gamma_{1L}^{-} + \gamma_{1ML}^{+} + \gamma_{1MR}^{-} + \gamma_{1U}^{+}) \\
&\quad \text{subject to} \\
&\quad T_1^L(\rho^-) + \gamma_{1L}^{-} - \gamma_{1L}^{+} = t_1^L \\
&\quad T_1^{ML}(\rho^-) + \gamma_{1ML}^{-} - \gamma_{1ML}^{+} = t_1^{ML} \\
&\quad T_1^{ML}(\rho^-) + \gamma_{1ML}^{-} - \gamma_{1ML}^{+} = t_1^{ML} \\
&\quad T_1^{MR}(\rho^-) + \gamma_{1MR}^{-} - \gamma_{1MR}^{+} = t_1^{MR} \\
&\quad T_1^U(\rho^-) + \gamma_{1U}^{-} - \gamma_{1U}^{+} = t_1^U \\
&\quad \frac{Z_k(x) - L_k}{U_k - L_k} + \rho_k^- - \rho_k^+ = 1, \qquad k = 1,2,\dots,K \\
&\quad \frac{U_k - Z_k(x)}{U_k - L_k} + \rho_k^- - \rho_k^+ = 1, \qquad k = (K+1),(K+2),\dots,g \\
&\quad X \in S^* = \left\{X \in R^{n\times m} \middle| \begin{Bmatrix} AX \geq C \\ AX \leq C \end{Bmatrix}, X \geq 0, C, A \in R^{n\times m}\right\} \\
&\quad \rho_k^-, \rho_k^+ \geq 0 \\
&\quad X \geq 0
\end{aligned}\right\} \quad (4.58)
$$

4.7 Development of the Proposed GP Model

Similarly, the development of a GP model is proposed for the improvement of the crops production problem by embedding the novel method of MIW as well, as described in Section 4.5.4. Therefore, the framework of the model, and the overall formulation of the proposed MIWGP model follow.

4.7.1 Goal Programming Framework

Based on the crops production problem in this research, GP is still to be one of the stronger techniques available that has a close correspondence with a more practical decision making model dealing with multiple conflicting goals. The framework for the GP is as shown in Figure 4.6.

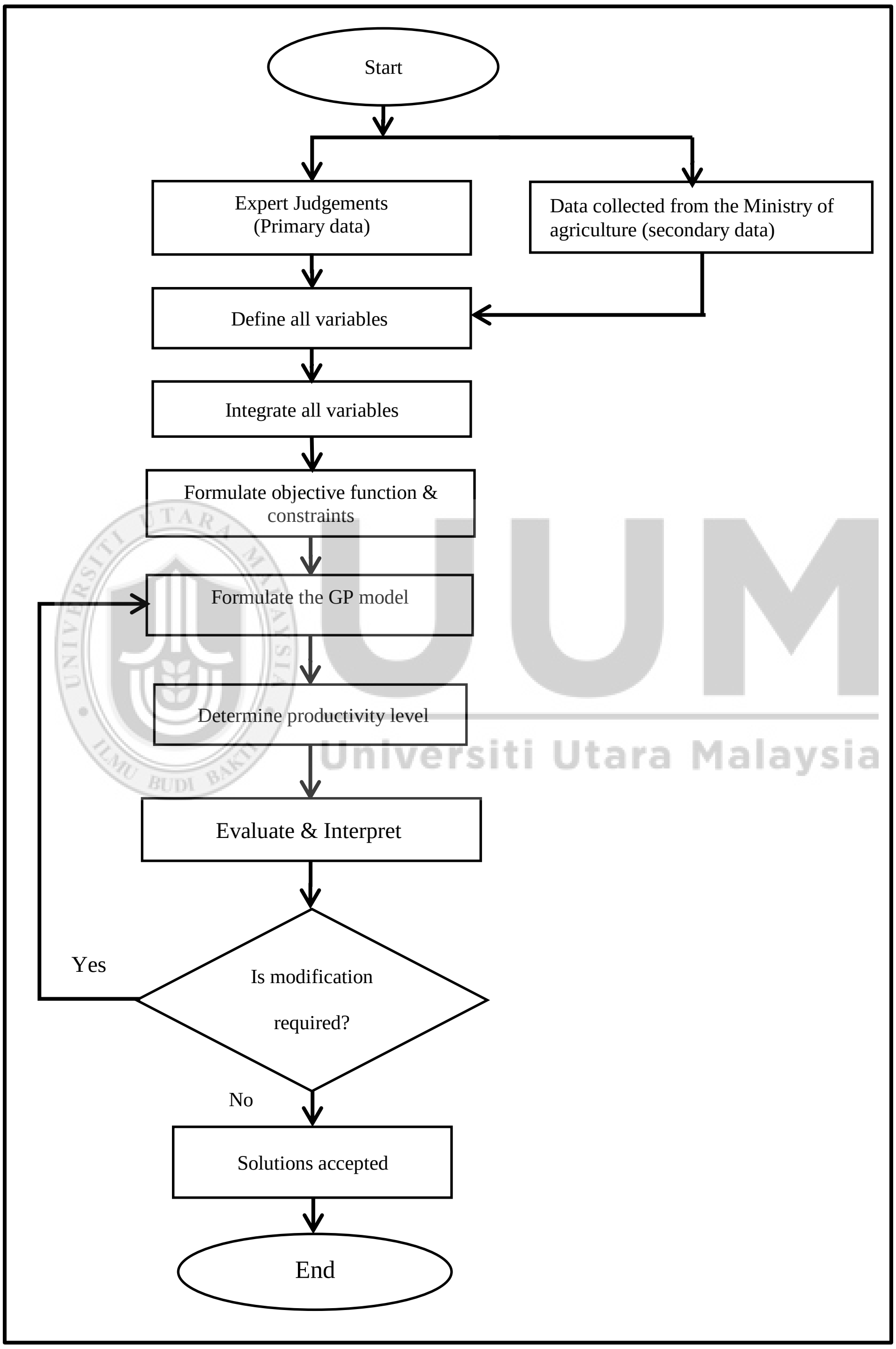


Figure 4.6. Framework of the proposed GP model

4.7.2 Goals and MIW in the GP

The GP formulation consists of a number of constraints representing conditions which must be met as a number of goals to represent the various goals. With the objective function formulated to minimize the total under- and over-deviational variables between goal achievement and the goal. The goals which are known as the soft constraints can be presented as follows.

$$Z_k(x) + \rho_k^- - \rho_k^+ = t_k \quad k = 1,2,\dots,g \tag{4.59}$$

The proposed GP model to improve the crops production problem through the conflicted goals simultaneously, subjected to a set of constraints and can be summarized as follows.

$$\text{Min} \sum_{k=1}^{g} W_k\,(\rho_k^-, \rho_k^+) \tag{4.60}$$

$$\left.\begin{array}{l} \text{subject to} \\ Z_k(x) + \rho_k^- - \rho_k^+ = t_k \qquad k = 1,2,\dots,g \\ X \in S^* = \left\{ X \in R^{n\times m} \middle| \begin{Bmatrix} AX \geq C \\ AX \leq C \end{Bmatrix}, X \geq 0, C, A \in R^{n\times m} \right\} \\ \rho_k^-, \rho_k^+ \geq 0 \\ X \geq 0 \end{array}\right\} \tag{4.61}$$

where, ρ_k^- and ρ_k^+ are under- and over-deviational variables concerned with achieving the aspired level of the kth goal. W_k is the interval weight (i.e., MIW) as assessed through the MIW method. X is the $n \times m$ matrix of the decision variables in real values, R. S^* is the set of all feasible solutions, and A and C are the $n \times m$

constant matrix representing the amount of available resource requirements and the total available amounts used for each crop in each zone.

4.7.3 Overall Formulation of the Proposed MIWGP Model

The process of constructing the MIW is the same as was done in the FGP model in Section 4.6. Similarly, to achieve the interval goal in the specified interval [t_1^L , t_1^{ML}], [t_1^{MR} , t_1^U] , the sum of under-deviations (associated with the first and third goal in (4.57)) and over-deviations (associated with the second and fourth goal in (4.57)) should be minimized. Therefore, the overall deviations are combined as the objective function of the GP as given in $G = \gamma_{1L}^- + \gamma_{1ML}^+ + \gamma_{2MR}^- + \gamma_{2U}^+$.

Finally, the proposed GP with MIW for the crops production problem can be formulated as follows.

$$
\left.
\begin{array}{l}
\text{Min G } = \gamma_{1L}^{-} + \gamma_{1ML}^{+} + \gamma_{1MR}^{-} + \gamma_{1U}^{+} \\
\text{subject to} \\
T_1^{L}(\rho^-) + \gamma_{1L}^{-} - \gamma_{1L}^{+} \quad = t_1^{L} \\
T_1^{ML}(\rho^-) + \gamma_{1ML}^{-} - \gamma_{1ML}^{+} \quad = t_1^{ML} \\
T_1^{ML}(\rho^-) + \gamma_{1ML}^{-} - \gamma_{1ML}^{+} \quad = t_1^{ML} \\
T_1^{MR}(\rho^-) + \gamma_{1MR}^{-} - \gamma_{1MR}^{+} \quad = t_1^{MR} \\
T_1^{U}(\rho^-) + \gamma_{1U}^{-} - \gamma_{1U}^{+} \quad = t_1^{U} \\
Z_k(x) + \rho_k^- - \rho_k^+ = t_k \qquad k = 1,2,\dots,g \\
X \in S^* = \left\{ X \in R^{n\times m} \middle| \begin{Bmatrix} AX \geq C \\ AX \leq C \end{Bmatrix}, X \geq 0, C, A \in R^{n\times m} \right\} \\
\rho_k^-, \rho_k^+ \geq 0 \\
X \geq 0
\end{array}
\right\} \quad (4.62)
$$

4.8 Evaluation of the Proposed FGP and GP Models

Figure 4.1 illustrates that the fifth phase of the research activities is to evaluate the performance of the proposed FGP and GP models. Evaluation of the solutions for the FGP and GP models based on the proposed MIW method are done to show how the novel MIW method achieves the most appropriate weights to represent the levels of importance in the crops production problem. The performance of the proposed MIWFGP, MIWGP and the established SIWFGP and SIWGP models are analysed using several sets of data available for the years 2002 and 2010. Furthermore, the performance of the proposed MIWFGP model is compared to that of the SIWFGP model. Also, the performance of the proposed MIWGP model is compared to that of the SIWGP model.

4.9 Summary

In this chapter, we presented the methodology of the research and highlighted the research process, starting with the research design and determination of the most appropriate weights of criteria (i.e., goals) in the agriculture sector.

We have also provided the decision variables, the formulation of the membership function, and the formulation of the proposed FGP and GP models together with their constraints. Then, we have successfully presented a new novel method which introduced multi-interval weights in improving a crops production problem in a fuzzy manner. This is a novel means of exploiting weights in the form of intervals, but not in the conventionally single interval version. Subsequently, the results of these proposed models are discussed in the following Chapter Five.

CHAPTER FIVE
RESULTS AND DISCUSSIONS

This Chapter Five describes the implementation process of the proposed MIWFGP and MIWGP models together with the analyses results to improve the crops production problem. First, the data is described in Section 5.1 which includes two types of data involved. Second, in Section 5.2 the determination of weights using the proposed MIW method and the establish SIW method are presented. The identification of variables is briefly discussed in Section 5.3. Then the implementation of the proposed MIWFGP and MIWGP models are discussed in Sections 5.4 and 5.5 based on the available data. Subsequently, Section 5.6 highlighted the relevant results for these two models with years 2002 and 2010. Section 5.7 presented several analyses and evaluation on the proposed models.

5.1 Information and Data Collected

As described in Chapter Four, this research used two different sets of data. The first set of data is primary data which was collected via a questionnaire. The questionnaire was initially sent to several agriculture experts to verify that content is easily understood by respondents later. The second set is the secondary data which was gathered from different prior literature including reports. The information based on these two sets of data is presented in the next subsections.

5.1.1 Data from Questionnaire

Four hundred seventy questionnaires were distributed in five out of 15 governorates in Iraq among decision makers (DMs) in relevant agricultural sectors (i.e., farmers and employees). Through the e-mail communication, only 126 questionnaires were returned with responses. This data collection involving distribution of questionnaires at different zones in Iraq was assisted by 10 research assistants. They helped the respondents to understand the questionnaire and answer regarding the criteria being asked. These researcher assistants were trained to clarify any ambiguous questions raised by them. Table 5.1 summarizes the survey responses.

Table 5.1
Summary of Survey Responses

Description	**N**	**%**
Total questionnaires sent	470	100
Total questionnaires returned	246	52
Total questionnaires rejected.	15	
Total questionnaires received via e-mail.	14	
Total questionnaires received via research assistants	217	
Total usable questionnaires	231	49

5.1.1.1 Descriptive Result on Respondents

The descriptive result on respondents includes demographic characteristics of the respondents as presented in Table 5.2. The results show that the respondents had diversified characteristics in terms of gender, age, education qualification, job in the agricultural sector, and years of experience in agricultural sector (see Part 1 in Appendix A). In terms of gender, more than 73% of the respondents were males, whereas only about 27% were females. It is obvious in Arab countries, the males constitute the majority of the workforce and females have limited freedom to work in any field of the agricultural sectors. Moreover, males in the Iraqi society often handle all issues related to the agricultural production sectors.

Table 5.2

Profile of the Respondents

Demographic Characteristic	Category	Frequency	%	Cumulative %
Gender	Male	169	73.2	73.2
	Female	62	26.8	100.0
	Total	231	100.0	
Age	20-25	4	1.7	1.7
	26-30	3	1.3	3.0
	31-35	30	13.0	16.0
	36-40	60	26.0	42.0
	41-45	62	26.8	68.8
	46-50	64	27.7	96.5
	more 50	8	3.5	100.0
	Total	231	100.0	
Education Qualification	Degree	17	7.4	7.4
	Master	91	39.4	46.8
	PhD	108	46.8	93.5
	Others	15	6.5	100.0
	Total	231	100.0	
Job in Agriculture sectors	Field Crops	30	13.0	13.0
	Food Industry	47	20.3	33.3
	Plant Protection	26	11.3	44.6
	Biological techniques	12	5.2	49.8
	Designing Gardens	28	12.1	61.9
	Agricultural Engineering	12	5.2	67.1
	Department of Soil	18	7.8	74.9
	Biological Chemistry	5	2.2	77.1
	Agricultural economy	39	16.9	93.9
	Farmers	14	6.1	100.0
	Total	231	100.0	
Experience in years	1-10	33	14.3	14.3
	11-20	124	53.7	68.0
	21-30	71	30.7	98.7
	31-40	3	1.3	100.0
	Total	231	100.0	
Other Experiences	Peasant associations	34	14.7	14.7
	Indicative associations	64	27.7	42.4
	Agricultural pesticides	48	20.8	63.2
	Agricultural equipment	26	11.3	74.5
	Consulting agricultural engineering	34	14.7	89.2
	agricultural commodity marketing	25	10.8	100.0
	Total	231	100.0	

Based on age, the majority were more than 40 years old. Moreover, most of the respondents have more than 10 years of experience in agriculture sectors. In terms of qualification, the majority had doctoral education.

The respondents had been working in different types of jobs related to agriculture sectors, such as in food industry, agricultural economy, field crops, designing gardens, and plant protection. In terms of experience, the majority had work experience between 21 and 30 years. The same respondents also indicated that they had other experiences which are related to agriculture. These other experiences are such as engineering consultants and agricultural machinery workers.

5.1.1.2 Establishing Criteria as Goals

As is based on the reliable literature, the selection of the most suitable criteria was successfully done and being use for evaluation by the decision makers. The criteria are identified as agricultural benefit, water irrigation, fertilizer requirement and pesticides requirement. These four important criteria are used to represent goals in the proposed models. There are also other criteria being identified as suitable which are agricultural labour, agricultural equipment, and agricultural seeds. However, they are most suitable to be considered as constraints in the proposed models.

In this research, criteria need to be given weights, which represent the level of importance in the crops production problem. These weights were obtained through the questionnaire as exhibited in Table 5.3. The 231 usable responses from DMs, gave their opinions and decisions on the importance of four criteria through pairwise comparison judgment as explained in Section 2.4.2.

The DMs are experts and authorities in the agricultural sector. After analysing the responses, we categorised the responses into 13 different groups based on the same opinions gathered from the 231 responses. The first group (P_1) with exactly the same opinion consists of 48 DMs, the second group (P_2) with another exactly same opinions consists of 44 DMs, the third group (P_3) consists of 47 DMs, the fourth group ($P4$) consists of 36 DMs, the fifth group (P_5) consists of 42 DMs, the sixth group ($P6$) consists of four DMs, the seventh group (P_7) consists of three DMs, while the eighth group (P_8) consists of two DMs. The balance of five DMs had individual different opinions in their responses. Accordingly, Table 5.3 presents the comparison pairwise judgement for the first group, Table 5.4 for the second group, Table 5.5 for the third group, Table 5.6 for the forth group, and Table 5.7 for the fifth group. The overall judgements for the 231 DMs are presented in Table 5.8. The computations of weights were assisted by the use of the Expert Choice Software (Version 11) (Forman, Saaty, Selly, & Waldron, 1983).

Table 5.3

Pairwise Judgments of 48 Decision Makers

	Agricultural benefit	Water irrigation	Fertilizer requirement	Pesticides requirement
Agricultural benefit	1	1/3	5	3
Water irrigation	3	1	4	3
Fertilizer requirement	1/5	1/4	1	1
Pesticides requirement	1/3	1/3	1	1

The weights vector, $W_{Ph} = (w_{P1}, w_{P2}, w_{P3}, w_{P4})$ where $P = P_1,\ P_2, \dots, P_{13}$ is the P^{th} group of decision makers and $h\ = 1,2,3,4$ is the four criteria taken as goals. W_{Ph} for the first group is calculated as $W_{P_1h} = (0.299,\ 0.498,\ 0.092,\ 0.111)$. It means that 48 decision makers believe that the importance of agricultural benefit, water irrigation, fertilizer requirement and pesticides requirement is represented numerically as $0.299, 0.498, 0.092$ and 0.111, respectively with inconsistency value of 0.08. The following Table 5.4 expressed judgement for the second group (P_2).

Table 5.4

Pairwise Judgments of 44 Decision Makers

	Agricultural benefit	Water irrigation	Fertilizer requirement	Pesticides requirement
Agricultural benefit	1	1	9	9
Water irrigation	1	1	9	5
Fertilizer requirement	1/9	1/9	1	1
Pesticides requirement	1/9	1/5	1	1

The weights vector is calculated as $W_{P_2h} = (0.473, 0.412, 0.053,\ 0.062)$. It means that 44 decision makers believe that the importance of agricultural benefit, water irrigation, fertilizer requirement and pesticides requirement is represented numerically as $0.473, 0.412, 0.053$ and 0.062, respectively with inconsistency value of 0.02 . The following Table 5.5 expressed judgement for the third group (P_3).

Table 5.5

Pairwise Judgments of 47 Decision Makers

	Agricultural benefit	Water irrigation	Fertilizer requirement	Pesticides requirement
Agricultural benefit	1	1	5	9
Water irrigation	1	1	9	9
Fertilizer requirement	1/5	1/9	1	1
Pesticides requirement	1/9	1/9	1	1

The weights vector is calculated as is $W_{P_3h} = (0.412, 0.473, 0.062, 0.053)$. It means that 47 decision makers believe that the importance of agricultural benefit, water irrigation, fertilizer requirement and pesticides requirement is represented numerically as $0.412, 0.473, 0.062$ and 0.053, respectively with inconsistency value of 0.02. The following Table 5.6 expressed judgement for the fourth group (P_4).

Table 5.6

Pairwise Judgments of 42 Decision Makers

	Agricultural benefit	Water irrigation	Fertilizer requirement	Pesticides requirement
Agricultural benefit	1	1	9	7
Water irrigation	1	1	7	7
Fertilizer requirement	1/9	1/7	1	1
Pesticides requirement	1/7	1/7	1	1

The weights vector is calculated as is $W_{P_4 h} = (0.455, 0.427, 0.057, 0.061)$. It means that 42 decision makers believe that the importance of agricultural benefit, water irrigation, fertilizer requirement and pesticides requirement is represented numerically as $0.455, 0.427, 0.057$ and 0.061, respectively with inconsistency value of 0.002. The following Table 5.7 expressed judgement for the fifth group (P_5).

Table 5.7

Pairwise Judgments of 36 Decision Makers

	Agricultural benefit	Water irrigation	Fertilizer requirement	Pesticides requirement
Agricultural benefit	1	1	9	9
Water irrigation	1	1	9	5
Fertilizer requirement	1/9	1/9	1	1
Pesticides requirement	1/9	1/5	1	1

The weights vector is calculated as $W_{P_5h} = (0.423,\ 0.456,\ 0.054, 0.067)$. It means that 36 decision makers believe that the importance of agricultural benefit, water irrigation, fertilizer requirement and pesticides requirement is represented numerically as $0.423,\ 0.456,\ 0.054,$ and 0.067, respectively with inconsistency value of 0.01. The following Table 5.8 expressed judgement for the sixth group (P_6).

Table 5.8

Pairwise Judgments of Four Decision Makers

	Agricultural benefit	Water irrigation	Fertilizer requirement	Pesticides requirement
Agricultural benefit	1	1	9	5
Water irrigation	1	1	7	7
Fertilizer requirement	1/9	1/7	1	1
Pesticides requirement	1/5	1/7	1	1

The weights vector is calculated as $W_{P_6h} = (0.434, 0.438, 0.059, 0.069)$. It means that four decision makers believe that the importance of agricultural benefit, water irrigation, fertilizer requirement and pesticides requirement is represented numerically as $0.434, 0.438, 0.059$ and 0.069, respectively with inconsistency value of 0.01. The following Table 5.9 expressed judgement for the seventh group (P_7).

Table 5.9

Pairwise Judgments of Three Decision Makers

	Agricultural benefit	Water irrigation	Fertilizer requirement	Pesticides requirement
Agricultural benefit	1	1	9	9
Water irrigation	1	1	1	7
Fertilizer requirement	1/9	1	1	1
Pesticides requirement	1/9	1/7	1	1

The weights vector is calculated as $W_{P_7h} = (0.526, 0.297, 0.116,0.061)$. It means that three decision makers believe that the importance of agricultural benefit, water irrigation, fertilizer requirement and pesticides requirement is represented numerically as $0.526, 0.297, 0.116$ and 0.061, respectively with inconsistency value of 0.01. The following Table 5.10 expressed judgement for the eighth group (P_8).

Table 5.10

Pairwise Judgments of Two Decision Makers

	Agricultural benefit	Water irrigation	Fertilizer requirement	Pesticides requirement
Agricultural benefit	1	1	9	5
Water irrigation	1	1	7	7
Fertilizer requirement	1/9	1/7	1	1
Pesticides requirement	1/5	1/7	1	1

The weights vector is calculated as $W_{P_8h} = (0.254,0.244,0.343,0.158)$. It means that two decision makers believe that the importance of agricultural benefit, water irrigation, fertilizer requirement and pesticides requirement is represented numerically as $0.254,0.244,0.343$ and 0.158 , respectively with inconsistency value of 0.01.

The five individual DMs whose pairwise judgements were computed and translated to respective weight vectors are, $W_{P_9h} = (0.071, 0.409, 0.319, 0.201)$, $W_{P_{10}h} = (0.054, 0.337, 0.109, 0.5)$,$W_{P_{11}h} = (0.046, 0.436, 0.15, 0.368)$,$W_{P_{12}h} = (0.033, 0.7, 0.089, 0.178)$ and $W_{P_{13}h} = (0.024, 0.451, 0.312, 0.213)$.

The calculated weights vectors for all 13 different groups of DMs are presented in Table 5.11.

Table 5.11

Summary Pairwise Judgments of the Decision Maker's Weights

Groups of DMs	Agricultural benefit	Water irrigation	Fertilizer requirement	Pesticides requirement
48	0.299	0.498	0.092	0.111
44	0.473	0.412	0.053	0.062
47	0.412	0.473	0.062	0.053
36	0.455	0.427	0.057	0.061
42	0.423	0.456	0.054	0.067
4	0.434	0.438	0.059	0.069
3	0.526	0.297	0.116	0.061
2	0.254	0.244	0.343	0.158
1	0.071	0.409	0.319	0.201
1	0.054	0.337	0.109	0.5
1	0.046	0.436	0.15	0.368
1	0.033	0.7	0.089	0.178
1	0.024	0.451	0.312	0.213

The four criteria in the proposed models are represented by the goals, Z_k. Then the maximum, minimum and middle (mean) values of weights for each goal are calculated from Table 5.11, and presented in the following Table 5.12.

Table 5.12

Statistic of the Decision Maker's Level Weights

	w_1	w_2	w_3	w_4
Minimum value of weight	0.024	0.244	0.053	0.053
Maximum value of weight	0.526	0.700	0.343	0.500
Middle value of weight (mean)	0.400	0.447	0.071	0.081

The middle value of the weight (mean) is represented by the geometric mean of each goal, k obtained by multiplying the first column (in Table 5.11) with weight vectors of agricultural benefit, water irrigation, fertilizer requirement and pesticides requirement, then the total of each column is divided by the total number of DMs which are 231.

5.1.2 Data from Reports

The data of 22 types crops that are gathered from reports, which obtained by the Manual of Agricultural Statistical Indicators for the period of 2002 and 2010 in Iraq (Ministry of Planning, 2011b). The 22 crops are considered as the decision variables in the proposed models. However, this research focused in only 20 types of crops where two crops that are sugar beet and sugar cane have not considered due to the missing data. The crops production for two several different years 2002 and 2010 is presented in the following subsections.

5.1.2.1 Crops Productions for Year 2002

The crops productions are presented in Table 5.13 for year 2002 data. This table contains the productions of 20 types of crops at each zone with their percentage. However, these crops productions are supported for short term planning in Iraq (Ministry of Planning, 2011b).

Table 5.13

Crops Production in Iraq during 2002

Zones	Ninevah		Al-Anbar		Baghdad		Al-Qadisiya		Maysan	
	Production in Tonne									
Crops	Production	Percent	Production	Percent	Production	Percent	Production	Percent	Production	Percent
Wheat	954084	53.5	66997	18.0	83583	7.2	124959	39.8	78794	42.0
Barley	539334	30.3	1760	0.5	4493	0.4	50884	16.2	21470	12.0
Onions	8811	0.5	43864	11.8	29761	2.5	5660	1.8	65	0.0
Potatoes	42186	2.4	146242	39.3	568877	48.7	29	0.0	477	0.3
Lettuce	466	0.0	806	0.2	594	0.1	520	0.2	63	0.0
Carrot	336	0.0	16569	4.5	7175	0.6	248	0.1	88	0.0
Tomatoes	175503	9.9	2253	0.6	90161	7.7	2495	0.8	1030	0.6
Mash	4	0.0	1390	0.4	1245	0.1	2294	0.7	420	0.2
Pepper	2130	0.1	4654	1.3	55142	4.7	377	0.1	334	0.2
Green Beans	8163	0.5	8483	2.3	40682	3.5	941	0.3	14937	8.0
Rice	315	0.0	264	0.1	8348	0.7	101571	32.3	3479	1.9
String Beans	380	0.0	9284	2.5	32793	2.8	1113	0.4	2593	1.4
Garlic	466	0.0	806	0.2	594	0.1	520	0.2	63	0.0
Squash	1932	0.1	15461	4.2	81155	7.0	2492	0.8	202	0.1
Cucumber	10323	0.6	34128	9.2	99721	8.5	4863	1.5	38739	21
Millet	0	0.0	780	0.2	557	0.0	746	0.2	33	0.0
Corn	17747	1.0	11300	3.0	53813	4.6	8168	2.6	22839	12.0
Sunflower	96	0.0	1196	0.3	3708	0.3	174	0.1	313	0.2
Cotton	19795	1.1	927	0.2	4123	0.4	114	0.0	0	0.0
Sesame Seeds plant	430	0.0	4533	1.2	879	0.1	5991	1.9	375	0.2
Total	1782537	100	371697	100	1167404	100	314159	100	186314	100

(Source: Ministry of Planning, 2011b)

This research focused on only 20 crops, namely, wheat, barley, onions, potatoes, lettuce, carrot, tomatoes, mash, pepper, green beans, rice, string beans, garlic, squash, cucumber, millet, corn, sunflower, cotton, and sesame seeds plant as shown in Figure 5.1.

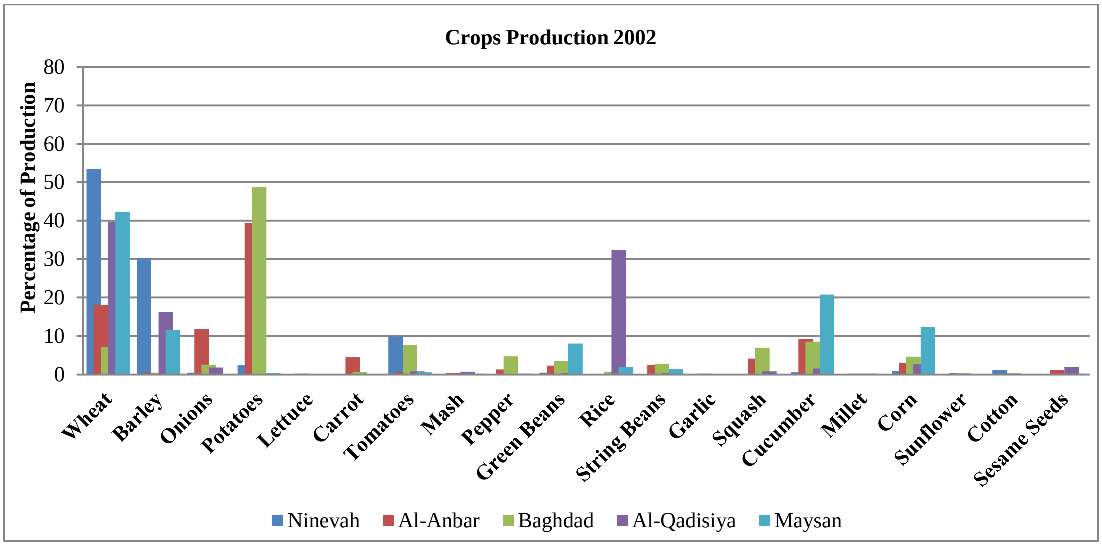


Figure 5.1. Crops production in the Iraqi zones 2002

In 2002, the important crops production in Ninevah are wheat (53.5%), barley (30%), tomatoes (10%), and potatoes (2%), while other crops constitute less than 1% production. In Al-Anbar, the important crops are potatoes (39%), wheat (18%), onions (12%), cucumber (9%), carrot (4%) squash (4%), corn (3%), green beans (2%), string beans (2%), and other crops are less than 1% production. In Baghdad, the important crops are potatoes (49%), cucumber (9%), tomatoes (8%), wheat (7%), squash (7%), pepper (5%), green beans (3%), string beans (3%), onions (3%), and other crops less than 1% production. In Al-Qadisiya, the important crops are wheat (40%), rice (32%), barley (16%), corn (3%), onions (12%), cucumber (2%), and other crops less than 1% production. Finally, in Maysan, the important crops are wheat (42%), barley (12%), corn (12%), cucumber (12%), green beans (8%), rice (2%), and other crops accounted for less than 1% production.

5.1.2.2 Crops Productions for Year 2010

The crops productions are presented in Table 5.14 for year 2010 data. This table contains the productions of 20 types of crops at each zone with their percentage.

Table 5.14

Crops Productions in Iraq during 2010

Zones	Ninevah		Al-Anbar		Baghdad		Al-Qadisiya		Maysan	
	Production in Tonne									
Crops	Production	Percent	Production	Percent	Production	Percent	Production	Percent	Production	Percent
Wheat	689731	49.1	164745	36.5	98941	13.3	218426	47.2	81420	36.0
Barley	594437	42.3	5422	1.2	8142	1.1	131179	28.4	66864	29.6
Onions	22473	1.6	22680	5.0	9541	1.3	2181	0.5	1358	0.6
Potatoes	42418	3.0	93977	20.8	46682	6.3	339	0.1	477	0.2
Lettuce	1100	0.1	10692	2.4	39383	5.3	0	0.0	4636	2.1
Carrot	336	0.0	16569	3.7	7175	1.0	0	0.0	88	0.0
Tomatoes	15502	1.1	33117	7.3	200000	26.9	18001	3.9	6681	3.0
Mash	0	0.0	0	0.0	28	0.0	192	0.0	86	0.0
Pepper	6217	0.4	0	0.0	48381	6.5	0	0.0	210	0.1
Green Beans	2822	0.2	16231	3.6	29646	4.0	2215	0.5	8400	3.7
Rice	0	0.0	310	0.1	0	0.0	65930	14.3	170	0.1
String Beans	1731	0.1	17298	3.8	38120	5.1	5270	1.1	4679	2.1
Garlic	466	0.0	806	0.2	594	0.1	520	0.1	63	0.0
Squash	3522	0.3	14927	3.3	84634	11.4	714	0.2	42	0.0
Cucumber	21848	1.6	39963	8.9	75792	10.2	13321	2.9	34742	15.4
Millet	0	0.0	780	0.2	557	0.1	746	0.2	33	0.0
Corn	90	0.0	9883	2.2	53590	7.2	2322	0.5	16016	7.1
Sunflower	1309	0.1	1001	0.2	581	0.1	0	0.0	59	0.0
Cotton	34	0.0	0	0.0	211	0.0	153	0.0	0	0.0
Sesame Seeds plant	73	0.0	2606	0.6	1171	0.2	1029	0.2	33	0.0
Total	1404109	100	451007	100	743169	100	462538	100	226057	100

(Source: Ministry of Planning, 2011b)

In 2010, the most important crops in Ninevah are wheat (49%), barley (42%), potatoes (3%), cucumber (2%), and other crops constitute less than 1% production. In the same period, the most important crops production in Al-Anbar are wheat (37%), potatoes (21%), cucumber (9%), tomatoes (7%), onions (5%), carrots (4%), green beans (4%), string beans (4%), squash (3%), corn (2%), lettuce (2%), while other crops account for less than 1% production. In Baghdad, the most important crops are tomatoes (23%), wheat (14%), squash (12%), cucumber (11%), corn (8%), pepper (7%), potatoes (7%), tomatoes (7%), lettuce (2%), green beans (4%), string beans (4%), and other crops constitute less than 1% production. In Al-Qadisiya, the important crops are wheat (47%), barley (28%), rice (14%), tomatoes (4%), cucumber (3%), and other crops less than 1% production. In Maysan, the most important crops produced are wheat (34%), barley (28%), cucumber (15%), corn (7%), green beans (4%), tomatoes (3%), lettuce (2%), string beans (2%), and other crops constitute less than 1% production (see Figure 5.2).

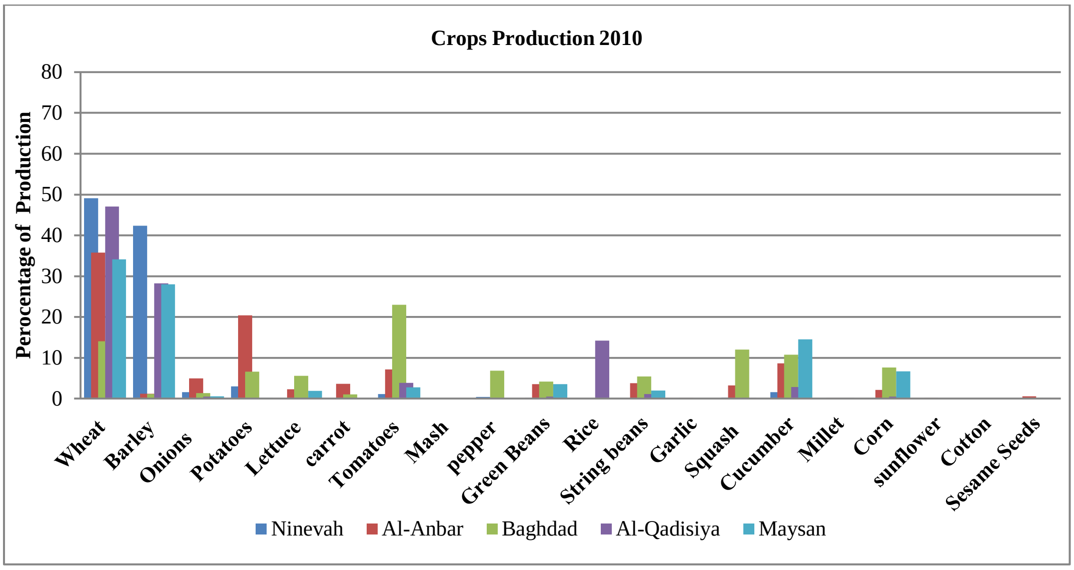


Figure 5.2. Crops production in the Iraqi zones 2010

5.2 Determination of Interval Weights

The vector of weights based on use of the comparison matrix for the weights as interval in exhibition. Two methods are used which included the established SIW and the proposed MIW methods with detail as follows.

5.2.1 Single Interval Weights as Initial Results

The imprecise pairwise comparison matrix can be written by using the minimum and maximum values of weight from Table 5.12 and the formulation (3.19),which considered the lower and upper weights vector according to Sen and Pal (2013) as A^L and A^U follows.

$$A^L = \begin{bmatrix} 1.000 & 0.034 & 0.070 & 0.048 \\ 0.464 & 1.000 & 0.711 & 0.488 \\ 0.101 & 0.076 & 1.000 & 0.106 \\ 0.101 & 0.076 & 0.155 & 1.000 \end{bmatrix}$$

and

$$A^U = \begin{bmatrix} 1.000 & 2.156 & 9.925 & 9.925 \\ 29.167 & 1.000 & 13.208 & 13.208 \\ 14.292 & 1.406 & 1.000 & 6.472 \\ 20.833 & 2.049 & 9.434 & 1.000 \end{bmatrix}$$

Using the formulation in (3.22), the GP method to determine the weights, W_k^L and W_k^U as interval form which can be presented as

$$\text{Min } Z = \sum_{e=1}^{2}\sum_{k=1}^{4}(d_{ek}^{-} + d_{ek}^{+})$$

subject to

$$(0)W_1^U + (0.034)W_2^U + (0.070)W_3^U + (0.048)W_4^U - (3)W_1^L + d_{11}^{-} - d_{11}^{+} = 0$$
$$(0.464)W_1^U + (0)W_2^U + (0.711)W_3^U + (0.488)W_4^U - (3)W_2^L + d_{12}^{-} - d_{12}^{+} = 0$$
$$(0.101)W_1^U + (0.076)W_2^U + (0)W_3^U + (0.106)W_4^U - (3)W_3^L + d_{13}^{-} - d_{13}^{+} = 0$$
$$(0.101)W_1^U + (0.076)W_2^U + (0.155)W_3^U + (0)W_4^U - (3)W_4^L + d_{14}^{-} - d_{14}^{+} = 0$$
$$(0)W_1^L + (2.156)W_2^L + (9.925)W_3^L + (9.925)W_4^L - (3)W_1^U + d_{21}^{-} - d_{21}^{+} = 0$$
$$(29.167)W_1^L + (0)W_2^L + (13.208)W_3^L + (13.208)W_4^L - (3)W_2^U + d_{22}^{-} - d_{22}^{+} = 0$$
$$(14.292)W_1^L + (1.046)W_2^L + (0)W_3^L + (6.472)W_4^L - (3)W_3^U + d_{23}^{-} - d_{23}^{+} = 0$$
$$(20.833)W_1^L + (2.049)W_2^L + (9.434)W_3^L + (0)W_4^L - (3)W_4^U + d_{24}^{-} - d_{24}^{+} = 0$$
$$W_1^L + W_2^U + W_3^U + W_4^U \geq 1$$
$$W_2^L + W_1^U + W_3^U + W_4^U \geq 1$$
$$W_3^L + W_1^U + W_2^U + W_4^U \geq 1$$
$$W_4^L + W_1^U + W_2^U + W_3^U \geq 1$$
$$W_1^U + W_2^L + W_3^L + W_4^L \leq 1$$
$$W_2^U + W_1^L + W_3^L + W_4^L \leq 1$$
$$W_3^U + W_1^L + W_2^L + W_4^L \leq 1$$
$$W_4^U + W_1^L + W_2^L + W_3^L \leq 1$$
$$W_1^U \geq W_1^L,\ W_2^U \geq W_2^L,\ W_3^U \geq W_3^L,\ W_4^U \geq W_4^L$$
$$W_1^L \leq W_1^U,\ W_2^L \leq W_2^U,\ W_3^L \leq W_3^U,\ W_4^L \leq W_4^U \tag{5.1}$$

where, d_{ek}^{-} and d_{ek}^{+} $(k = 1,2,\dots,4;\ \ e = 1,2)$ represent the vectors of the deviational variables and the SIW method treats the weights of criteria as decision variables, W_k^L and W_k^U, the lower and upper bounds of the interval weights of each goal, Z_k. Then, the calculated weights generated from the GP method as in formulation (3.22) to determine the lower and upper bounds of weights based on the established SIW method are written as

$$\left.\begin{aligned} W_1 &= [W_1^L,\ W_1^U] = [0.02, \quad 0.34] \\ W_2 &= [W_2^L,\ W_2^U] = [0.16, \quad 0.45] \\ W_3 &= [W_3^L,\ W_3^U] = [0.03, \quad 0.22] \\ W_4 &= [W_4^L,\ W_4^U] = [0.03, \quad 0.32] \end{aligned}\right\} \tag{5.2}$$

5.2.2 Multi-Interval Weights as Initial Results

The pairwise comparison matrix can be written by using the minimum and maximum values of weight obtained from Table 5.12 by applying the formulation (4.33) and (4.34). Therefore, the comparison matrices representing the lower and upper weights vectors for A^L, A^{ML}, A^{MR} and A^U can be presented as follows.

$$A^L = \begin{bmatrix} 1.000 & 0.054 & 0.336 & 0.295 \\ 0.610 & 1.000 & 3.416 & 3.001 \\ 0.133 & 0.118 & 1.000 & 0.652 \\ 0.133 & 0.118 & 0.742 & 1.000 \end{bmatrix},$$

$$A^{ML} = \begin{bmatrix} 1.000 & 1.638 & 7.543 & 7.543 \\ 18.645 & 1.000 & 8.443 & 8.443 \\ 2.977 & 0.293 & 1.000 & 1.348 \\ 3.387 & 0.333 & 1.534 & 1.000 \end{bmatrix}$$

$$A^{MR} = \begin{bmatrix} 1.000 & 0.571 & 1.166 & 0.800 \\ 0.851 & 1.000 & 1.305 & 0.895 \\ 0.136 & 0.102 & 1.000 & 0.143 \\ 0.155 & 0.116 & 0.237 & 1.000 \end{bmatrix},$$

and

$$A^U = \begin{bmatrix} 1.000 & 1.175 & 7.363 & 6.470 \\ 1.751 & 1.000 & 9.799 & 8.611 \\ 0.858 & 0.766 & 1.000 & 4.219 \\ 1.251 & 1.117 & 6.999 & 1.000 \end{bmatrix}$$

Using the four matrices above and the formulation in (4.43) and (4.44), the GP method for determination the weights, W_k^L , W_k^{MR}, W_k^{ML} and W_k^U in the multi-interval form, can be presented as follows.

$$\text{Min } Z = \sum_{e=1}^{4}\sum_{k=1}^{4}(d_{ek}^- + d_{ek}^+)$$

subject to

$$(0)W_1^{ML} + (0.05)W_2^{ML} + (0.34)W_3^{ML} + (0.30)W_4^{ML} - (3)W_1^L + d_{11}^- - d_{11}^+ = 0$$

$$(0.61)W_1^{ML} + (0)W_2^{ML} + (3.42)W_3^{ML} + (3.0)W_4^{ML} - (3)W_2^L + d_{12}^- - d_{12}^+ = 0$$

$$(0.13)W_1^{ML} + (0.12)W_2^{ML} + (0.74)W_3^{ML} + (0)W_4^{ML} - (3)W_4^L + d_{14}^- - d_{14}^+ = 0$$

$$(0)W_1^L + (1.64)W_2^L + (7.54)W_3^L + (7.54)W_4^L - (3)W_1^{ML} + d_{21}^- - d_{21}^+ = 0$$

$$(18.65)W_1^L + (0)W_2^L + (8.44)W_3^L + (8.44)W_4^L - (3)W_2^{ML} + d_{22}^- - d_{22}^+ = 0$$

$$(2.98)W_1^L + (0.29)W_2^L + (0)W_3^L + (1.35)W_4^L - (3)W_3^{ML} + d_{23}^- - d_{23}^+ = 0$$

$$(3.39)W_1^L + (0.33)W_2^L + (1.53)W_3^L + (0)W_4^L - (3)W_4^{ML} + d_{24}^- - d_{24}^+ = 0$$

$$(0)W_1^U + (0.57)W_2^U + (1.17)W_3^U + (0.80)W_4^U - (3)W_1^{MR} + d_{31}^- - d_{31}^+ = 0$$

$$(0.85)W_1^U + (0)W_2^U + (1.30)W_3^U + (0.89)W_4^U - (3)W_2^{MR} + d_{32}^- - d_{32}^+ = 0$$

$$(0.14)W_1^U + (0.10)W_2^U + (0)W_3^U + (0.14)W_4^U - (3)W_3^{MR} + d_{33}^- - d_{33}^+ = 0$$

$$(0.15)W_1^U + (0.12)W_2^U + (0.24)W_3^U + (0)W_4^U - (3)W_4^{MR} + d_{34}^- - d_{34}^+ = 0$$

$$(0)W_1^{MR} + (1.18)W_2^{MR} + (7.36)W_3^{MR} + (6.47)W_4^{MR} - (3)W_1^U + d_{41}^- - d_{41}^+ = 0$$

$$(1.75)W_1^{MR} + (0)W_2^{MR} + (9.80)W_3^{MR} + (8.61)W_4^{MR} - (3)W_2^U + d_{42}^- - d_{42}^+ = 0$$

$$(0.86)W_1^{MR} + (0.77)W_2^{MR} + (0)W_3^{MR} + (4.22)W_4^{MR} - (3)W_3^U + d_{43}^- - d_{43}^+ = 0$$

$$(1.25)W_1^{MR} + (1.12)W_2^{MR} + (7.00)W_3^{MR} + (0)W_4^{MR} - (3)W_4^U + d_{44}^- - d_{44}^+ = 0$$

$$W_1^L + W_2^{ML} + W_3^{ML} + W_4^{ML} \geq 1 \quad ,$$
$$W_2^L + W_1^{ML} + W_3^{ML} + W_4^{ML} \geq 1 \ ,$$
$$W_3^L + W_1^{ML} + W_2^{ML} + W_4^{ML} \geq 1,$$
$$W_4^L + W_1^{ML} + W_2^{ML} + W_3^{ML} \geq 1,$$
$$W_1^{ML} + W_2^L + W_3^L + W_4^L \leq 1,$$
$$W_2^{ML} + W_1^L + W_3^L + W_4^L \leq 1,$$
$$W_3^{ML} + W_1^L + W_2^L + W_4^L \leq 1,$$
$$W_4^{ML} + W_1^L + W_2^L + W_3^L \leq 1,$$
$$W_1^{MR} + W_2^U + W_3^U + W_4^U \geq 1,$$
$$W_2^{MR} + W_1^U + W_3^U + W_4^U \geq 1,$$
$$W_3^{MR} + W_1^U + W_2^U + W_4^U \geq 1,$$
$$W_4^{MR} + W_1^U + W_2^U + W_3^U \geq 1,$$
$$W_1^U + W_2^{MR} + W_3^{MR} + W_4^{MR} \leq 1,$$
$$W_2^U + W_1^{MR} + W_3^{MR} + W_4^{MR} \leq 1,$$
$$W_3^U + W_1^{MR} + W_2^{MR} + W_4^{MR} \leq 1,$$
$$W_1^{ML} \geq W_1^L,\ W_2^{ML} \geq W_2^L\ ,$$
$$W_3^{ML} \geq W_3^L, W_4^{ML} \geq W_4^L$$
$$W_1^{MR} \leq W_1^U, W_2^{MR} \leq W_2^U$$
$$W_3^{MR} \leq W_3^U,\ W_4^{MR} \leq W_4^U \tag{5.3}$$

where, d_{ek}^- and d_{ek}^+ $(k = 1,2,3,4\ ; \quad e = 1,2,3,4)$ represent the vectors of the deviational variables and the MIW method treats the weights of criteria as decision variables, W_k^L , W_k^{MR}, W_k^{ML} and W_k^U, the lower and upper bounds of the interval weights of each goal, Z_k. Then, the calculated weights generated from the GP method as in formulations (4.43) and (4.44) to determine the lower and upper bounds of weights based on the proposed MIW method are written as

$$\left.\begin{aligned}
W_1 &= \left[[W_1^L, \quad W_1^{ML}], [W_1^{MR}, \quad W_1^U]\right] = \left[[0.056, \quad 0.506], [0.242, \quad 0.318]\right] \\
W_2 &= \left[[W_2^L, \quad W_2^{ML}], [W_2^{MR}, \quad W_2^U]\right] = \left[[0.374, \quad 0.688], [0.270, \quad 0.424]\right] \\
W_3 &= \left[[W_3^L, \quad W_3^{ML}], [W_3^{MR}, \quad W_3^U]\right] = \left[[0.081, \quad 0.110], [0.043, \quad 0.208]\right] \\
W_4 &= \left[[W_4^L, \quad W_4^{ML}], [W_4^{MR}, \quad W_4^U]\right] = \left[[0.039, \quad 0.146], [0.050, \quad 0.302]\right]
\end{aligned}\right\} \quad (5.4)$$

5.3 Variables for the Models

The main objective of this research is to develop the FGP and GP models to improve crops production, while satisfying demands and requirements of the population. At the same time, the models are to maximize the benefits of the agricultural crops production, minimizing the exploitation of water irrigation, fertilizer requirements, and pesticides requirements. These four important goals are considered to have the same level of priority.

As explained in Section 4.4, the Ministry of Planning Iraq (2011b) suggested 22 strategic crops in agriculture production. Since, only 20 crops have complete data and the two crops that are sugar beet and sugar cane have missing data, therefore the representation for the two crops are $x_{17\,j} = 0$ and $x_{18\,j} = 0$, respectively.

Table 5.15

Basic Variables of Different Types of Strategic Crop Grown

Variable	Kind of crops	Remarks	Variable	Kind of crops	Remarks
x_{1j}	Wheat		x_{12j}	String Beans	
x_{2j}	Barley		x_{13j}	Garlic	
x_{3j}	Onions		x_{14j}	Squash	
x_{4j}	Potatoes		x_{15j}	Cucumber	
x_{5j}	Lettuce		x_{16j}	Millet	
x_{6j}	Carrot		x_{17j}	Sugar Beet	Not consider
x_{7j}	Tomatoes		x_{18j}	Sugar Cane	Not consider
x_{8j}	Mash		x_{19j}	Corn	
x_{9j}	Pepper		x_{20j}	Sunflower	
x_{10j}	Green Beans		x_{21j}	Cotton	
x_{11j}	Rice		x_{22j}	Sesame Seeds plant	

Table 5.16 illustrates the types of constraints, variables and type of crops that are considered in each of the constraint in proposed MIWFGP and MIWGP models.

Table 5.16

Strategic Crops with Related Constraints for the FGP and GP Models

Type of constraints	Variables	Type of crops	index
land area for yearly food crops	$x_{1j}, x_{2j}, x_{3j}, x_{4j}, x_{5j}, x_{6j}, x_{7j}, x_{8j}, x_{9j}, x_{10j}, x_{11j}, x_{12j}, x_{13j}, x_{14j}, x_{15j}$	wheat, barley, onions, potatoes, lettuce, carrot, tomatoes, mash, pepper, green beans, rice, string beans, garlic, squash, cucumber, millet	i =1,2,…,15
land area for industrial crops	$x_{16j}, x_{17j}, x_{18j}, x_{19j}, x_{21j}$	millet, sugar beet , sugar cane, corn and cotton	i =16, 17, 18, 19, and 21
land area for oil crops	$x_{19j}\, x_{20j}, x_{22j}$	corn, sunflower and sesame seeds plant	i =19,20, and 22
land area for drought resistant crops	$x_{8j}, x_{19j}, x_{20j}, x_{22j}$	mash, corn, sunflower and sesame seeds plant	i =8,19,20, and 22
surface water irrigation	$x_{1j}, x_{2j}, x_{3j}, x_{4j}, x_{5j}, x_{6j}, x_{7j}, x_{8j}, x_{9j}, x_{10j}, x_{11j}, x_{12j}, x_{13j}, x_{14j}, x_{15j}, x_{16j}, , x_{17j}, x_{18j}, x_{19j}, x_{20j}, x_{21j}, x_{22j}$	wheat, barley, onions, potatoes, lettuce, carrot, tomatoes, mash, pepper, green beans, rice, cowpea , garlic, squash, cucumber, millet, sugar beet, sugar cane, corn, sunflower, cotton and sesame seeds plant	i =1, 2,…, 22
sprinkler irrigation	$x_{1j}, x_{2j}, x_{3j}, x_{5j}, x_{6j}, x_{8j}, x_{10j}, x_{13j}, x_{16j}, x_{19j}, x_{20j}, x_{22j}$	wheat, barley, onions, potatoes, lettuce, carrot, mash, green beans, garlic, corn, sunflower, cotton and sesame seeds plant	i =1,2, 3, 5, 6, 8, 10,13,16, 19, 20, and 22
drip irrigation	$x_{3j}, x_{4j}, x_{5j}, x_{6j}, x_{7j}, x_{9j}, x_{10j}, x_{12j}, x_{13j}, x_{14j}, x_{15j}, x_{19j}, x_{20j}, x_{22j}$	onions, potatoes, lettuce, carrot, tomatoes, pepper, green beans, cowpea , garlic, squash, cucumber, millet, corn, sunflower, cotton and sesame seeds plant	i = 3, 4, 5, 6, 7, 9, 10, 12, 13, 14, 15, 19, 20, 21, and 22
chemical fertilizer natural fertilizer azotic fertilizer labour requirement pesticides requirement agricultural equipment agricultural seeds	$x_{1j}, x_{2j}, x_{3j}, x_{4j}, x_{5j}, x_{6j}, x_{7j}, x_{8j}, x_{9j}, x_{10j}, x_{11j}, x_{12j}, x_{13j}, x_{14j}, x_{15j}, x_{16j}, , x_{17j}, x_{18j}, x_{19j}, x_{20j}, x_{21j}, x_{22j}$	wheat, barley, onions, potatoes, lettuce, carrot, tomatoes, mash, pepper, green beans, rice, cowpea , garlic, squash, cucumber, millet, sugar beet, sugar cane, corn, sunflower, cotton and sesame seeds plant	i =1, 2,…, 22
demand	$x_{1j}, x_{2j}, x_{3j}, x_{4j}, x_{5j}, x_{6j}, x_{7j}, x_{8j}, x_{9j}, x_{10j}, x_{11j}, x_{12j}, x_{13j}, x_{14j}, x_{15j}, x_{16j}, , x_{17j}, x_{18j}, x_{19j}, x_{20j}, x_{21j}, x_{22j}$	wheat, barley, onions, potatoes, lettuce, carrot, tomatoes, mash, pepper, green beans, rice, cowpea , garlic, squash, cucumber, millet, sugar beet, sugar cane, corn, sunflower, cotton and sesame seeds plant	j=1, 2, …, 5
demand for each zone	$x_{\mathrm{i}(j=1)}, x_{\mathrm{i}(j=2)}, x_{\mathrm{i}(j=3)}, x_{\mathrm{i}(j=4)}, x_{\mathrm{i}(j=5)}$	wheat, barley, onions, potatoes, lettuce, carrot, tomatoes, mash, pepper, green beans, rice, cowpea , garlic, squash, cucumber, millet, sugar beet, sugar cane, corn, sunflower, cotton and sesame seeds plant	$\forall i, i = 1,2,\ldots,22$

5.4 Implementation of the Proposed Models with 2002 Data

In this section, the implementation of proposed models MIWFGP and MIWGP are carried out with 16 different types of constraints for 20 strategic crops. The performance of the novel MIW method is tested in the implementation of the two models.

5.4.1 MIWFGP Model for 2002 Data

The implementation of the proposed MIWFGP model with the embedded MIW to improve crops production in five different zones is successfully done based on the formulation (4.58) and MIW in (5.4). The results are presented in in Table 5.18.

Overall, all crops productions have increased to about 14.8 million tonne based on the MIWFGP model as summarized in Table 5.17. Table 5.18 further shows the actual and recommended productions for each of the 20 strategic crops in the five zones after the MIWFGP model was run with the 2002 data. For example, in Ninevah zone the actual production of wheat was 954084 tonne (53.5%), followed by barley was 539334 tonne (30.3%), tomatoes were 175503 tonne (9.85%) and potatoes were 42186 tonne (2.4%). However, the recommended production with MIWFGP model for wheat is 1882447 tonne (49.9%), barley is 539334 tonne (14.3%) and tomatoes are 284679 tonne (7.5%). It can be noted practically that the recommended production with MIWFGP model for potatoes are 564381 tonne and pepper is 431131.2 tonne are at a rate of up to (15%) and (11.4%), respectively.

In Al-Anbar, the actual production of potatoes were 146242 tonne (39.3%), onions were 43864 tonne (11.8%), wheat was 66997 tonne (18%), followed by cucumber was 34128 tonne (9.2%). However, the recommended production with MIWFGP model for potatoes are 146242 tonne (28.6%) and wheat is 86420.03 tonne (16.7%), which are presented as the main crops. Also, the recommended production with MIWFGP model in Al-Anbar shows that some of crops that are pepper and mash are increased to be 84339.64 tonne (16.3%) and 47390 tonne (9.2%), respectively comparing with the actual production, which are 4654 tonne (1.3%) for pepper and 1390 tonne (0.4 %) for mash.

In Baghdad, the actual productions of potatoes were 568877 tonne (48.7%), tomatoes were 90161 tonne (7.7%), followed by wheat was 83583 (7.2%). However, the recommended productions with MIWFGP model are decreased for potatoes to be 46682 tonne (2.6) and tomatoes 90161 tonne (5.1%). The recommended production of wheat is increased from 83583 tonne (7.2%) to 8114961 tonne (46%) to be the main recommended productions with MIWFGP model. In the same zone, barley is recorded as the second main crop which is increased from 4493 tonne (0.4%) to 304493 tonne (17.2 %).

On the other hand, the results for Al-Qadisia and Maysan were observed that there are no changes in the recommended production and the crops ranking with MIWFGP model. Moreover, the results are explained by the fact that wheat is the basic and the main production in the all zones except in Al-Anbar. Furthermore, the results based on the proposed MIWFGP model showed that the recommended productions of crops wheat, lettuce, pepper and corn are generally capable of fulfilling the demand constraints with increasing of the production during the 2002. Other crops are achieved with exact demand without any increment. The proposed MIWFGP model formulation and solutions are shown in Appendix C2.

Table 5.17

Total Actual and Recommended Productions with MIWFGP Model for 2002 Data

Crops	Actual Production	Recommended Production with MIWGP
Wheat	10290661	10290661
Barley	917941	917941
Onions	88161	88161
Potatoes	757811	757811
Lettuce	41238	41238
Carrot	24416	24416
Tomatoes	380618	380618
Mash	51353	51353
Pepper	1655527	1655527
Green Beans	73206	73206
Rice	114013	114013
String Beans	46163	46163
Garlic	2449	2449
Squash	101242	101242
Cucumber	187774	187774
Millet	2136	2136
Corn	113867	113867
Sunflower	5487	5487
Cotton	24959	24959
Sesame seeds plant	12208	12208
Total	14891230	14891230

Table 5.18

Recommended Productions Based on the MIWFGP for 2002 Data

Zones		Ninevah				Al-Anbar				Baghdad				Al-Qadisia				Maysan			
		Production in Tonne																			
Crops	variables	Actual Production	Percentage	Recommended Production with MIWFGP	Percentage	Actual Production	Percentage	Recommended Production with MIWFGP	Percentage	Actual Production	Percentage	Recommended Production with MIWFGP	Percentage	Actual Production	Percentage	Recommended Production with MIWFGP	Percentage	Actual Production	Percentage	Recommended Production with MIWFGP	Percentage
Wheat	x_{1j}	954084	53.5	1882447	49.9	66997	18	86420.03	16.7	83583	7.2	8114961	46.0	124959	39.8	124959	39.6	78794	42.3	81874	42.9
Barley	x_{2j}	539334	30.3	539334	14.3	1760	0.5	1760	0.3	4493	0.4	304493	17.2	50884	16.2	50884	16.1	21470	11.5	21470	11.3
Onions	x_{3j}	8811	0.5	8811	0.2	43864	11.8	43864	8.5	29761	2.5	29761	1.7	5660	1.8	5660	1.8	65	0	65	0.0
Potatoes	x_{4j}	42186	2.4	564381	15.0	146242	39.3	146242	28.6	568877	48.7	46682	2.6	29	0	29	0.0	477	0.3	477	0.3
Lettuce	x_{5j}	466	0	466	0.0	806	0.2	806	0.2	594	0.1	39383	2.2	520	0.2	520	0.2	63	0	63	0.0
Carrot	x_{6j}	336	0	336	0.0	16569	4.5	16569	3.2	7175	0.6	7175	0.4	248	0.1	248	0.1	88	0	88	0.0
Tomatoes	x_{7j}	175503	9.8	284679	7.5	2253	0.6	2253	0.4	90161	7.7	90161	5.1	2495	0.8	2495	0.8	1030	0.6	1030	0.5
Mash	x_{8j}	4	0	4	0.0	1390	0.4	47390	9.2	1245	0.1	1245	0.1	2294	0.7	2294	0.7	420	0.2	420	0.2
Pepper	x_{9j}	2130	0.1	431131.2	11.4	4654	1.3	84339.64	16.3	55142	4.7	1136545	6.4	377	0.1	1829.8	0.6	334	0.2	1681.5	0.9
Green Beans	x_{10j}	8163	0.5	8163	0.2	8483	2.3	8483	1.6	40682	3.5	40682	2.3	941	0.3	941	0.3	14937	8	14937	7.8
Rice	x_{11j}	351	0	351	0.0	264	0.1	264	0.1	8348	0.7	8348	0.5	101571	32.3	101571	32.8	3479	1.9	3479	1.8
String Beans	x_{12j}	380	0	380	0.0	9284	2.5	9284	1.8	32793	2.8	32793	1.9	1113	0.4	1113	0.4	2593	1.4	2593	1.4
Garlic	x_{13j}	466	0	466	0.0	806	0.2	806	0.2	594	0.1	594	0.0	520	0.2	520	0.2	63	0	63	0.0
Squash	x_{14j}	1932	0.1	1932	0.1	15461	4.2	15461	3.0	81155	7	81155	4.6	2492	0.8	2492	0.8	202	0.1	202	0.1
Cucumber	x_{15j}	10323	0.6	10323	0.3	34128	9.2	34128	6.6	99721	8.5	99721	5.6	4863	1.5	4863	1.5	38739	20.8	38739	20.3
Millet	x_{16j}	0	0	0	0.0	780	0.2	780	0.2	557	0	577	0	746	0.2	746	0.2	33	0	33	0.0
Corn	x_{19j}	17747	1	17747	0.5	11300	3	11300	2.2	53813	4.6	53813	3.0	8168	2.6	8168	2.6	22839	12.3	22839	12.0
Sunflower	x_{20j}	96	0	96	0.0	1196	0.3	1196	0.2	3708	0.3	3708	0.2	174	0.1	174	0.1	313	0.2	313	0.2
Cotton	x_{21j}	19795	1.1	19795	0.5	927	0.2	927	0.2	4123	0.4	4123	0.2	114	0	114	0.0	0	0	0	0.0
Sesame seeds plant	x_{22j}	430	0	430	0.0	4533	1.2	4533	0.9	879	0.1	879	0.0	5991	1.9	5991	1.9	375	0.2	375	0.2
Total	x_{ij}	1782537	100	3771272.2	100	371697	100	516805.67	100	1167404	100	17704441	100	314159	100	315611.8	100	186314	100	190741.5	100

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5.4.2 MIWGP Model for 2002 Data

The implementation of the proposed MIWGP model with the embedded MIW to improve crops production in five different zones is successfully done based on the formulation (4.62) and MIW in (5.4). The results are presented in in Table 5.20.

Overall, all crops productions have increased to about 6.9 million tonne based on the MIWGP model as summarized in Table 5.19. Table 5.20 further shows the actual and recommended productions for each of the 20 strategic crops in the five zones after the MIWGP model was run with the 2002 data. For example, in Ninevah zone the actual production and the recommended production of wheat reveals that the wheat still continues to be the primary crops but at lower level (42.4%) compared with 49.9% by using MIWGP. The results show that the most important crops after wheat are potatoes with 824054 tonne (21.3%), barley with 539334 tonne (13.9%) and pepper with 512193 tonne (13.2%). It is observed that the improvement is only in the production of potatoes (21.3%) and pepper (13.2%) as compared with actual production of 2.4% and 0.1%, respectively.

Besides, the implementation of the MIWGP model indicates that wheat is the basic and the main production in the all zones. The results from the proposed MIWGP model show that the recommended productions of crops which are wheat, potatoes, lettuce, pepper, rice and corn are generally capable of achieving the demands through higher recommended productions for 2002 data. Therefore, for wheat and pepper, the recommended productions are not too high, only 0.7 tonne more than the actual demand for wheat, and only 0.229 tonne more than the actual demand for pepper. Other crops are achieved with exact demand without any increment. The formulation and results of the proposed MIWGP model are shown in Appendix C4.

Table 5.19

Total Actual and Recommended Productions with MIWGP Model for 2002 Data

Crops	**Actual Production**	**Recommended Production with MIWGP**
Wheat	1308417	2984117
Barley	617941	917941
Onions	88161	88161
Potatoes	757811	1017484
Lettuce	2449	41238
Carrot	24416	24416
Tomatoes	271442	380618
Mash	5353	51353
Pepper	62637	632637
Green Beans	73206	73206
Rice	114013	228019
String Beans	46163	46163
Garlic	2449	2449
Squash	101242	101242
Cucumber	187774	187774
Millet	2116	2136
Corn	113867	113867
Sunflower	5487	5487
Cotton	24959	24959
Sesame seeds plant	12208	12208
Total	3822111	6935475

Table 5.20

Recommended Productions Based on the MIWGP for 2002 Data

Zones		Ninevah				Al-Anbar				Baghdad				Al-Qadisiya				Maysan			
		Production in Tonne																			
Crops	variables	Actual Production	Percentage	Recommended Production with MIWGP	Percentage	Actual Production	Percentage	Recommended Production with MIWGP	Percentage	Actual Production	Percentage	Recommended Production with MIWGP	Percentage	Actual Production	Percentage	Recommended Production with MIWGP	Percentage	Actual Production	Percentage	Recommended Production with MIWGP	Percentage
Wheat	x_{1j}	95408	53.5	1641	42.4	66997	18	27466	43.9	83583	7.2	86080	44.5	12495	39.8	124994.	39.6	78794	42.3	81874	43.2
Barley	x_{2j}	53933	30.3	5393	13.9	1760	0.5	1760	0.3	4493	0.4	30449	15.7	50884	16.2	50884	16.1	21470	11.5	21470	11.3
Onions	x_{3j}	8811	0.5	8811	0.2	43864	11.8	43864	7	29761	2.5	29761	1.5	5660	1.8	5660	1.8	65	0	65	0
Potatoes	x_{4j}	42186	2.4	8240	21.3	14624	39.3	14624	23.4	56887	48.7	46682	2.4	29	0	29	0	477	0.3	477	0.3
Lettuce	x_{5j}	466	0	466	0	806	0.2	806	0.1	594	0.1	39383	2	520	0.2	520	0.2	63	0	63	0
Carrot	x_{6j}	336	0	336	0	16569	4.5	16569	2.6	7175	0.6	7175	0.4	248	0.1	248	0.1	88	0	88	0
Tomatoes	x_{7j}	17550	9.8	2846	7.4	2253	0.6	2253	0.4	90161	7.7	90161	4.7	2495	0.8	2495	0.8	1030	0.6	1030	0.5
Mash	x_{8j}	4	0	4	0	1390	0.4	47390	7.6	1245	0.1	1245	0.1	2294	0.7	2294	0.7	420	0.2	420	0.2
Pepper	x_{9j}	2130	0.1	5121	13.2	4654	1.3	4654	0.7	55142	4.7	11365	5.9	377	0.1	1801.22	0.6	334	0.2	334	0.2
Green Beans	x_{10j}	8163	0.5	8163	0.2	8483	2.3	8483	1.4	40682	3.5	40682	2.1	941	0.3	941	0.3	14937	8	14937	7.9
Rice	x_{11j}	351	0	351	0	264	0.1	264	0	8348	0.7	12235	6.3	10157	32.3	101571	32.2	3479	1.9	3479	1.8
String Beans	x_{12j}	380	0	380	0	9284	2.5	9284	1.5	32793	2.8	32793	1.7	1113	0.4	1113	0.4	2593	1.4	2593	1.4
Garlic	x_{13j}	466	0	466	0	806	0.2	806	0.1	594	0.1	594	0	520	0.2	520	0.2	63	0	63	0
Squash	x_{14j}	1932	0.1	1932	0	15461	4.2	15461	2.5	81155	7	81155	4.2	2492	0.8	2492	0.8	202	0.1	202	0.1
Cucumber	x_{15j}	10323	0.6	1032	0.3	34128	9.2	34128	5.5	99721	8.5	99721	5.2	4863	1.5	4863	1.5	38739	20.8	38739	20.5
Millet	x_{16j}	0	0	0	0	780	0.2	780	0.1	557	0	577	0	746	0.2	746	0.2	33	0	33	0
Corn	x_{19j}	17747	1	1774	0.5	11300	3	11300	1.8	53813	4.6	53813	2.8	8168	2.6	8168	2.6	22839	12.3	22839	12.1
Sunflower	x_{20j}	96	0	96	0	1196	0.3	1196	0.2	3708	0.3	3708	0.2	174	0.1	174	0.1	313	0.2	313	0.2
Cotton	x_{21j}	19795	1.1	1979	0.5	927	0.2	927	0.1	4123	0.4	4123	0.2	114	0	114	0	0	0	0	0
Sesame seeds plant	x_{22j}	430	0	430	0	4533	1.2	4533	0.7	879	0.1	879	0	5991	1.9	5991	1.9	375	0.2	375	0.2
Total	x_{ij}	17825	100	3871	100	37169	100	62536	100	11674	100	19337	100	31415	100	315618.	100	18631	100	18939	100

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5.5 Implementation of Proposed Models with 2010 Data

In this section, the implementation of proposed models MIWFGP and MIWGP are done with 2010 data. The performance of the novel MIW method is tested in the implementation of the two models but with other set of data.

5.5.1 MIWFGP Model for 2010 Data

The implementation of the proposed MIWFGP model with the embedded MIW to improve crops production in five different zones is successfully done based on the formulation (4.58) and MIW in (5.4). The results are presented in in Table 5.22.

Overall, all crops productions have increased to about 17.6 million tonne based on the MIWFGP model as summarized in Table 5.21. Table 5.22 further shows the actual and recommended productions for each of the 20 strategic crops in the five zones after the MIWFGP model was run with the 2010 data. For example, in Ninevah zone the actual production of wheat was 689731 tonne (49.1%), followed by barley was 594437 tonne (42.3%) and potatoes were 42418 tonne (3%). However, the recommended production with MIWFGP model for wheat is 2202209 tonne (71.4%) and barley is 594437 tonne (19.3%). Also, it can be noted that the recommended productions of rice was increased with tangible increment from 67 tonne (0.0%) to 128444 tonne (4.2%) under the proposed MIWGP model.

As a summary from Table 5.22, the most notable changes after implementation of the proposed MIWFGP model are the increment of wheat production in zones

Ninevah, Al-Anbar, and Baghdad, while the production of wheat in Al-Qadisiya and Maysan have decreased in comparison with that of potatoes.

The recommended productions of potatoes are increased from 46682 tonne (6.6%), to 606032.9 tonne (34.7%) in Al-Qadisiya and from 477 tonne (0.2%), to 267586 tonne (53.6%) in Maysan. The results from the proposed MIWFGP model show that the recommended productions of all crops are generally capable of achieving the demands, which in fact, most of the productions are higher than demands for 2010 data, except for four crops. Therefore, for carrot and sesame seeds plant the productions achieved exactly the same with their respective demands. The results of the proposed MIWFGP model are shown in Appendix D2.

Table 5.21
Total Actual and Recommended Productions with MIWFGP Model for 2010 Data

Crops	Actual Production	Recommended Production with MIWGP
Wheat	1133778	11808848
Barley	683007	2272395
Onions	65593	178453
Potatoes	230236	1070188
Lettuce	95194	156371
Carrot	31343	24416
Tomatoes	379824	163462
Mash	1536	18237
Pepper	109252	1149423
Green Beans	86745	70350
Rice	16793	204458
String Beans	99948	61771
Garlic	2523	21249
Squash	187759	100360
Cucumber	248137	209595
Millet	1927	2180
Corn	133169	82124
Sunflower	3531	33470
Cotton	1052	13852
Sesame seeds plant	5054	4620
Total	3516401	17645822

Table 5.22

Recommended Productions Based on the MIWFGP for 2010 Data

Zones		**Ninevah**				**Al-Anbar**				**Baghdad**				**Al-Qadisiya**				**Maysan**			
		Production in Tonne																			
Crops	variables	Actual Production	Percentage	Recommended Production with MIWFGP	Percentage	Actual Production	Percentage	Recommended Production with MIWFGP	Percentage	Actual Production	Percentage	Recommended Production with MIWFGP	Percentage	Actual Production	Percentage	Recommended Production with MIWFGP	Percentage	Actual Production	Percentage	Recommended Production with MIWFGP	Percentage
Wheat	x_{1j}	689731	49.1	2202209	71.4	164745	35.8	1185267	53.8	98941	13.9	8114961	46	98941	13.9	218426	12.39	81420	35.9	87985	17.6
Barley	x_{2j}	594437	42.3	594437	19.3	5422	1.2	715741.50	32.5	8142	1.1	304493	17.2	8142	1.1	590859.5	33.53	66864	29.5	66864	13.4
Onions	x_{3j}	22473	1.6	22473	0.7	22680	4.9	22680	1.0	9541	1.3	29761	1.7	9541	1.3	102181	5.80	1358	0.6	1358	0.3
Potatoes	x_{4j}	42418	3	55910.17	1.8	93977	20.4	93977	4.3	46682	6.6	46682	2.6	46682	6.6	606032.9	34.39	477	0.2	267586	53.6
Lettuce	x_{5j}	1100	0.1	1100	0.0	10692	2.3	10692	0.5	39383	5.5	39383	2.2	39383	5.5	100560	5.71	4636	2	4636	0.9
Carrot	x_{6j}	336	0	0	0.0	16569	3.6	17153	0.8	7175	1	7175	0.4	7175	1	0	0.00	88	0	88	0
Tomatoes	x_{7j}	15502	1.1	15502	0.5	33117	7.2	33117	1.5	162262	22.8	90161	5.1	162262	22.8	18001	1.02	6681	2.9	6681	1.3
Mash	x_{8j}	4	0	16714	0.5	1390	0.3	0.00	0.0	28	0	1245	0.1	28	0	192	0.01	86	0	86	0
Pepper	x_{9j}	6217	0.4	6217	0.2	6063	1.3	0.00	0.0	48381	6.8	1136545	6.4	48381	6.8	6451	0.37	210	0.1	210	0
Green Beans	x_{10j}	2822	0.2	2822	0.1	16231	3.5	16231	0.7	29646	4.2	40682	2.3	29646	4.2	2215	0.13	8400	3.7	8400	1.7
Rice	x_{11j}	67	0	128444	4.2	1566	0.3	1566	0.1	7130	1	8348	0.5	7130	1	65930	3.74	900	0.4	170	0
String Beans	x_{12j}	1731	0.1	1731	0.1	17298	3.8	17298	0.8	38120	5.3	32793	1.9	38120	5.3	5270	0.30	4679	2.1	4679	0.9
Garlic	x_{13j}	466	0	9346.481	0.3	806	0.2	10725.52	0.5	594	0.1	594	0.0	594	0.1	520	0.03	63	0	63	0
Squash	x_{14j}	3522	0.3	3522	0.1	14927	3.2	14927	0.7	84634	11.9	81155	4.6	84634	11.9	714	0.04	42	0	42	0
Cucumber	x_{15j}	21848	1.6	21848	0.7	39963	8.7	39963	1.8	75792	10.6	99721	5.6	75792	10.6	13321	0.76	34742	15.3	34742	7
Millet	x_{16j}	0	0	0	0.0	780	0.2	824	0.0	557	0.1	577	0	557	0.1	746	0.04	33	0	33	0
Corn	x_{19j}	90	0	90	0.0	9883	2.1	9883	0.4	53590	7.5	53813	3.0	53590	7.5	2322	0.13	16016	7.1	16016	3.2
Sunflower	x_{20j}	1309	0.1	1309	0.0	1001	0.2	1001	0.0	581	0.1	3708	0.2	581	0.1	27452	1.56	59	0	0	0
Cotton	x_{21j}	34	0	34	0.0	596	0.1	9542	0.4	211	0	4123	0.2	211	0	153	0.01	0	0	0	0
Sesame seeds plant	x_{22j}	73	0	73	0.0	2606	0.6	2606	0.1	1171	0.2	879	0.0	1171	0.2	1029	0.06	33	0	33	0
Total	x_{ij}	1404180	100	3083781.7	100	460312	100	2203194.02	100	712561	100	17704441	100	712561	100	1762375.4	100	226787	100	499671	100

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5.5.2 MIWGP Model for 2010 Data

The implementation of the proposed MIWGP model with the embedded MIW to improve crops production in five different zones is successfully done based on the formulation (4.58) and MIW in (5.4).

Overall, all crops productions have increased to about 13.2 million tonne based on the MIWGP model as summarized in Table 5.23. Table 5.24 further shows the actual and recommended productions for each of the 20 strategic crops in the five zones after the MIWGP model was run with the 2010 data. For example, in Ninevah the recommended productions of onions are 2034591 tonne (39.9%), wheat is 1896048 tonne (37.2%), barley is 594437 tonne (11.7%), rice is 455385 tonne (8.9%).

It can be observed that the implementation of the proposed MIWGP model in the first zone could improve the recommended production of crops like onions, lettuce, and rice. Also, in Al Anbar the recommended productions of wheat is 1491428 tonne (42.5%),tomatoes are 777559.4 tonne (22.2%), lettuce is 497900.6 tonne (14.2%), barley is 466396.8 tonne (13.3%), potatoes are 93977 tonne (2.7%), while the crops for tomatoes and lettuce have been increased considerably.

In Baghdad, Al-Qadisiya, and Maysan the recommended productions of potatoes are recorded as 113784.7 tonne (14.7%), 6537558.8tonne (13.3%), and 267586 tonne (53.6%), respectively. Furthermore, the recommended production of wheat in Al-Qadisiya is 218426 tonne (5.4 %), and in Maysan 87984.9 tonne (17.6%).

The results from the proposed MIWGP model show that the recommended productions of wheat, barley, onions, potatoes, lettuce, tomatoes, rice, squash and sunflower are generally capable of achieving the demands, which in fact, the productions are higher than demands for 2010 data. Other crops are achieved with exact demand without any increment. The results of the proposed MIWGP model are shown in Appendix D4.

Table 5.23

Total Actual and Recommended Productions with MIWGP Model for 2010 Data

Crops	Actual Production	Recommended Production with MIWGP
Wheat	1253263	3786263
Barley	806044	1976044
Onions	58233	2070351
Potatoes	183893	1046620
Lettuce	55811	543019.6
Carrot	24168	24416
Tomatoes	235563	3301381
Mash	1700	17020
Pepper	60871	61259
Green Beans	59314	59314
Rice	75593	523051
String Beans	67098	67098
Garlic	2449	21249
Squash	103839	103839
Cucumber	185666	185666
Millet	2116	2160
Corn	81901	81901
Sunflower	2950	30343
Cotton	994	9940
Sesame seeds plant	4912	4912
Total	3266378	13915846.8

Table 5.24

Recommended Productions Based on the MIWGP for 2010 Data

Zones		Ninevah				Al-Anbar				Baghdad				Al-Qadisiya				Maysan			
		Production in Tonne																			
Crops	variables	Actual Production	Percentage	Recommended Production with MIWGP	Percentage	Actual Production	Percentage	Recommended Production with MIWGP	Percentage	Actual Production	Percentage	Recommended Production with MIWGP	Percentage	Actual Production	Percentage	Recommended Production with MIWGP	Percentage	Actual Production	Percentage	Recommended Production with MIWGP	Percentage
Wheat	x_{1j}	689731	49.1	1896048	37.2	164745	35.8	1491428	42.5	98941	13.9	98941	12.8	218426	47.2	218426	5.4	81420	35.9	87984.92	17.6
Barley	x_{2j}	594437	42.3	594437	11.7	5422	1.2	466396.8	13.3	8142	1.1	8142	1.1	131179	28.4	840204.2	20.8	66864	29.5	66864	13.4
Onions	x_{3j}	22473	1.6	2034591	39.9	22680	4.9	22680	0.6	9541	1.3	9541	1.2	2181	0.5	2181	0.1	1358	0.6	1358	0.3
Potatoes	x_{4j}	42418	3.0	42418	0.8	93977	20.4	93977	2.7	46682	6.6	113784.7	14.7	339	0.1	537558.8	13.3	477	0.2	267585.5	53.6
Lettuce	x_{5j}	1100	0.1	1100	0.0	10692	2.3	497900.6	14.2	39383	5.5	39383	5.1	0	0.0	0	0.0	4636	2.0	4636	0.9
Carrot	x_{6j}	336	0.0	0	0.0	16569	3.6	17153	0.5	7175	1.0	7175	0.9	0	0.0	0	0.0	88	0.0	88	0.0
Tomatoes	x_{7j}	15502	1.1	15502	0.3	33117	7.2	777559.4	22.2	162262	22.8	162262	21.0	18001	3.9	2339377	58.0	6681	2.9	6681	1.3
Mash	x_{8j}	4	0.0	16714	0.3	1390	0.3	0	0.0	28	0.0	28	0.0	192	0.0	192	0.0	86	0.0	86	0.0
Pepper	x_{9j}	6217	0.4	6217	0.1	6063	1.3	0	0.0	48381	6.8	48381	6.3	0	0.0	6451	0.2	210	0.1	210	0.0
Green Beans	x_{10j}	2822	0.2	2822	0.1	16231	3.5	16231	0.5	29646	4.2	29646	3.8	2215	0.5	2215	0.1	8400	3.7	8400	1.7
Rice	x_{11j}	67	0.0	455385	8.9	1566	0.3	1566	0.0	7130	1.0	0	0.0	65930	14.3	65930	1.6	900	0.4	170	0.0
String Beans	x_{12j}	1731	0.1	1731	0.0	17298	3.8	17298	0.5	38120	5.3	38120	4.9	5270	1.1	5270	0.1	4679	2.1	4679	0.9
Garlic	x_{13j}	466	0.0	751.1592	0.0	806	0.2	806	0.0	594	0.1	594	0.1	520	0.1	520	0.0	63	0.0	63	0.0
Squash	x_{14j}	3522	0.3	3522	0.1	14927	3.2	14927	0.4	84634	11.9	84634	11.0	714	0.2	714	0.0	42	0.0	42	0.0
Cucumber	x_{15j}	21848	1.6	21848	0.4	39963	8.7	39963	1.1	75792	10.6	75792	9.8	13321	2.9	13321	0.3	34742	15.3	34742	7.0
Millet	x_{16j}	0	0.0	0	0.0	780	0.2	780	0.0	557	0.1	557	0.1	746	0.2	790	0.0	33	0.0	33	0.0
Corn	x_{19j}	90	0.0	90	0.0	9883	2.1	9883	0.3	53590	7.5	53590	6.9	2322	0.5	2322	0.1	16016	7.1	16016	3.2
Sunflower	x_{20j}	1309	0.1	1309	0.0	1001	0.2	28453	0.8	581	0.1	581	0.1	0	0.0	0	0.0	59	0.0	0	0.0
Cotton	x_{21j}	34	0.0	34	0.0	596	0.1	9542	0.3	211	0.0	211	0.0	153	0.0	153	0.0	0	0.0	0	0.0
Sesame seeds	x_{22j}	73	0.0	73	0.0	2606	0.6	2606	0.1	1171	0.2	1171	0.2	1029	0.2	1029	0.0	33	0.0	33	0.0
Total	x_{ij}	1404180	100	5094592	100.0	460312	100	3509149.8	100.0	712561	100	772533.7	100	462538	100	4036654	100	226787	100	499671.42	100.0

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5.6 Results of Production for Agricultural Zones

This section discussed the suggested crops in detail with their percentages in each of the five zones.

5.6.1 Ninevah

The biggest agricultural zone is Ninevah with 44% of the area covered. The crops production in this zone has the most influence on total production. The results in Tables 5.18 and 5.20 show the recommended productions for each of the 20 strategic crops in this zone after the proposed MIWFGP and MIWGP models were run with the 2002 data. The actual production of wheat was 954084 tonne (53.5%), followed by barley was 539334 tonne (30.3%), tomatoes were 175503 tonne (9.85%), potatoes were 42186 tonne (2.4%), cotton was 19795 tonne (1.1%) and corn was 17747 (1%) tonne.

However, the recommended production for 2002 data with MIWFGP model for wheat is 1882447 tonne (49.9%), potatoes are 564381 tonne (15%), barley is 539334 tonne (14.3%), pepper is 431131 tonne (11.4%), and tomatoes are 284679 tonne (7.5%). The other crops constitute less than 1% production, which are corn with 17747 tonne, cotton with 19795 tonne, cucumbers with 10323 tonne, onions with 8811 tonne, green beans with 8163 tonne, squash with 1932 tonne, lettuce with 466 tonne, garlic with 466 tonne, sesame seeds plant with 430 tonne, string beans with 380 tonne, rice with 351 tonne, carrot with 336 tonne, sunflower with 96 tonne, mash with 4 tonne, and no production for millet as shown in Table 5.25.

Table 5.25

Recommended Productions Based on the MIWFGP and MIWGP models in Nineveh for 2002 Data

Zone		**Ninevah**					
		Production in Tonne					
Crops	variables	Actual Production	Percentage	Recommended Production with MIWFGP	Percentage	Recommended Production with MIWGP	Percentage
Wheat	x_{1j}	954084	53.5	1882447.0	49.9	1641781	42.4
Barley	x_{2j}	539334	30.3	539334.0	14.3	539334	13.9
Onions	x_{3j}	8811	0.5	8811.0	0.2	8811	0.2
Potatoes	x_{4j}	42186	2.4	564381.0	15.0	824054	21.3
Lettuce	x_{5j}	466	0.0	466.0	0.0	466	0.0
Carrot	x_{6j}	336	0.0	336.0	0.0	336	0.0
Tomatoes	x_{7j}	175503	9.8	284679.0	7.5	284679	7.4
Mash	x_{8j}	4	0.0	4.0	0.0	4	0.0
Pepper	x_{9j}	2130	0.1	431131.2	11.4	512192.9	13.2
Green Beans	x_{10j}	8163	0.5	8163.0	0.216	8163	0.2
Rice	x_{11j}	351	0.0	351.0	0.009	351	0.0
String Beans	x_{12j}	380	0.0	380.0	0.010	380	0.0
Garlic	x_{13j}	466	0.0	466.0	0.012	466	0.0
Squash	x_{14j}	1932	0.1	1932.0	0.1	1932	0.0
Cucumber	x_{15j}	10323	0.6	10323.0	0.3	10323	0.3
Millet	x_{16j}	0	0.0	0.0	0.0	0	0.0
Corn	x_{19j}	17747	1.0	17747.0	0.5	17747	0.5
Sunflower	x_{20j}	96	0.0	96.0	0.0	96	0.0
Cotton	x_{21j}	19795	1.1	19795.0	0.5	19795	0.5
Sesame seeds plant	x_{22j}	430	0.0	430.0	0.0	430	0.0
Total	x_{ij}	1782537	100	3771272.2	100	3871340.9	100

Moreover, the recommended production for 2002 data with MIWGP model for wheat is 1641781 tonne (42.4%), potatoes are 824054 tonne (21.3%), barley is 539334 tonne (13.9%), pepper are 512193 tonne (13.2%), and tomatoes are 284679 tonne (7.4%). Other crops constitute less than 1% production, which are corn with 17747, cotton with 19795 tonne, cucumber with 10323 tonne, onions with 8811 tonne, green beans with 8163 tonne, squash with 1932 tonne, lettuce with 466 tonne, garlic with 466 tonne, sesame seeds plant with 430 tonne, string beans with 380 tonne, rice with 351 tonne, carrot with 336 tonne, sunflower with 96 tonne, mash with 4 tonne and no production for millet as shown in Table 5.25.

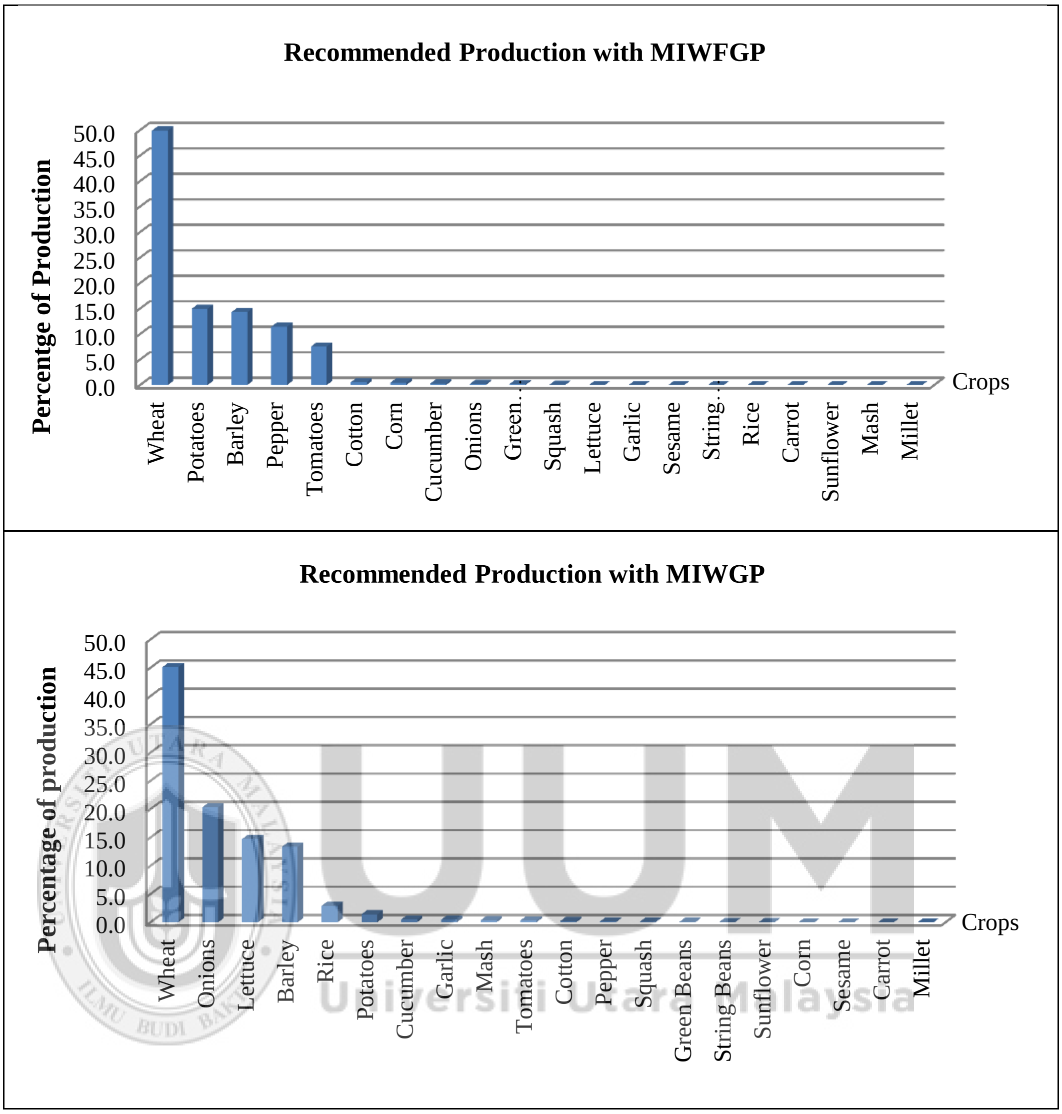

Figure 5.3. Recommended crops productions in Nineveh 2002

Furthermore, Figure 5.3 shows the recommended productions as based on DMs' suggestions which focus on some of the crops that have high to be planted in this zone. These crops are wheat, potatoes, barley, pepper and onions, which can improve the overall crops productions in Iraq. Based on the results, the proposed MIWFGP model is considered an efficient tool for crops production planning.

Similarly, Tables 5.22 and 5.24 show the recommended productions for each of the 20 strategic crops in this zone after the MIWFGP and MIWGP models were run with the 2010 data. The actual production of wheat was 689731 tonne (49.1%), followed by barley was 594437 tonne (42.3%), potatoes were 42418 tonne (3%), onions were 22473 tonne (1.6%), cucumber was 19795 tonne (1.6%) and tomatoes were 175503 tonne (1.1%) as shown in Table 5.26.

However, the recommended production for 2010 data with MIWFGP model for wheat is 2202209 tonne (71%), barley is 594437 tonne (19%), rice is 128444 tonne (4%), potatoes are 55910.17 (1.8). The other crops constitute less than 1% production, which are onions with 22473 tonne, cucumber with 21848 tonne, tomatoes with 15502 tonne, mash with 16714 tonne, garlic with 9346.481 tonne, pepper with 6217 tonne, green beans with 2822 tonne, string beans with 1731 tonne, squash with 3522 tonne, lettuce with 1100 tonne, corn with 90 tonne, sunflower with 1309 tonne, cotton with 34 tonne, sesame seeds plant with 73 tonne and no production for carrot and millet as shown in Table 5.26.

Table 5.26

Recommended Productions Based on the MIWFGP and MIWGP models in Nineveh for 2010 Data

Zone	Ninevah						
	Production in Tonne						
Crops	variables	Actual Production	Percentage	Recommended Production with MIWFGP	Percentage	Recommended Production with MIWGP	Percentage
Wheat	x_{1j}	689731	49.1	2202209	71.4	1896048	37.2
Barley	x_{2j}	594437	42.3	594437	19.3	594437	11.7
Onions	x_{3j}	22473	1.6	22473	0.7	2034591	39.9
Potatoes	x_{4j}	42418	3.0	55910.17	1.8	42418	0.8
Lettuce	x_{5j}	1100	0.1	1100	0.0	1100	0.0
Carrot	x_{6j}	336	0.0	0	0.0	0	0.0
Tomatoes	x_{7j}	15502	1.1	15502	0.5	15502	0.3
Mash	x_{8j}	4	0.0	16714	0.5	16714	0.3
Pepper	x_{9j}	6217	0.4	6217	0.2	6217	0.1
Green Beans	x_{10j}	2822	0.2	2822	0.1	2822	0.1
Rice	x_{11j}	67	0.0	128444	4.2	455385	8.9
String Beans	x_{12j}	1731	0.1	1731	0.1	1731	0.0
Garlic	x_{13j}	466	0.0	9346.481	0.3	751.1592	0.0
Squash	x_{14j}	3522	0.3	3522	0.1	3522	0.1
Cucumber	x_{15j}	21848	1.6	21848	0.7	21848	0.4
Millet	x_{16j}	0	0.0	0	0.0	0	0.0
Corn	x_{19j}	90	0.0	90	0.0	90	0.0
Sunflower	x_{20j}	1309	0.1	1309	0.0	1309	0.0
Cotton	x_{21j}	34	0.0	34	0.0	34	0.0
Sesame seeds plant	x_{22j}	73	0.0	73	0.0	73	0.0
Total	x_{ij}	1782537	100	3771272.2	100	5094592	100.0

Moreover, the recommended production for 2010 data with MIWGP model for onions are 2034591 tonne (39.9%), wheat is 1896048 tonne (37.2%), barley is 594437 tonne (11.7%), rice is 455385 tonne (8.9%), potatoes are 42418 tonne (1%) as shown in Table 5.22 and Figure 5.4. Other crops constitute less than 1% production, which are cucumber with 21848 tonne, mash with16714 tonne, tomatoes with 15502 tonne, pepper with 6217 tonne, squash with 3522 tonne, green beans with 2822 tonne, string beans with 1731 tonne, sunflower with 1309 tonne, lettuce with 1100 tonne, garlic with 751.1592 tonne, corn with 90 tonne, sesame with 73 tonne, cotton with 34 tonne, and no production for carrot and millet as shows in Table 5.26.

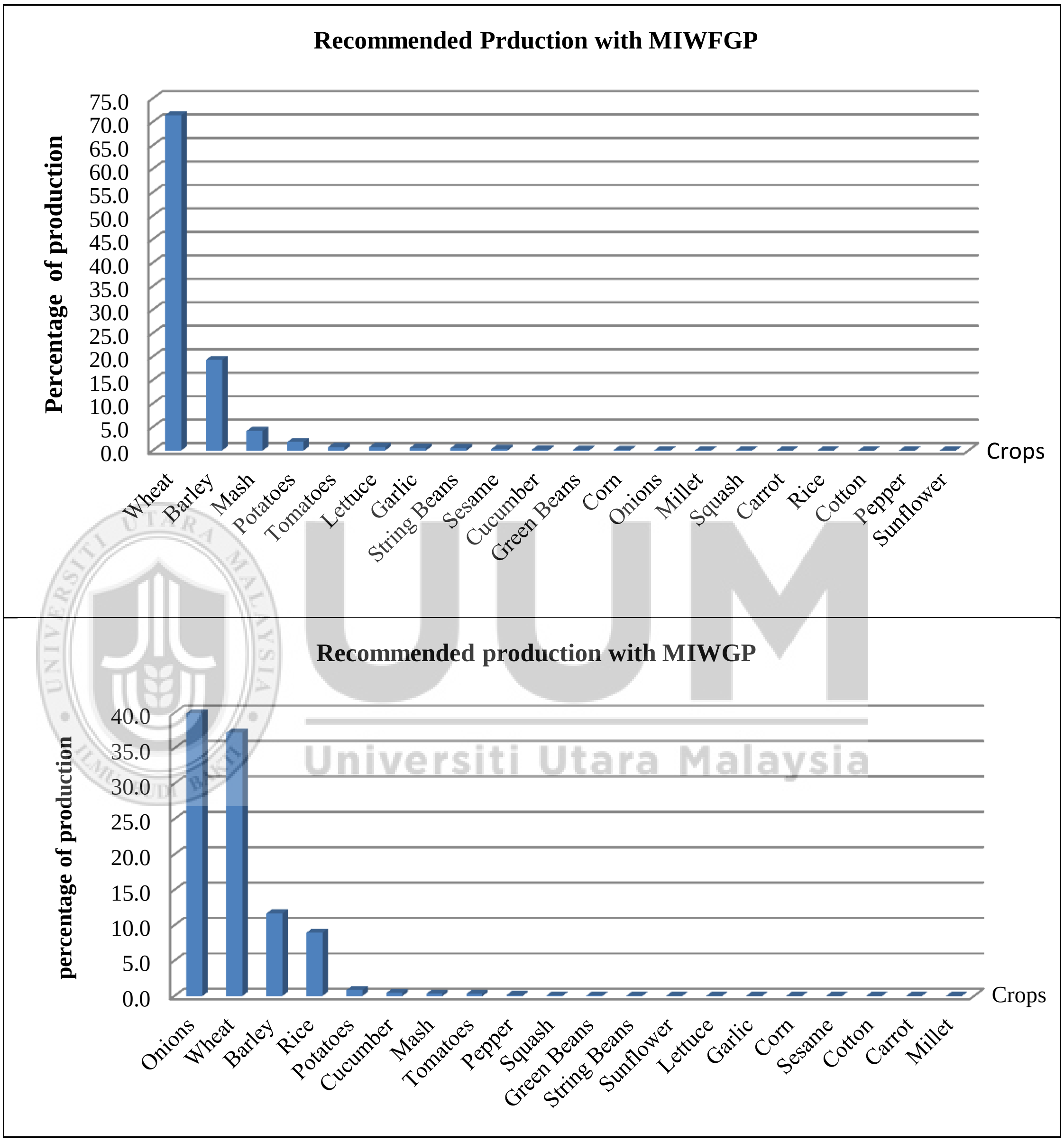

Figure 5.4. Recommended crops productions in Nineveh 2010

Furthermore, Figure 5.4 shows the recommended productions as based on DMs' suggestions which focus on some of the crops that have high to be planted in this zone. These crops are onions, wheat, barley, potatoes, cucumber, mash and tomatoes, which can improve the overall crops productions in Iraq. Based on the results, the proposed MIWFGP model is considered an efficient tool for crops production planning.

5.6.2 Al-Anbar

This zone has desert crops and experienced the main changes in terms of crops production. The results in Tables 5.18 and 5.20 show the recommended productions for each of the 20 strategic crops in this zone after the proposed MIWFGP and MIWGP models were run with the 2002 data. The actual production of potatoes were 146242 tonne (39.3%),wheat was 66997 tonne (18%), onions were 43864 tonne (11.8%), cucumber was 34128 tonne (9.2%), carrot was 16569 tonne (4.5%), squash was 15461 tonne (4.2%), corn was 11300 tonne (3%), string beans were 9284 tonne (2.5%), green beans were 8483 tonne (2.3%), pepper was 4654 tonne (1.3%) and sesame seeds plant were 4533 tonne (1.2%).

However, the recommended production for 2002 data with MIWFGP model for potatoes are 146242 tonne (28.3%), wheat is 86420.03 tonne (16.7%), pepper is 84339.64 tonne (16.3%), mash is 47390 tonne (9.2%), onions are 43864 tonne (8.5%), cucumber is 34128 tonne (6.6%), carrot is 16569 tonne (3.2%), squash is 15461 tonne (3%), corn is 11300 tonne (2.2%), string beans are 9284 tonne (1.8%), green beans are 8483 tonne (1.6%), sesame seeds plant are 4533 tonne (1%). Other crops constitute less than 1% production, which are tomatoes with 2253 tonne, barley with 1760 tonne, sunflower with 1196 tonne, cotton with 927 tonne, lettuce with 806 tonne, garlic with 806 tonne, millet with 780 tonne and rice with 264 tonne as shown in Table 5.27.

Table 5.27

Recommended Productions Based on the MIWFGP and MIWGP models in Al-Anbar for 2002 Data

Zone		Al-Anbar					
		Production in Tonne					
Crops	variables	Actual Production	Percentage	Recommended Production with MIWFGP	Percentage	Recommended Production with MIWGP	Percentage
Wheat	x_{1j}	66997	18.024628	86420.03	16.721959	274664.7	43.9
Barley	x_{2j}	1760	0.5	1760.00	0.34	1760.00	0.3
Onions	x_{3j}	43864	11.8	43864.00	8.49	43864.00	7.0
Potatoes	x_{4j}	146242	39.3	146242.00	28.30	146242.00	23.4
Lettuce	x_{5j}	806	0.2	806.00	0.16	806.00	0.1
Carrot	x_{6j}	16569	4.5	16569.00	3.21	16569.00	2.6
Tomatoes	x_{7j}	2253	0.6	2253.00	0.44	2253.00	0.4
Mash	x_{8j}	1390	0.4	47390.00	9.17	47390.00	7.6
Pepper	x_{9j}	4654	1.3	84339.64	16.32	4654.00	0.7
Green Beans	x_{10j}	8483	2.3	8483.00	1.64	8483.00	1.4
Rice	x_{11j}	264	0.1	264.00	0.05	264.00	0.0
String Beans	x_{12j}	9284	2.5	9284.00	1.80	9284.00	1.5
Garlic	x_{13j}	806	0.2	806.00	0.16	806.00	0.1
Squash	x_{14j}	15461	4.2	15461.00	2.99	15461.00	2.5
Cucumber	x_{15j}	34128	9.2	34128.00	6.60	34128.00	5.5
Millet	x_{16j}	780	0.2	780.00	0.15	780.00	0.1
Corn	x_{19j}	11300	3.0	11300.00	2.19	11300.00	1.8
Sunflower	x_{20j}	1196	0.3	1196.00	0.23	1196.00	0.2
Cotton	x_{21j}	927	0.2	927.00	0.18	927.00	0.1
Sesame seeds plant	x_{22j}	4533	1.2	4533.00	0.88	4533.00	0.7
Total		371697	100	516805.67	100	625364.70	100

Moreover, the recommended production for 2002 data with MIWGP model for wheat is 274664.7 tonne (43.9%), potatoes are 146242 tonne (23.4%), mash is 47390 tonne (7.6%), onions are 43864 tonne (7.0%), cucumber is 34128 tonne (5.5%), carrot is 16569 tonne (2.6%), squash is 15461 tonne (2.5%), corn is 11300 tonne (1.8%), string beans are 9284 tonne (1.5%), green beans are 8483 tonne (1.4%), pepper is 4654 tonne (1%) and sesame seeds plant are 4533 tonne (1%). Other crops constitute less than 1% production, which are tomatoes with 2253 tonne, barley with 1760 tonne, sunflower with 1196 tonne, cotton with 927 tonne, lettuce with 806 tonne, garlic with 806 tonne, millet with 780 tonne and rice with 264 tonne. as shown in Table 5.27.

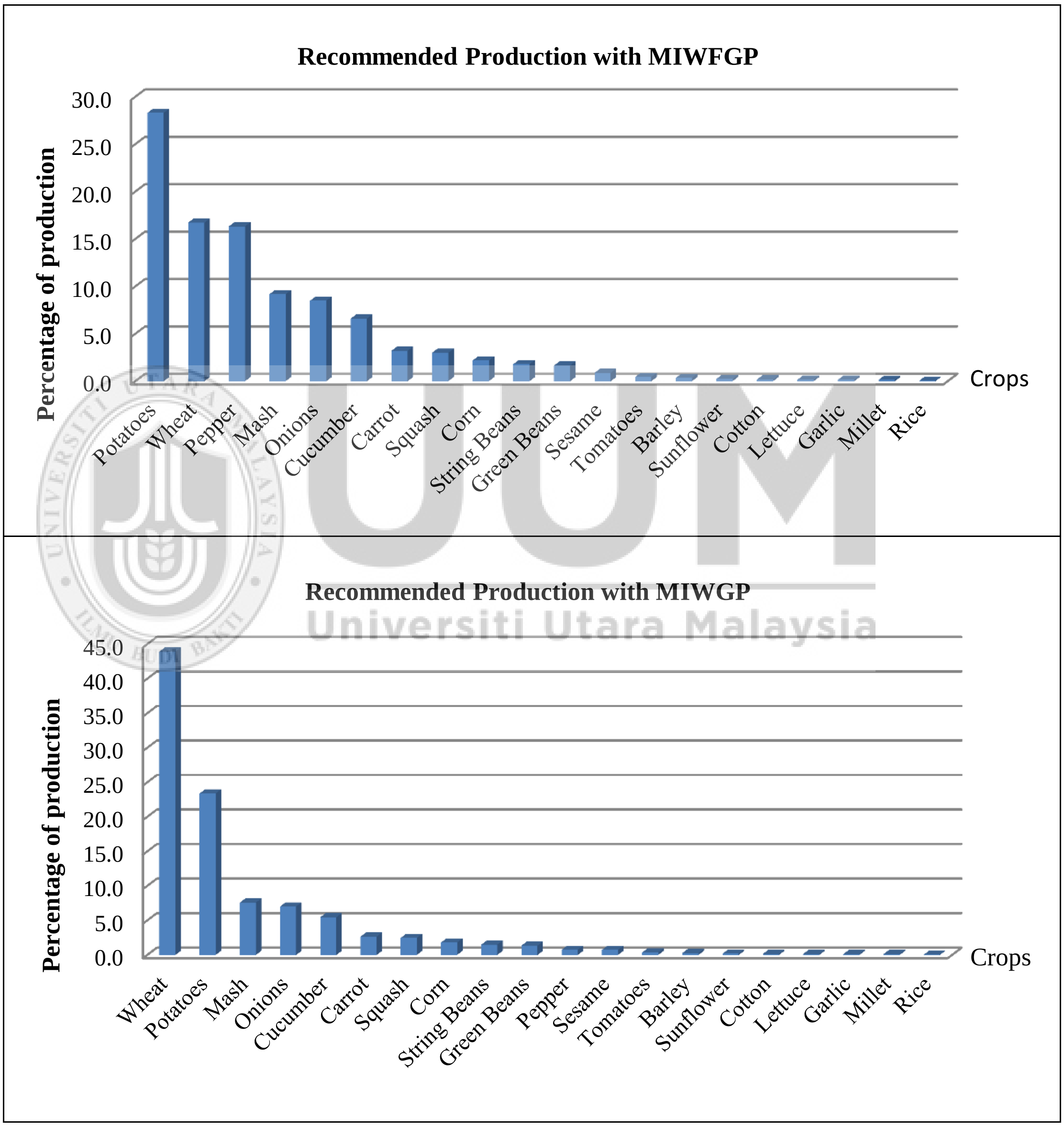

Figure 5.5. Recommended crops productions in Al-Anbar 2002

Furthermore, Figure 5.5 shows the recommended productions as based on DMs' suggestions which focus on some of the crops that have high to be planted in this zone. These crops are wheat, potatoes are, mash, onions, cucumber, carrot, squash, corn and string beans which can improve the overall crops productions in Iraq.

Similarly, Tables 5.22 and 5.24 show the recommended productions for each of the 20 strategic crops in this zone after the MIWFGP and MIWGP models were run with the 2010 data. The actual production of wheat was 164745 tonne (35.8%), potatoes were 93977 tonne (20.4%), cucumber was 39963 tonne (8.7%), tomatoes were 33117 tonne (7.2%), onions were 22680 tonne (4.9%), string beans were 17298 tonne (3.8%), carrot was 16569 tonne (3.6%), green beans were 16231 tonne (3.5%), squash was 14927 tonne (3%), lettuce was 10692 tonne (2%), corn was 9883 tonne (2%), pepper was 6063 (1%) and barley was 5422 (1%) as shown in Table 5.28.

However, the recommended production for 2010 data with MIWFGP model for wheat is 1185267 tonne (53.8%), barley is 15741.5 tonne (32.5%), potatoes are 93977 tonne (4.3%), cucumber is 39963 tonne (1.8%), tomatoes are 33117 tonne (1.5%), onions are 22680 tonne (1%), string beans are 17298 tonne (1%), carrot is 17153 tonne (1%), green beans are 16231 tonne (1%), squash is 14927 tonne (1%), garlic is 10725.52 tonne (1%), lettuce is 10692 tonne (1%). The other crops constitute less than 1% production, which are corn with 9883 tonne, cotton with 9542 tonne, sesame seeds plant with 2606 tonne, rice with 1566 tonne, and no production for mash and pepper as shown in Table 5.28.

Table 5.28

Recommended Productions Based on the MIWFGP and MIWGP models in Al-Anbar for 2010 Data

Zone		**Al-Anbar**					
		Production in Tonne					
Crops	variables	Actual Production	Percentage	Recommended Production with MIWFGP	Percentage	Recommended Production with MIWGP	Percentage
Wheat	x_{1j}	164745	35.8	1185267.00	53.8	1491428	42.5
Barley	x_{2j}	5422	1.2	715741.50	32.5	466396.8	13.3
Onions	x_{3j}	22680	4.9	22680.00	1.0	22680	0.6
Potatoes	x_{4j}	93977	20.4	93977.00	4.3	93977	2.7
Lettuce	x_{5j}	10692	2.3	10692.00	0.5	497900.6	14.2
Carrot	x_{6j}	16569	3.6	17153.00	0.8	17153	0.5
Tomatoes	x_{7j}	33117	7.2	33117.00	1.5	777559.4	22.2
Mash	x_{8j}	1390	0.3	0.0	0.0	0	0.0
Pepper	x_{9j}	6063	1.3	0.0	0.0	0	0.0
Green Beans	x_{10j}	16231	3.5	16231.00	0.7	16231	0.5
Rice	x_{11j}	1566	0.3	1566.00	0.1	1566	0.0
String Beans	x_{12j}	17298	3.8	17298.00	0.8	17298	0.5
Garlic	x_{13j}	806	0.2	10725.52	0.5	806	0.0
Squash	x_{14j}	14927	3.2	14927.00	0.7	14927	0.4
Cucumber	x_{15j}	39963	8.7	39963.00	1.8	39963	1.1
Millet	x_{16j}	780	0.2	824.00	0.0	780	0.0
Corn	x_{19j}	9883	2.1	9883.00	0.4	9883	0.3
Sunflower	x_{20j}	1001	0.2	1001.00	0.0	28453	0.8
Cotton	x_{21j}	596	0.1	9542.00	0.4	9542	0.3
Sesame seeds plant	x_{22j}	2606	0.6	2606.00	0.1	2606	0.1
Total	x_{ij}	460312	100	2203194.02	100	3509149.8	100.0

Moreover, the recommended production for 2010 data with MIWGP model for wheat is1491428 tonne (42.5%),tomatoes are 777559.4 tonne (22.2%), lettuce is 497900.6 tonne (14.2%), barley is 466396.8 tonne (13.3%), potatoes are 93977 tonne (2.7%), cucumber is 39963 tonne (1.1%), sunflower is 28453 tonne (1%), onions are 22680 tonne (1%), string beans are 17298 tonne (1%), carrot is 17153 tonne (1%), green beans are 16231 tonne (1%). Other crops constitute less than 1% production, which are squash with 14927 tonne, corn with 9883 tonne, cotton with 9542 tonne, sesame with 2606 tonne, rice with 1566 tonne, garlic with 806 tonne, millet with 780 tonne, and no production for mash and pepper as shows in Table 5.28.

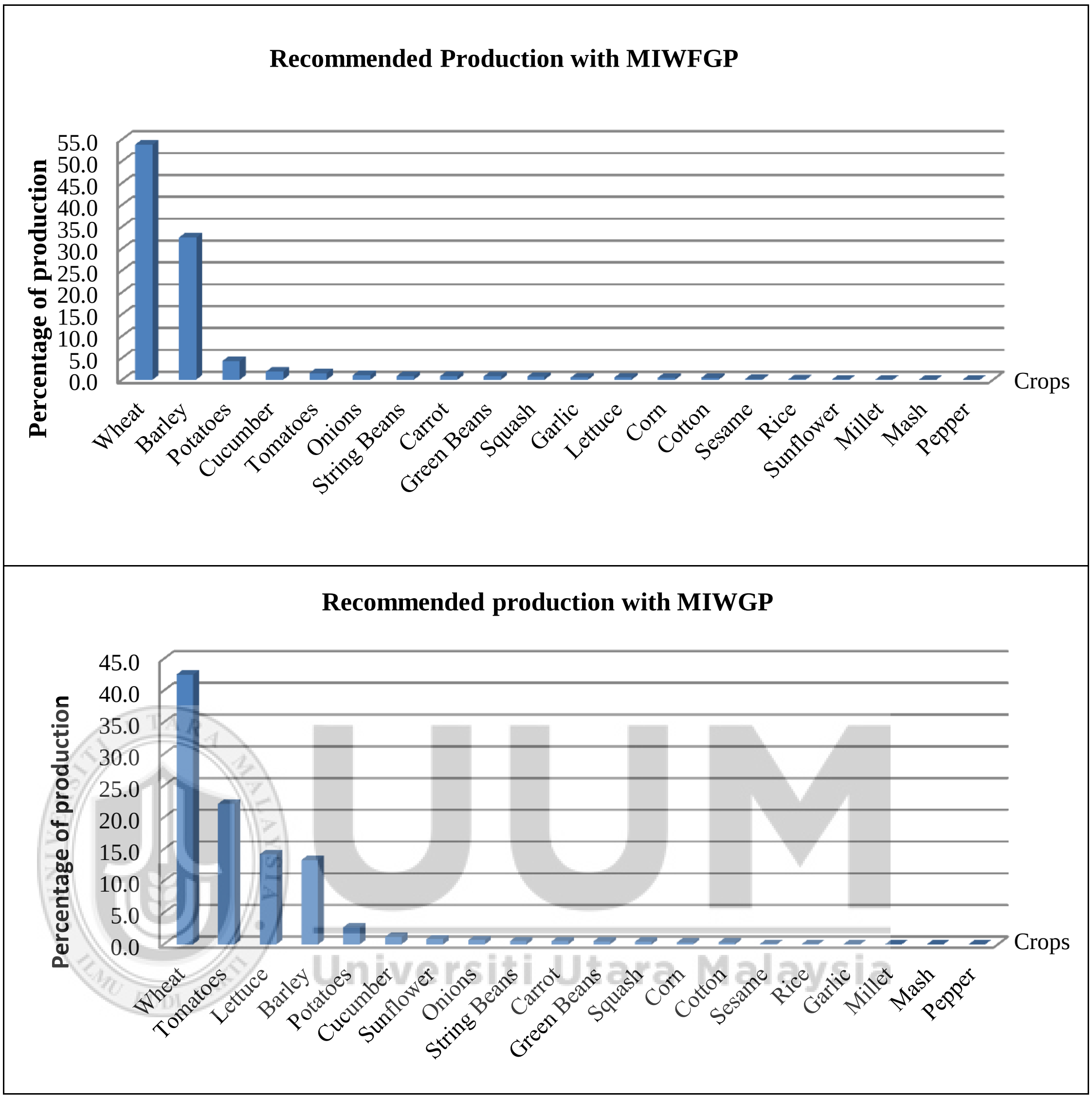

Figure 5.6. Recommended crops productions in Al-Anbar 2010

Furthermore, Figure 5.6 shows the recommended productions as based on DMs' suggestions which focus on some of the crops that have high to be planted in this zone. These crops are wheat, tomatoes, barley, lettuce and potatoes which can improve the overall crops productions in Iraq. Based on the results, the proposed MIWFGP and MIWGP models are considered as efficient tools for crops production planning.

5.6.3 Baghdad

The middle zone represented by Baghdad the capital city of Iraq. The results in Tables 5.18 and 5.20, show the recommended productions for each of the 20 strategic crops in this zone after the proposed MIWFGP and MIWGP models were run with the 2002 data. The actual production of potatoes were 568877 tonne (48.7%), cucumber was 99721 tonne (8.5%),tomatoes were 90161 tonne (7.7%), wheat was 83583 tonne (7.2%), squash was 81155 tonne (7%), pepper was 55142 tonne (4.7%), corn was 53813 tonne (4.6%), green beans were 40682 tonne (3.5%), string beans were 32793 tonne (2.8%), onions were 29761 tonne (2.5%), rice was 8348 tonne (1%) and carrot was 7175 tonne (1%).

However, the recommended production for 2002 data with MIWFGP model for wheat is 8114961 tonne (46%), pepper is 1136545 tonne (6.4%), barley is 304493 tonne (17.2%), cucumber is 99721 tonne (5.6%), tomatoes are 90161 tonne (5.1%), squash is 81155 tonne (4.6%), corn is 53813 tonne (3%), potatoes are 46682 tonne (2.6%), green beans are 40682 tonne (2.3%), lettuce is 39383 tonne (2.2%), string beans are 32793 tonne (1.9%) and onions are 29761 tonne (1.7%). The other crops constitute less than 1% production, which are rice with 8348 tonne (1%), carrot with 7175 tonne, cotton with 4123 tonne, sunflower with 3708 tonne, mash with 1245 tonne, sesame seeds plant with 879 tonne, garlic with 594 tonne, millet with 577 tonne as shown in Table 5.29.

Table 5.29

Recommended Production Based on the MIWFGP and MIWGP models in Baghdad for 2002 Data

Zone		**Baghdad**					
		Production in Tonne					
Crops	variables	Actual Production	Percentage	Recommended Production with MIWFGP	Percentage	Recommended Production with MIWGP	Percentage
Wheat	x_{1j}	83583	7.2	8114961	46	860803	44.5
Barley	x_{2j}	4493	0.4	304493	17.2	304493	15.7
Onions	x_{3j}	29761	2.5	29761	1.7	29761	1.5
Potatoes	x_{4j}	568877	48.7	46682	2.6	46682	2.4
Lettuce	x_{5j}	594	0.1	39383	2.2	39383	2.0
Carrot	x_{6j}	7175	0.6	7175	0.4	7175	0.4
Tomatoes	x_{7j}	90161	7.7	90161	5.1	90161	4.7
Mash	x_{8j}	1245	0.1	1245	0.1	1245	0.1
Pepper	x_{9j}	55142	4.7	1136545	6.4	113654.9	5.9
Green Beans	x_{10j}	40682	3.5	40682	2.3	40682	2.1
Rice	x_{11j}	8348	0.7	8348	0.5	122354.1	6.3
String Beans	x_{12j}	32793	2.8	32793	1.9	32793	1.7
Garlic	x_{13j}	594	0.1	594	0	594	0.0
Squash	x_{14j}	81155	7	81155	4.6	81155	4.2
Cucumber	x_{15j}	99721	8.5	99721	5.6	99721	5.2
Millet	x_{16j}	557	0	577	0	577	0.0
Corn	x_{19j}	53813	4.6	53813	3	53813	2.8
Sunflower	x_{20j}	3708	0.3	3708	0.2	3708	0.2
Cotton	x_{21j}	4123	0.4	4123	0.2	4123	0.2
Sesame seeds plant	x_{22j}	879	0.1	879	0	879	0.0
Total		1167404	100	17704441	100	1933757	100

Moreover, the recommended production for 2002 data with MIWGP model for wheat is 860803 tonne (44.5%), barley is 304493 tonne (15.7%), rice is 122354.1 tonne (6.3%), pepper is 113654.9 tonne (5.9%), cucumber is 99721 tonne (5.2%), tomatoes are 90161 tonne (4.7%), squash is 81155 tonne (4.2%), corn is 53813 tonne (2.8%), potatoes are 46682 tonne (2.4%), green beans are 40682 tonne (2.1%), lettuce is 39383 tonne (2.0%), string beans are 32793 tonne (1.7%), onions are 29761 tonne (1.5%). Other crops constitute less than 1% production, which are carrot with 7175 tonne, cotton with 4123 tonne, sunflower with 3708 tonne, mash with 1245 tonne, sesame seeds plant with 879 tonne, garlic with 594 tonne and millet with 577 tonne as shown in Table 5.29.

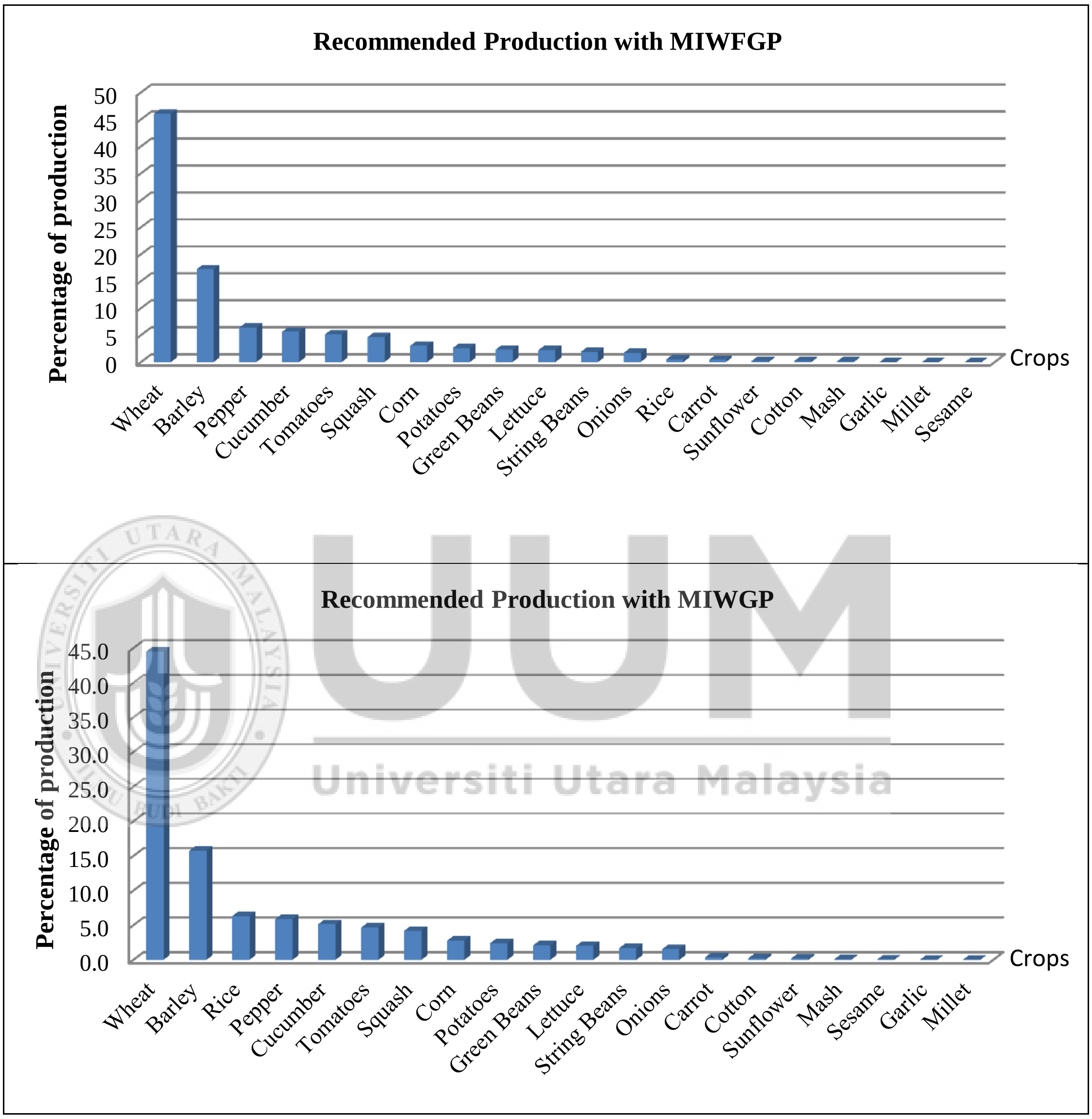

Figure 5.7. Recommended crops productions in Baghdad 2002

Furthermore, Figure 5.7 shows the recommended productions as based on DMs' suggestions which focus on some of the crops that have high to be planted in this zone. These crops are wheat, barley, rice, pepper, cucumber, tomatoes, squash, corn, potatoes, green beans, lettuce, string beans and onions which can improve the overall crops productions in Iraq. Based on the results, the proposed MIWFGP and MIWGP models are considered as efficient tools for crops production planning..

Similarly, Tables 5.22 and 5.24 show the recommended productions for each of the 20 strategic crops in this zone after the MIWFGP and MIWGP models were run with the 2010 data. The actual production of tomatoes were 162262 tonne (22.8%), wheat was 98941 tonne (13.9%), squash was 84634 tonne (11.9%), cucumber was 75792 tonne (10.6%), corn was 53590 tonne (7.5%), pepper was 48381 tonne (6.8%), potatoes were 46682 tonne (6.6%), lettuce was 39383 tonne (5.5%), string beans were 38120 tonne (5.3%), green beans were 29646 tonne (4.2%), onions were 9541 tonne (1%), barley was 8142 tonne (1%), carrot was 7175 tonne (1%), rice was 7130 tonne (1%). The other crops constitute less than 1% production, which are sesame seeds plant with 1171 tonne, garlic with 594 tonne, sunflower with 581 tonne, millet with 557 tonne, cotton with 211 tonne and mash with 28 tonne.

However, the recommended production for 2010 data with MIWFGP model for tomatoes are 162262 tonne (22.4%), potatoes are 113784.70 tonne (15.7%), wheat is 98941 tonne (13.7%), squash is 84634 tonne (11.7%), cucumber is 75792 tonne (10.5%), pepper is 48381 tonne (6.7%), lettuce is 39383 tonne (5.4%), string beans are 38120 tonne (5.3%), green beans are 29646 tonne (4.1%), onions are 9541 tonne (1.3%), barley is 8142 tonne (1.1%), carrot is 7175 tonne (1%) sesame seeds plant are 4561 tonne (1%). The other crops constitute less than 1% production, which are sunflower with 1171 tonne, garlic with 594 tonne, millet with 557 tonne, corn with 211 tonne, cotton with 211 tonne, mash with 28 tonne and no production for rice as shown in Table 5.30.

Table 5.30

Recommended Productions Based on the MIWFGP and MIWGP models in Baghdad for 2010 Data

Zone	Baghdad						
	Production in Tonne						
Crops	variables	Actual Production	Percentage	Recommended Production with MIWFGP	Percentage	Recommended Production with MIWGP	Percentage
Wheat	x_{1j}	98941	13.9	98941.00	13.7	98941	12.8
Barley	x_{2j}	8142	1.1	8142.00	1.1	8142	1.1
Onions	x_{3j}	9541	1.3	9541.00	1.3	9541	1.2
Potatoes	x_{4j}	46682	6.6	113784.70	15.7	113784.7	14.7
Lettuce	x_{5j}	39383	5.5	39383.00	5.4	39383	5.1
Carrot	x_{6j}	7175	1.0	7175.00	1.0	7175	0.9
Tomatoes	x_{7j}	162262	22.8	162262.00	22.4	162262	21.0
Mash	x_{8j}	28	0.0	28.00	0.0	28	0.0
Pepper	x_{9j}	48381	6.8	48381.00	6.7	48381	6.3
Green Beans	x_{10j}	29646	4.2	29646.00	4.1	29646	3.8
Rice	x_{11j}	7130	1.0	0.0	0.0	0	0.0
String Beans	x_{12j}	38120	5.3	38120.00	5.3	38120	4.9
Garlic	x_{13j}	594	0.1	594	0.1	594	0.1
Squash	x_{14j}	84634	11.9	84634.00	11.7	84634	11.0
Cucumber	x_{15j}	75792	10.6	75792.00	10.5	75792	9.8
Millet	x_{16j}	557	0.1	557.00	0.1	557	0.1
Corn	x_{19j}	53590	7.5	211.	0.0	53590	6.9
Sunflower	x_{20j}	581	0.1	1171	0.2	581	0.1
Cotton	x_{21j}	211	0.0	211	0.0	211	0.0
Sesame seed plant	x_{22j}	1171	0.2	4561	0.6	1171	0.2
Total		712561	100	723134.70	100	772533.7	100

Moreover, the recommended production for 2010 data with MIWGP model for tomatoes are 162262 tonne (21.0%), potatoes are 113784.7 tonne (14.7%), wheat is 98941 tonne (12.8%), squash is 84634 tonne (11.0%), cucumber is 75792 tonne (9.8%), corn is 53590 tonne (6.9%), pepper is 48381 tonne (6.3%), lettuce is 39383 tonne (5.1%), string beans are 38120 tonne (4.9%), green beans are 29646 tonne (3.8%), onions are 9541 tonne (1.2%), barley is 8142 (1.1%) and carrot is 7175 (1%). Other crops constitute less than 1% production, which are sesame seeds plant with 1171 tonne, garlic with 594 tonne, sunflower with 581 tonne, millet with 557 tonne, cotton with 211 tonne, mash with 28 tonne and no production for rice as shown in Table 5.30.

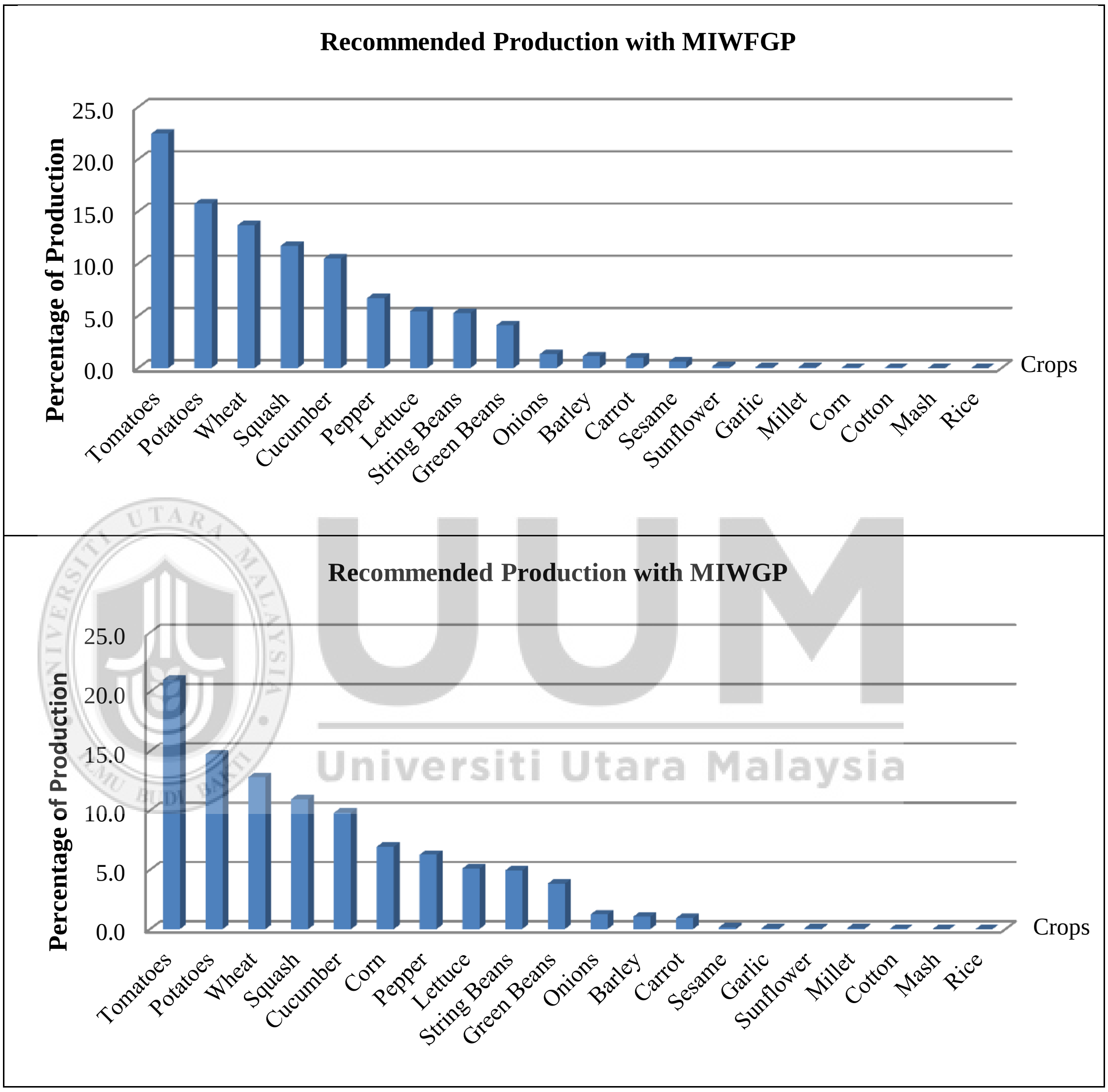

Figure 5.8. Recommended crops productions in Baghdad 2010

Furthermore, Figure 5.8 shows the recommended productions as based on DMs' suggestions which focus on some of the crops that have high to be planted in this zone. These crops are tomatoes, potatoes, wheat, squash, cucumber, pepper, lettuce, string beans, green beans, onions, barley, carrot and sesame seeds plant which can improve the overall crops productions in Iraq.

5.6.4 Al-Qadisiya

This section discussed the suggestion crops of Al-Qadisiya. The results in Tables 5.18 and 5.20 show the recommended productions for each of the 20 strategic crops in this zone after the proposed MIWFGP and MIWGP models were run with the 2002 data. The actual production of wheat was 124959 tonne (39.8%), followed by rice was 101571 tonne (32.3%), barley was 50884 tonne (16.2%), corn was 8168 tonne (2.6%), sesame seeds plant were 5991 tonne (1.9%), onions were 5660 tonne (1.8%), cucumber was 4863 tonne (1.5%), tomatoes were 2495 tonne (1%), squash was 2492 tonne (1%) and mash was 2294 tonne (16.2%).

However, the recommended production for 2002 data with MIWFGP model for wheat is 124959 tonne (39.6%), rice is 101571 tonne (32.2%), barley is 50884 tonne (16.1%), corn is 8168 tonne (2.6%), sesame seeds plant are 5991 tonne (1.9%), onions are 5660 tonne (1.8%), cucumber is 4863 tonne (1.5%), tomatoes are 2495 tonne (1%), squash is 2492 tonne (1%), mash is 2294 tonne (1%), pepper is 1829.8 tonne (1%). Other crops constitute less than 1% production, which are string beans with 1113 tonne, green beans with 941 tonne, millet with 746 tonne, lettuce with 520 tonne, garlic with 520 tonne, carrot with 248 tonne, sunflower with 174 tonne, cotton with 114 tonne and potatoes with 29 tonne as shown in Table 5.31.

Table 5.31

Recommended Productions Based on the MIWFGP and MIWGP models in Al-Qadisiya for 2002 Data

Zones		**Al-Qadisiya**					
		Production in Tonne					
Crops	variables	Actual Production	Percentage	Recommended Production with MIWFGP	Percentage	Recommended Production with MIWGP	Percentage
Wheat	x_{1j}	124959	39.8	124959	39.6	124994.7	39.6
Barley	x_{2j}	50884	16.2	50884.0	16.1	50884	16.1
Onions	x_{3j}	5660	1.8	5660.0	1.8	5660	1.8
Potatoes	x_{4j}	29	0.0	29.0	0.0	29	0.0
Lettuce	x_{5j}	520	0.2	520.0	0.2	520	0.2
Carrot	x_{6j}	248	0.1	248.0	0.1	248	0.1
Tomatoes	x_{7j}	2495	0.8	2495.0	0.8	2495	0.8
Mash	x_{8j}	2294	0.7	2294.0	0.7	2294	0.7
Pepper	x_{9j}	377	0.1	1829.8	0.6	1801.229	0.6
Green Beans	x_{10j}	941	0.3	941.0	0.3	941	0.3
Rice	x_{11j}	101571	32.3	101571.0	32.2	101571	32.2
String Beans	x_{12j}	1113	0.4	1113.0	0.4	1113	0.4
Garlic	x_{13j}	520	0.2	520.0	0.2	520	0.2
Squash	x_{14j}	2492	0.8	2492.0	0.8	2492	0.8
Cucumber	x_{15j}	4863	1.5	4863.0	1.5	4863	1.5
Millet	x_{16j}	746	0.2	746.0	0.2	746	0.2
Corn	x_{19j}	8168	2.6	8168.0	2.6	8168	2.6
Sunflower	x_{20j}	174	0.1	174.0	0.1	174	0.1
Cotton	x_{21j}	114	0.0	114.0	0.0	114	0.0
Sesame	x_{22j}	5991	1.9	5991.0	1.9	5991	1.9
Total		314159	100	315611.8	100	315618.93	100

Moreover, the recommended production for 2002 data with MIWGP model for wheat is 124994.7 tonne (39.6%), rice is 101571 tonne (32.2%), barley is 50884 tonne (16.1%), corn is 8168 tonne (2.6%), sesame seeds plant is 5991 tonne (1.9%), onions are 5660 tonne (1.8%), cucumber is 4863 tonne (1.5%), tomatoes are 2495 tonne (1%), squash is 2492 tonne (1%), mash is 2294 tonne (1%) and pepper is 1829.2 tonne (1%). Other crops constitute less than 1% production, which are string beans with 1113 tonne, green beans with 941 tonne, millet with 746 tonne, lettuce with 520 tonne, garlic with 520 tonne, carrot with 248 tonne, sunflower with 174 tonne, cotton with 114 tonne, potatoes with 29 tonne as shown in Table 5.31.

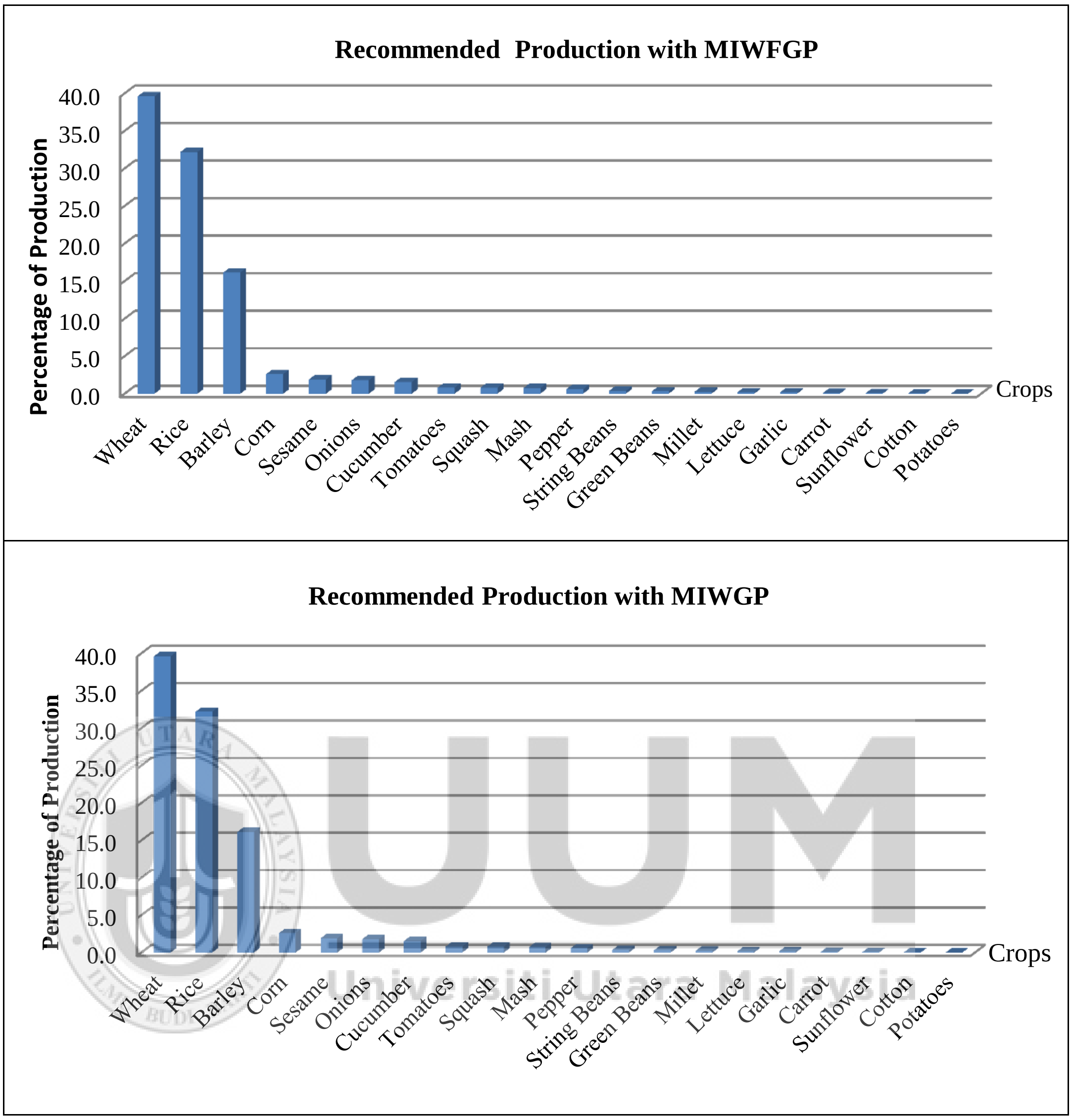

Figure 5.9. Recommended crops productions in Al-Qadisiya 2002

Furthermore, Figure 5.9 shows the recommended productions as based on DMs' suggestions which focus on some of the crops that have high to be planted in this zone. These crops are wheat, rice, barley, corn, sesame, onions, cucumber, tomatoes, squash, mash and pepper, which can improve the overall crops productions in Iraq.

Similarly, Tables 5.22 and 5.24 show the recommended productions for each of the 20 strategic crops in this zone after the MIWFGP and MIWGP models were run with the 2010 data. The actual crops production of wheat was 689731 tonne (49.1%), followed by barley was 594437 tonne (42.3%), potatoes were 42418 tonne (3%), onions were 22473 tonne (1.6%), cucumber was 19795 tonne (1.6%) and tomatoes were 175503 tonne (1.1%).

However, the recommended production for 2010 data with MIWFGP model for potatoes are 606032.9 tonne (34.4%), barley is 590859.5 tonne (33.5%), wheat is 218426 tonne (12.4%), onions are 102181 tonne (5.8%), lettuce is 100560 tonne (5.7%), rice is 65930 tonne (3.7%) and sunflower is 27452 tonne (1%). Other crops constitute less than 1% production, which are tomatoes with 18001 tonne, cucumber with 13321 tonne, pepper with 6451 tonne, string beans with 5270 tonne, corn with 2322 tonne, green beans with 2215 tonne, sesame seeds plant with 1029 tonne, millet with 746 tonne, squash with 714 tonne, garlic with 520 tonne, mash with 192 tonne, cotton with 153 tonne and no production for carrot as shown in Table 5.32.

Table 5.32

Recommended Productions Based on the MIWFGP and MIWGP models in Al-Qadisiya for 2010 Data

Zone		Al-Qadisiya					
		Production in Tonne					
Crops	variables	Actual Production	Percentage	Recommended Production with MIWFGP	Percentage	Recommended Production with MIWGP	Percentage
Wheat	x_{1j}	218426	47.2	218426	12.4	218426	5.4
Barley	x_{2j}	131179	28.4	590859.5	33.5	840204.2	20.8
Onions	x_{3j}	2181	0.5	102181	5.8	2181	0.1
Potatoes	x_{4j}	339	0.1	606032.9	34.4	537558.8	13.3
Lettuce	x_{5j}	0	0.0	100560	5.7	0	0.0
Carrot	x_{6j}	0	0.0	0	0.0	0	0.0
Tomatoes	x_{7j}	18001	3.9	18001	1.0	2339377	58.0
Mash	x_{8j}	192	0.0	192	0.0	192	0.0
Pepper	x_{9j}	0	0.0	6451	0.4	6451	0.2
Green Beans	x_{10j}	2215	0.5	2215	0.1	2215	0.1
Rice	x_{11j}	65930	14.3	65930	3.7	65930	1.6
String Beans	x_{12j}	5270	1.1	5270	0.3	5270	0.1
Garlic	x_{13j}	520	0.1	520	0.0	520	0.0
Squash	x_{14j}	714	0.2	714	0.0	714	0.0
Cucumber	x_{15j}	13321	2.9	13321	0.8	13321	0.3
Millet	x_{16j}	746	0.2	746	0.0	790	0.0
Corn	x_{19j}	2322	0.5	2322	0.1	2322	0.1
Sunflower	x_{20j}	581	0.1	1171.00	0.2	0	0.0
Cotton	x_{21j}	211	0.0	211.00	0.0	153	0.0
Sesame seeds plant	x_{22j}	1171	0.2	4561.00	0.6	1029	0.0
Total		712561	100.0	723134.70	100	4036654	100

Moreover, the recommended production for 2010 data with MIWGP model for tomatoes are 2373412 tonne (58%), barley is 712788.7 tonne (20.8%), potatoes are 571486.3 tonne (13.3%), wheat is 218426 tonne (5.4%) and rice is 65930 tonne (1.6%). Other crops constitute less than 1% production, which are cucumber with 13321 tonne, pepper with 6451 tonne, string beans with 5270 tonne, corn with 2322 tonne, green beans with 2215 tonne, onions with 2181 tonne, sesame seeds plant with 1029 tonne, millet with 790 tonne, squash with 714 tonne, garlic with 520 tonne, mash with 192 tonne, cotton with 153 tonne, and no production for lettuce, carrot and sunflower as shown in Table 5.32..

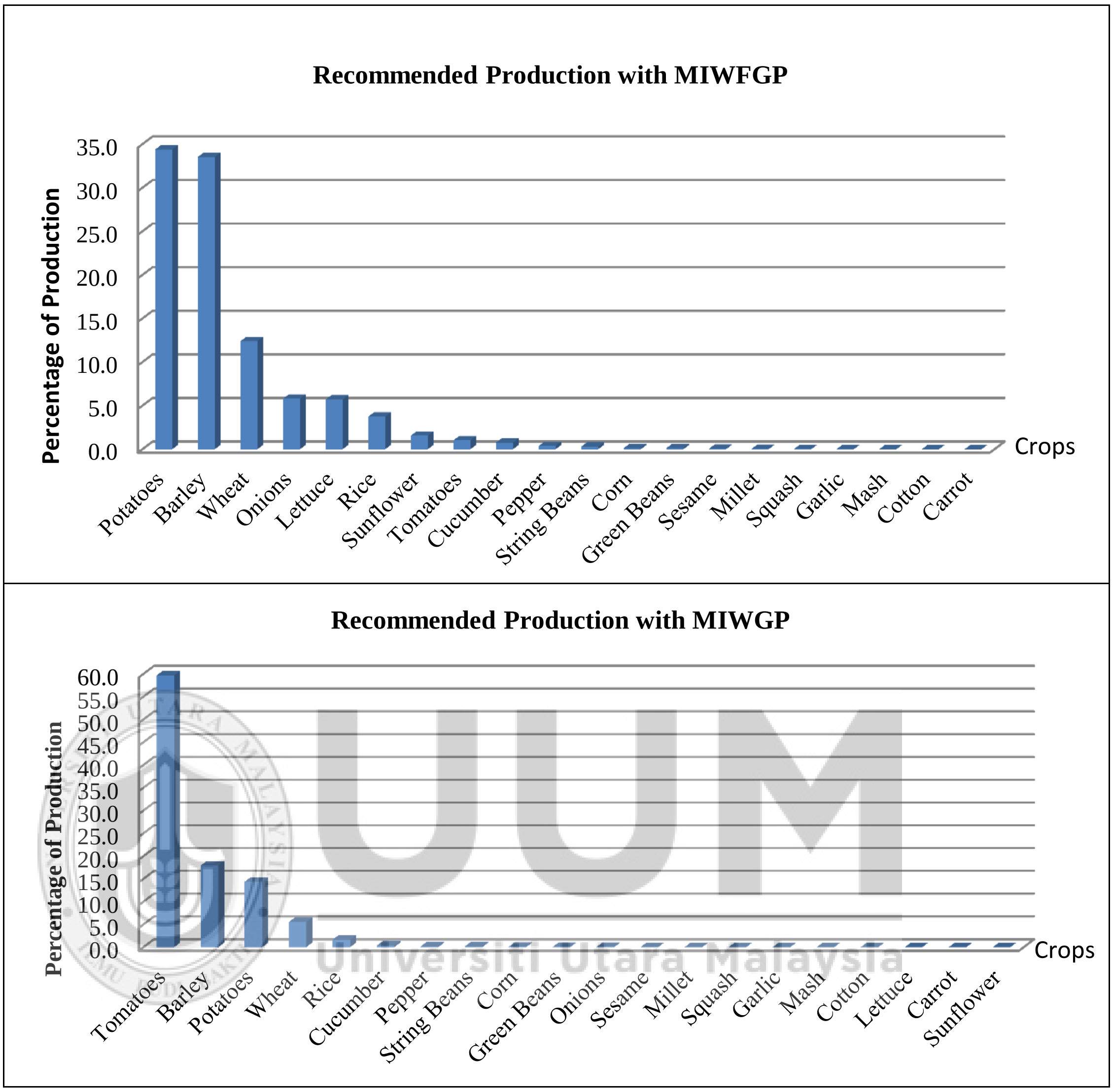

Figure 5.10. Recommended crops productions in Al-Qadisiya 2010

Furthermore, Figure 5.10 shows the recommended productions as based on DMs' suggestions which focus on some of the crops that have high to be planted in this zone. These crops are potatoes, barley, wheat, lettuce, pepper and sunflower, tomatoes and rice, which can improve the overall crops productions in Iraq.

5.6.5 Maysan

This section discussed the suggestion crops of Maysan. The results in Tables 5.18 and 5.20 show the recommended productions for each of the 20 strategic crops in this zone after the proposed MIWFGP and MIWGP models were run with the 2002 data. It is appeared that no big improvement in the production which can be observed, it mean the agriculture planning for this zone to year 2002 introduced as the optimality in their using of resources use and planted suitable crops for this zone.

The actual production of wheat was 78794 tonne (42.3%), followed by cucumber was 38739 tonne (20.8%), corn was 22839 tonne (12.3%), barley was 21470 tonne (11.5%), green beans were 14937 tonne (8%), rice was 3479 tonne (2%), string beans were 2593 (1%) tonne and tomatoes were 1030 tonne (1%).

However, the recommended production for 2002 data with MIWFGP model presented an improvement for wheat with 81874 tonne (42.9%) and pepper with 1681.5 tonne (0.9%), while other crops have the same amount of production and no production for cotton as shown in Table 5.33.

Table 5.33

Recommended Productions Based on the MIWFGP and MIWGP models in Maysan for 2002 Data

Zone		**Maysan**					
		Production in Tonne					
Crops	variables	Actual Production	Percentage	Recommended Production with MIWFGP	Percentage	Recommended Production with MIWGP	Percentage
Wheat	x_{1j}	78794	42.3	81874.0	42.9	81874	43.2
Barley	x_{2j}	21470	11.5	21470.0	11.3	21470	11.3
Onions	x_{3j}	65	0.0	65.0	0.0	65	0.0
Potatoes	x_{4j}	477	0.3	477.0	0.3	477	0.3
Lettuce	x_{5j}	63	0.0	63.0	0.0	63	0.0
Carrot	x_{6j}	88	0.0	88.0	0.0	88	0.0
Tomatoes	x_{7j}	1030	0.6	1030.0	0.5	1030	0.5
Mash	x_{8j}	420	0.2	420.0	0.2	420	0.2
Pepper	x_{9j}	334	0.2	1681.5	0.9	334	0.2
Green Beans	x_{10j}	14937	8.0	14937.0	7.8	14937	7.9
Rice	x_{11j}	3479	1.9	3479.0	1.8	3479	1.8
String Beans	x_{12j}	2593	1.4	2593.0	1.4	2593	1.4
Garlic	x_{13j}	63	0.0	63.0	0.0	63	0.0
Squash	x_{14j}	202	0.1	202.0	0.1	202	0.1
Cucumber	x_{15j}	38739	20.8	38739.0	20.3	38739	20.5
Millet	x_{16j}	33	0.0	33.0	0.0	33	0.0
Corn	x_{19j}	22839	12.3	22839.0	12.0	22839	12.1
Sunflower	x_{20j}	313	0.2	313.0	0.2	313	0.2
Cotton	x_{21j}	0	0.0	0.0	0.0	0	0.0
Sesame seeds plant	x_{22j}	375	0.2	375.0	0.2	375	0.2
Total		186314	100	190741.5	100	189394	100

Moreover, the recommended production for 2002 data with MIWGP model presented an improvement for wheat production with 81874 tonne (43.2%), while other crops have the same amount of production and no production for cotton as shown in Table 5.33.

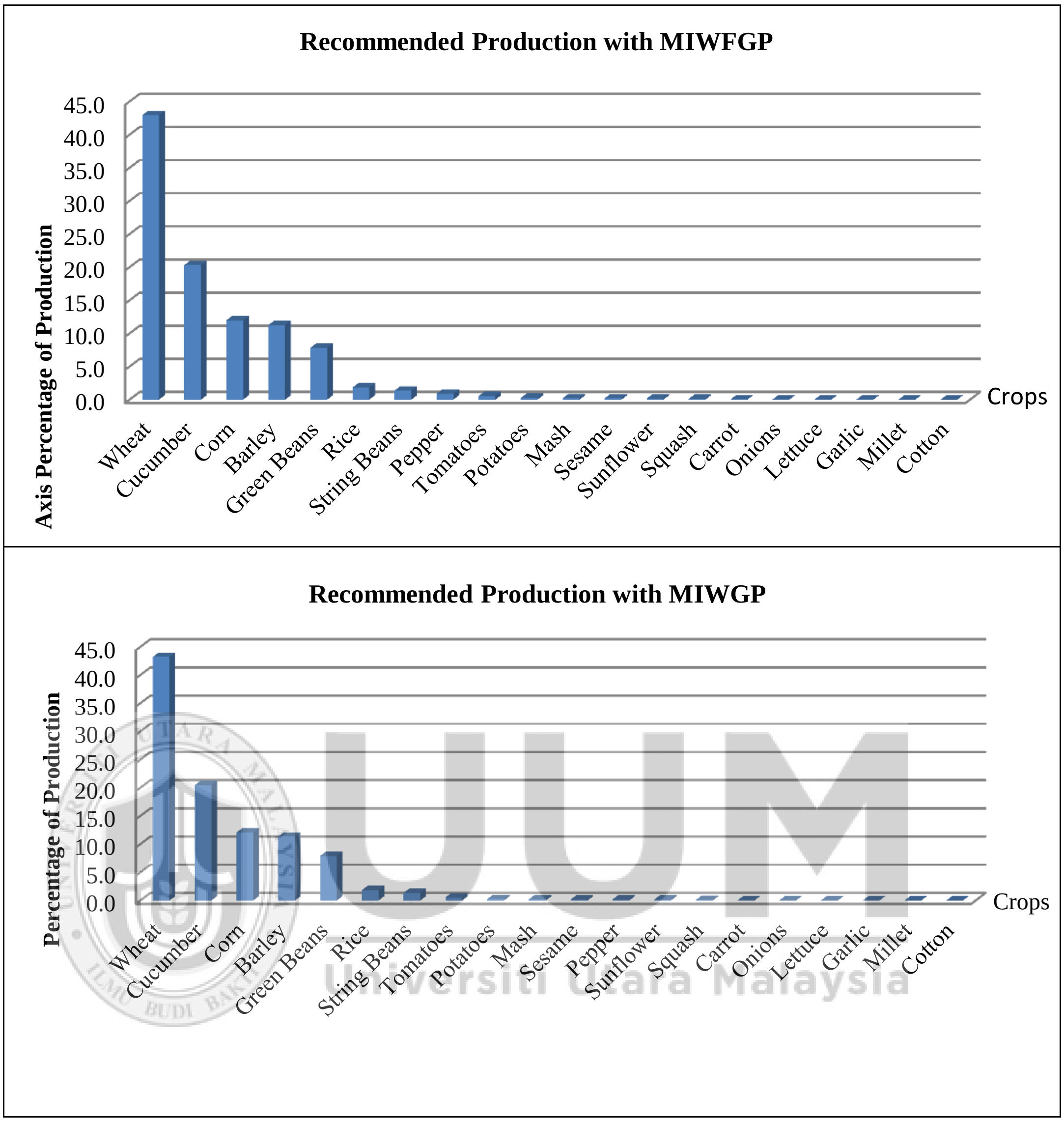

Figure 5.11. Recommended crops production after improvement in Maysan 2002

Furthermore, Figure 5.11 shows the recommended productions as based on DMs' suggestions which focus on some of the crops that have high to be planted in this zone. These crops are wheat, cucumber, corn, barley, green beans and rice, which can improve the overall crops productions in Iraq.

Similarly, Tables 5.22 and 5.24 show the recommended productions for each of the 20 strategic crops in this zone after the MIWFGP and MIWGP models were run with the 2010 data. The actual production of wheat was 81420 tonne (35.9%), barley was 66864 tonne (29.5%), cucumber was 34742 tonne (15.3%), corn was 16016 tonne (7.1%), green beans were 8400 tonne (3.7%), tomatoes were 6681 tonne (2.9%), string beans were 4679 tonne (2.1%), lettuce was 3479 tonne (2%) and onions was tonne (1%) as shown in Table 5.34.

However, the recommended production for 2010 data with MIWFGP model presented an improvement for potatoes with 268598.3 tonne (54.2%), while other crops have the same amount of production and no production for sunflower and cotton as shown in Table 5.34.

Table 5.34

Recommended Productions Based on the MIWFGP and MIWGP model in Maysan for 2010 Data

Zones		**Maysan**					
		Production in Tonne					
Crops	variables	Actual Production	Percentage	Recommended Production with MIWFGP	Percentage	Recommended Production with MIWGP	Percentage
Wheat	x_{1j}	81420	35.9	81420	16.4	87984.92	17.6
Barley	x_{2j}	66864	29.5	66864	13.5	66864	13.4
Onions	x_{3j}	1358	0.6	1358	0.3	1358	0.3
Potatoes	x_{4j}	477	0.2	268598.3	54.2	267585.5	53.6
Lettuce	x_{5j}	4636	2.0	4636	0.9	4636	0.9
Carrot	x_{6j}	88	0.0	88	0.0	88	0.0
Tomatoes	x_{7j}	6681	2.9	6681	1.3	6681	1.3
Mash	x_{8j}	86	0.0	86	0.0	86	0.0
Pepper	x_{9j}	210	0.1	210	0.0	210	0.0
Green Beans	x_{10j}	8400	3.7	8400	1.7	8400	1.7
Rice	x_{11j}	900	0.4	1680	0.3	170	0.0
String Beans	x_{12j}	4679	2.1	4679	0.9	4679	0.9
Garlic	x_{13j}	63	0.0	63	0.0	63	0.0
Squash	x_{14j}	42	0.0	42	0.0	42	0.0
Cucumber	x_{15j}	34742	15.3	34742	7.0	34742	7.0
Millet	x_{16j}	33	0.0	33	0.0	33	0.0
Corn	x_{19j}	16016	7.1	16016	3.2	16016	3.2
Sunflower	x_{20j}	59	0.0	0	0.0	0	0.0
Cotton	x_{21j}	0	0.0	0	0.0	0	0.0
Sesame	x_{22j}	33	0.0	33	0.0	33	0.0
Total		226787	226787.0	495629.3	100.0	499671.42	100.0

Moreover, the recommended production for 2010 data with MIWGP model presented an improvement for potatoes with 267585.5 tonne (53.6%) and wheat with 87984.92 tonne (17.6%), while other crops have the same amount of production and no production for sunflower and cotton as shown in Table 5.34.

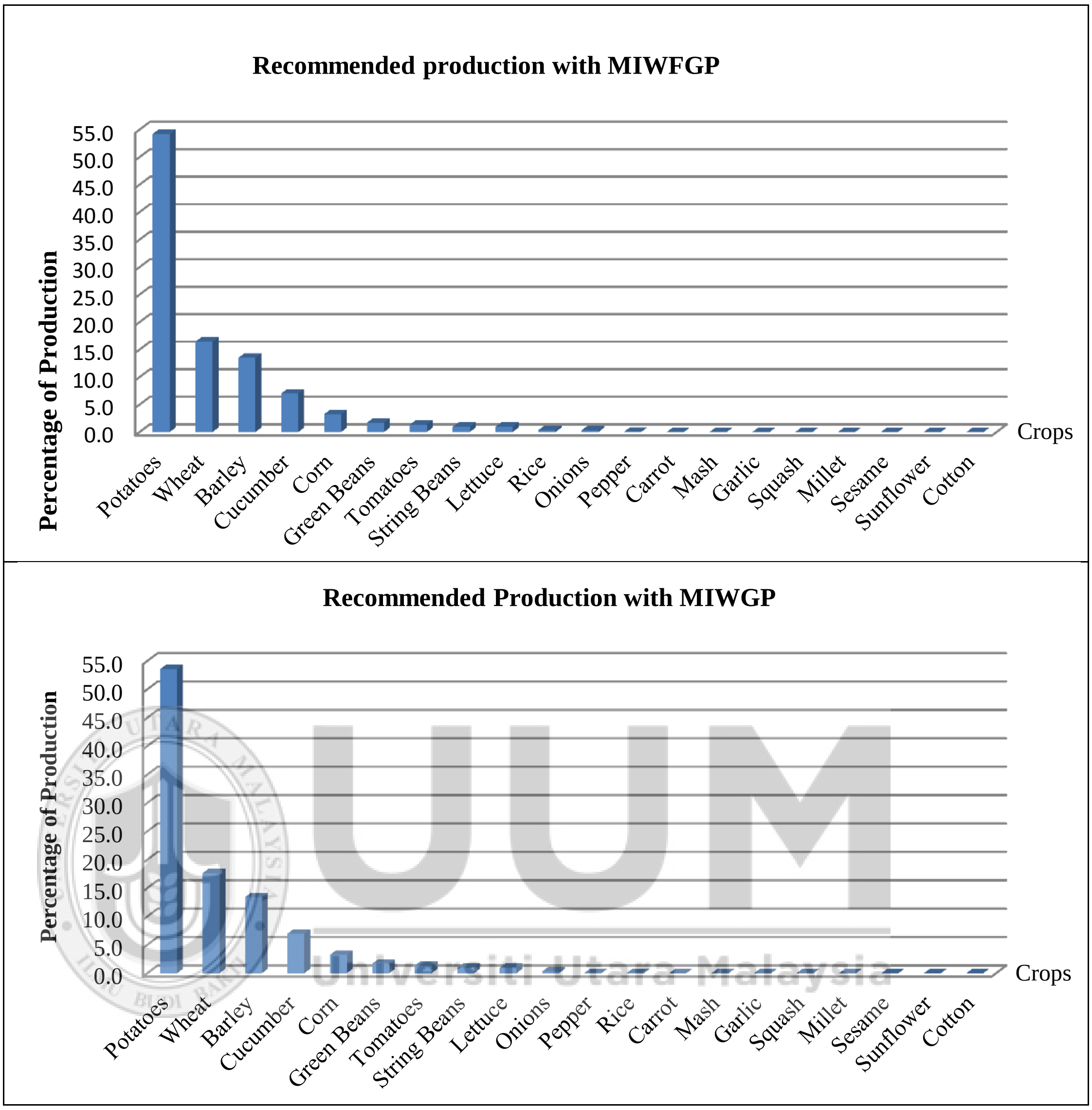

Figure 5.12. Recommended crops productions in Maysan 2010

Furthermore, Figure 5.12 shows the recommended productions as based on DMs' suggestions which focus on some of the crops that have high to be planted in this zone. These crops are potatoes, wheat, barley, cucumber, corn, green beans, tomatoes, string beans and rice which can improve the overall crops productions in Iraq.

5.7 Evaluation of the Proposed MIWFGP and MIWGP Models

Evaluation of the solutions for the FGP and GP models based on the proposed MIW method are presented in this section to show how the novel MIW method achieves the most appropriate weights to represent the levels of importance in the crops production problem. The performance of the proposed MIWFGP, MIWGP and the existing SIWFGP and SIWGP models are analysed using several sets of data available for the years 2002 and 2010.

Furthermore, the implementation of these proposed models with weights derived from existing SIW method are addressed to compare the solutions of proposed models.

5.7.1 Evaluation of the MIWFGP and MIWGP for 2002 Data

In order to evaluate the performance of the proposed MIW method, this research used the existing SIW method as a comparison. This comparison supports our proposed models under different methods for the preference of decision makers to improve crops production problem.

The existing SIW method with FGP and GP model are known as SIWFGP and SIWGP models. These two models are derived and applied to the same 2002 data to obtain crops production results. The first model SIWFGP is presented as follows.

$$
\left.
\begin{aligned}
&\text{Min } G = (\gamma_{1L}^{-} + \gamma_{1U}^{+}) \\
&\text{subject to} \\
&T_1^L(\rho^-) + \gamma_{1L}^{-} - \gamma_{1L}^{+} = t_1^L \\
&T_1^U(\rho^-) + \gamma_{1U}^{-} - \gamma_{1U}^{+} = t_1^U \\
&\frac{Z_k(x) - L_k}{U_k - L_k} + \rho_k^- - \rho_k^+ = 1, \quad k = 1,2,\dots,K \\
&\frac{U_k - Z_k(x)}{U_k - L_k} + \rho_k^- - \rho_k^+ = 1, \quad k = (K+1),(K+2),\dots,g \\
&X \in S^* = \left\{ X \in R^{n\times m} \middle| \begin{cases} AX \geq C \\ AX \leq C \end{cases}, X \geq 0, C, A \in R^{n\times m} \right\} \\
&\rho_k^-, \rho_k^+, \gamma_{1L}^-, \gamma_{1U}^+ \geq 0 \\
&X \geq 0
\end{aligned}
\right\} \quad (5.5)
$$

The second model SIWGP is presented as follows.

$$
\left.
\begin{aligned}
&\text{Min } G = (\gamma_{1L}^{-} + \gamma_{1U}^{+}) \\
&\text{subject to} \\
&T_1^L(\rho^-) + \gamma_{1L}^{-} - \gamma_{1L}^{+} = t_1^L \\
&T_1^U(\rho^-) + \gamma_{1U}^{-} - \gamma_{1U}^{+} = t_1^U \\
&Z_k(x) + \rho_k^- - \rho_k^+ = t_k, \quad k = 1,2,\dots,g \\
&X \in S^* = \left\{ X \in R^{n\times m} \middle| \begin{cases} AX \geq C \\ AX \leq C \end{cases}, X \geq 0, C, A \in R^{n\times m} \right\} \\
&\rho_k^-, \rho_k^+, \gamma_{1L}^-, \gamma_{1U}^+ \geq 0 \\
&X \geq 0
\end{aligned}
\right\} \quad (5.6)
$$

The goals values for 2002 data with MIWFGP and SIWFGP models based on the interval weights results from equations (5.4) and (5.2), respectively are shown in Table 5.35 and Appendices C1 and C2.

Table 5.35

Comparison of Goal Values Obtained under MIWFGP and SIWFGP Models for 2002 Data

Goals	agricultural benefit Z_1 ID)	water irrigation Z_2 (m^3)	fertilizer requirements Z_3 (tonne)	pesticides requirements Z_4 (kg)
Under proposed MIWFGP	7.507×10^{13}	4.796×10^{10}	4.726×10^{8}	1.398×10^{7}
Under SIWFGP	7.507×10^{13}	4.799×10^{10}	4.732×10^{8}	1.405×10^{7}

From Table 5.35, it can be observed that the agricultural benefit goal, Z_1 under each of SIWFGP and MIWFGP models is the same value of 7.507×10^{13} ID. However, the minimization goals which are the water irrigation goal, Z_2 decreased from 4.799×10^{10} m^3 under on SIWFGP model to 4.796×10^{10} m^3 under MIWFGP model, the fertilizer requirements goal, Z_3 decreased from 4.732×10^{18} tonne under the SIWFGP to 4.726×10^{18} tonne under MIWFGP. In addition, pesticides requirements goal, Z_4 decreased from 1.405×10^{7} kg under the SIWFGP to 1.398×10^{7} kg under the MIWFGP model.

In conclusion, the results show that the minimization values for goals Z_2, Z_3 and Z_4 are achieved through the proposed MIWFGP model, except for the Z_1. The monetary benefit seems to has same value but with good consideration of water, fertilizer and pesticide control.

Similarly, the goals values for 2002 data with MIWGP and SIWGP models based on the interval weights results from equations (5.4) and (5.2) respectively are shown in Table 5.36 and Appendices C3 and C4.

Table 5.36

Comparison of Goal Values Obtained under MIWGP and SIWGP Models for 2002 Data

Goals	agricultural benefit Z_1 (ID)	Water irrigation Z_2 (m^3)	fertilizer requirements Z_3 (tonne)	pesticides requirements Z_4 (kg)
Under proposed MIWGP	9.272×10^{13}	5.202×10^{10}	4.943×10^{8}	1.473×10^{7}
Under SIWGP	9.277×10^{13}	5.507×10^{10}	5.662×10^{8}	1.932×10^{7}

From Table 5.36, it can be observed that the agricultural benefit goal, Z_1 under MIWGP is 9.272×10^{13} ID, while under SIWGP is 9.277×10^{13} ID. That means the existing SIWGP method gives the value of goal, Z_1 more than that of proposed MIWGP method. However, the minimization goals which are the water irrigation goal, Z_2 decreased from 5.507×10^{10} m^3 based on the SIWGP model to 5.202×10^{10} m^3 with the MIWGP model. Furthermore, the fertilizer requirements goal, Z_3 decreased from 5.662×10^{8} tonne based on the SIWGP to 4.943×10^{10} tonne under the MIWGP. In addition, pesticides requirements goal, Z_4 is decreased from 1.932×10^{7} kg under the SIWGP to 1.473×10^{7} kg under the MIWGP models.

In conclusion, the results show that the minimization values for goals Z_2, Z_3 and Z_4 are achieved through the proposed MIWGP model, except for the Z_1. The monetary benefit seems to decrease but with good consideration of water, fertilizer and pesticide control.

In sum, the results show that the minimization values of goals Z_2, Z_3 and Z_4 are obtained through the proposed MIWFGP model. These results exhibit that the MIWFGP provided better recommended values for the relevant goals and thus there is improvement in solving the agriculture production problem. Furthermore, these results indicated that the proposed MIWGP model in this research led to the agricultural benefit maximization, while the concepts and goals of sustainable development purports that the decision-makers should consider all goals as the environmental goals are also important and the achievement of these targets should also be taken into account. These results indicated that clear MIWFGP model is superior to MIWGP model.

5.7.2 Evaluation of the MIWFGP and MIWGP for 2010 Data

The process of evaluating the proposed MIWFGP and MIWGP models for 2010 data is the same as was done with 2002 data in Section 5.7.1. Similarly, the goal values for 2010 data with MIWFGP and SIWFGP models based on the interval weights results from equations (5.4) and (5.2), respectively are shown in Table 5.37 and Appendices D1 and D2.

Table 5.37

Comparison of Goal Values Obtained under MIWFGP and SIWFGP Models for 2010 Data

Goals	agricultural benefit Z_1 (ID)	water irrigation Z_2 (m^3)	fertilizer requirements Z_3 (tonne)	pesticides requirements Z_4 (kg)
Under proposed MIWFGP	9.75×10^{13}	6.81×10^{10}	1.13×10^{9}	1.83×10^{7}
Under SIWFGP	7.86×10^{13}	6.86×10^{10}	1.20×10^{9}	1.52×10^{7}

From Table 5.37, it can be observed that the agricultural benefit goal, Z_1 under MIWFGP is 9.75×10^{13} ID, while under SIWFGP is 7.86×10^{13} ID. That means the proposed MIWFGP gives value of goal, Z_1 more than that of the existing SIWFGP method. However, the minimization goals which are the water irrigation goal, Z_2 decreased from 6.86×10^{10} m^3 under on SIWFGP model to 6.81×10^{10} m^3 under MIWFGP model, the fertilizer requirements goal, Z_3 decreased from 1.20×10^{9} tonne under the SIWFGP to 1.13×10^{9} tonne under MIWFGP. In addition, pesticides requirements goal, Z_4 increased from 1.52×10^{7} kg under the SIWFGP to 1.83×10^{7} kg under the MIWFGP model.

In conclusion, the results show that the value for goal, Z_1 and the minimization values for goals Z_2 and Z_3 are achieved through the proposed MIWFGP model, except for the Z_4. The pesticides requirements seem to increase but with good consideration of benefit, water and fertilizer control.

Similarly, the goals values for 2010 data with MIWGP and SIWGP models based on the interval weights results from equations (5.4) and (5.2), respectively are shown in Table 5.38 and Appendices D3 and D4.

Table 5.38

Comparison of Goal Values Obtained under MIWGP and SIWGP Models for 2010 Data

Goals	agricultural benefit Z_1 (ID)	water irrigation Z_2 (m^3)	fertilizer requirements Z_3 (tonne)	pesticides requirements Z_4 (kg)
Under proposed MIWGP	1.65×10^{14}	1.53×10^{11}	1.20×10^{9}	3.01×10^{7}
Under SIWGP	1.93×10^{14}	2.01×10^{11}	1.43×10^{9}	3.17×10^{7}

From Table 5.38, it can be observed that the agricultural benefit goal, Z_1 under MIWGP is 1.65×10^{14} ID, while under SIWGP is 1.93×10^{14} ID. That means the existing SIWGP method gives the value of goal, Z_1 more than that of proposed MIWGP method. However, the minimization goals which are the water irrigation goal, Z_2 decreased from 2.01×10^{11} m^3 based on the SIWGP model to 1.53×10^{11} m^3 with the MIWGP model. Furthermore, the fertilizer requirements goal, Z_3 decreased from 1.43×10^{9} tonne based on the SIWGP to 1.20×10^{9} tonne under the MIWGP. In addition, pesticides requirements goal, Z_4 is decreased from 3.17×10^{7} kg under the SIWGP to 3.01×10^{7} kg under the MIWGP models.

In conclusion, the results show that the minimization values for goals Z_2, Z_3 and Z_4 are achieved through the proposed MIWGP model, except for the Z_1. The monetary benefit seems to decrease but with good consideration of water, fertilizer and pesticide control. The results show that the minimization values of goals Z_2, Z_3 and Z_4 are obtained through the proposed MIWFGP model. These results exhibit that the MIWFGP provided better recommended values for the relevant goals and thus there is improvement in solving the agriculture production problem.

5.8 Summary

In this chapter, analysis and evaluation on the proposed MIWFGP and MIWGP models to solve real problems in the agricultural sector in Iraq were done. We summarize that the proposed models combine the attractive features of the MIW with FGP and GP. These models with interval weight aim to optimize the goals simultaneously in agricultural production problem. In the proposed models, we used two data sets from years 2002 and 2010. The comparisons support the effectiveness of our proposed models to solve the agriculture production problem in Iraq.

The results indicate that the MIWFGP model is superior to the MIWGP model since the MIWFGP was constructed as a model with the integrated management of various important resources. We conclude that the MIWFGP model can better improve the agriculture production if compared to the SIW model. The preceding results show that the proposed MIW method is better in achieving the objective values than the existing method SIW under both the MIWGP and the MIWFGP.

The results of proposed MIWFGP and MIWGP models can be applied to the agriculture crop production improvement to support their decision-making processes in allocating different land use to achieve specific objectives in this sector. The results of proposed MIWFGP and MIWGP models suggested that the DMs focus on some of the crops that have high values in maximizing the agricultural crop production.

CHAPTER SIX
CONCLUSIONS

A doubling in global food request projected for the coming 50 years poses huge challenges for the sustainability of food production and other similar activities related to the ecosystem. Hence, this research attempts to examine an agricultural crops production problem and then propose a suitable solution for the problem case. The main objective of this research is to develop a mathematical model to improve crops production, while considering sustainable agricultural development. In order to achieve the main objective, some specific objectives need to be fulfilled, which are: (a) to determine the main resources which affect the crop production in an attempt to improve the benefit of an agricultural production; (b) to develop a mathematical model that integrates the FGP and GP with measurement of weights; (c) to identify the performance of goals which are resources such as water, fertilizer, and pesticides on the environment in improving crops production in different geographical zones; (d) to compare the proposed multi-interval weights FGP and GP models with the existing single-interval weights models.

In this final chapter, a summary of the agricultural crops production problem being studied and the approach taken to solving it is presented. In addition, the accomplishment of the research objectives, contributions, limitations, and some recommendations for potential work in the future are offered.

6.1 Summary of Crops Production with FGP

The need to feed a developing population is a steady pressure on crops production, as well as coping with an increasingly degraded environment and uncertainties resulting from climate change. Various factors have brought about the deterioration of the agricultural production level including low water level, low capital, misuse of equipment, fertilizer, and pesticides, drought, war, and the ineffective role of extension services. In light of the growing international awareness of the importance of the value of agricultural and natural resources, therefore, recent trends indicate that the integration of the scientific principles with the management of the agricultural sector can enhance crop production. Hence, the need to efficiently model fuzzy goal programming (FGP) is necessary to maximize the crop production benefit while minimizing the main resources, such as water irrigation, fertilizer requirements, and pesticides requirements. The strategic crop farming is one of the ways to increase productivity and income growth that contribute to the economic growth in an agriculturally inclined country. Therefore, the authority in the agricultural sector has to find a good strategy to improve the production. As a consequence, in this research, we modelled a complex crops production problem by maximizing the crop production benefit and minimizing the water irrigation resources with the improvement allocation of fertilizer and pesticides in different agricultural environments.

This research presents a new insight into the interval weights to solve FGP problems and also experiment the hybrid model by considering the case of four conflicting goals in developing the strategic agricultural crops production. The interval is divided into sub-intervals to find the best representation. In the solution process, the interval weights (derived from a pairwise interval judgment matrix) associated with unwanted deviational variables is introduced to the goal achievement function with the objective of minimizing them, and thus, realizing the aspired goal levels of the problem. In the proposed model, the multi-interval weights that enable the fuzzy goals to achieve their aspired levels based on their relative importance are considered in the computation for an environment with farm uncertainty. In the proposed mathematical programming model, we used fuzzy concepts in the objective goals, which initially defined the aspiration levels and lower tolerance limits of these goals. Then, the membership goals associated with the objectives expressed as the executable model for this problem is the GP model with the determination of weights (in multi-interval concept). Consequently, better results are obtained with regard to the weights when the interval is divided into sub-intervals, which also shows better results of weights than that of the single interval under matrix comparing weights (Sen & Pal., 2013).

In summary, we propose a novel method to determine the optimal weights by using the interval method (i.e. multi-interval weights) to control all goals, applied to the whole FGP model, as the main contribution to the body of knowledge. This model guides the outputs toward more realistic and flexible improvement solutions for resource planning, especially for sustainable development. The goals can be identified as the economic and environmental goals. The economic goal is to maximize the agricultural production benefit, while the environmental goals are to minimize the exploitation of water irrigation and minimize the fertilizer requirements. The final goal is to minimize the pesticides requirement. All these goals are subjected to some of the constraints, which are newly introduced to the problem. Those constraints related to drought resistant crops, sprinkler irrigation, drip irrigation and natural fertilizer usage. 20 crops in five zones are considered in the formulation of the model. Consequently, the model is subjected to 16 constraints, where four are related to the land area, three for water irrigation, three for fertilizer requirements, one for labour requirements, one for pesticides requirements, one for agricultural equipment requirements, one for agricultural seeds requirements, one for demand requirements, and one for individual crops production.

Two models are proposed, which are the FGP and GP. The novel concept of MIW is then incorporated in the proposed models, which are as the MIWFGP and MIWGP. Due to the case of the crisp (non-fuzzy) model, the goal programming formulation was utilized because it is also capable in handling multiple, conflicting objectives and it is recognized as an important technique for agricultural planning. In this case, the results of the MIWGP model for 2002 data show that the benefit increase to 9.272×10^{13} ID compared with to that of the MIWFGP of 7.507×10^{13} ID. Also, the value of each goal of water irrigation, fertilizer requirements, and pesticides requirements in the MIWGP model increase more than that of the MIWFGP model. It is clear that if decision makers apply the cropping pattern suggested by MIWGP model, they will lose the environmental level goal. However, these results indicate that the MIWGP model in this study leads to maximize the agricultural benefit while the concepts and goals of sustainable development suggest that the decision makers should consider all goals, as the environmental goals are also important and the achievement of these targets should also, therefore, be taken into account. These results indicate that the MIWFGP model is superior to the non-fuzzy MIW GP described in section 5.7.

6.2 Accomplishment of the Research Objectives

This research has fruitfully achieved all the identified research objectives, as described in the first chapter. The main objective of this research is to develop a mathematical model to improve crops production, while considering sustainable agricultural development.

To reach the improvement of crops production, we outline four specific objectives. The first specific objective is to determine the main resources which affect the crop production in an attempt to improve the benefit of an agricultural production. This was accomplished by reviewing the literature and collecting data via questionnaire to the farmers and agricultural employees, as described in Section 4.4.

The second specific objective is to develop a mathematical model that integrates the FGP and GP with measurement of weights. This was accomplished in Section 4.5 to 4.7 and the results of its implementation are presented in Section 5.4 and 5.5.

The third specific objective is to identify the performance of goals which are resources such as water, fertilizer, and pesticide on the environment in improving crops production in different geographical zones. This objective was achieved via some modifications on the development of the model objectives through the proposed novel method to determine the weights by using the interval method (i.e.

multi-interval weights) to control all goals. These goals are subjected to some new constraints as described in Section 4.5.3.

The fourth specific objective is to compare the proposed multi-interval weights FGP and GP models with the existing single-interval weights models. This objective was approved as described in the implementation of MIWFGP, MIWGP, SIWFGP and SIWGP for years 2002 and 2010. The model applications and the results of the implementation are presented in Sections 5.4 to 5.7.

In summary, this research has succeeded in achieving the main and sub-objectives by testing the model outputs and conducting all the experiments, as shown in Chapter Five.

6.3 Research Contributions

This research contributes modestly towards understanding the agricultural crops production problem. The discussion on the contributions of this research is divided into three aspects: (a) theoretical contributions; (b) benefits to decision makers; and (c) benefits to policy makers. Theoretical contributions focus on the concept of the FGP and GP methodology, while the benefits to the decision makers look into the application of the proposed models to the agricultural sector problem and its benefits. Finally, the benefits to the policy makers emphasize the relevance in designing the model at the high level that can help in the planning of the agricultural sector in Iraq.

6.3.1 Theoretical Contributions

The main theoretical contribution in this research is the development of a mathematical programming model, i.e., based on the concept of multi-interval weights. It was developed using new multi-interval weight insights into each of the objectives function of a GP. Regarding the new insights on the agricultural problem constraints, we propose three new constraints, i.e., drought resistant crops, sprinkler irrigation and natural fertilizer usage. The proposed MIWFGP and MIWGP models are successful in providing a practical guide for the strategic crops production.

The most significant contribution of this research is a new method in constructing the objective functions for the FGP and GP models. The proposed method is known as multi-interval weight (MIW) method. This novel means of exploiting weights are in the form of intervals, but they are not the same as the conventional interval weights. Our recommendation of the MIW usage provides improved values or solutions from the GP. The interval is divided into two sub-intervals to find the appropriate weights representation. In this case, our method does not only focus on the two extreme values (i.e. the min and max), as reported in the previous literature but also covers all values of decision makers' responses. In this strategy, we find the representative value based on the computation of the geometric mean.

Moreover, in the solution process, the interval weights (derived from a pairwise interval judgment matrix) associated with the unwanted deviational variable is introduced to the goal achievement function with the objective of minimization. Then, these functions are transformed into membership goals by assigning the highest membership value and introducing under- and over-deviational variables to each. In the proposed approach, multi-interval weights that enable fuzzy goals to achieve their aspired levels based on their relative importance are considered in an uncertain environment of the problem. This novel contribution will certainly enrich the literature of multi-criteria method.

6.3.2 Benefit to Decision Makers

In terms of practical benefit, this research has several advantages to practitioners, who are working directly with the agricultural sector. Firstly, the main benefit is that the FGP model concentrates on the use of all elements that contribute to the increase in the production of crops and this helps increase a farmer's profit. This research provides invaluable information concerning resources (i.e. water irrigation, fertilizer requirements, pesticides requirements, and crops) to the decision makers to improve the geographic information use.

Secondly, this research suggests that decision makers could implement some changes in the cropping pattern so that they will be able to get more income and also conserve the environment. The farming operations contribute in various ways to the broader environmental problems. Multiple administrative practices and the sensitivity of the local landscape can affect whether or not a given farm might pose a threat to the environmental quality.

Thirdly, this research provides practical insight into the processes of rural development and the required information to design effective agricultural plans for decision makers. This research provides information on choosing the right crops in the arable land and the best solutions to use water irrigation, which may lead to quality crops, the best use of resources, and reduce money spent on the agricultural processes. The use of modern methods of irrigation, such as sprinkler irrigation and drip irrigation, which depends on the pipes under the surface, and magnetized water in the irrigation technology have been shown to be highly efficient in improving the water specifications and, hence, accelerating the process of plant growth. These modern methods provide double production capacity.

Finally, the proposed approach is advantageous in that better results in terms of better results can be obtained when the main interval is divided into two sub-intervals. In this case, our method does not focus on the two values (min, max) of the response as the previous methods in the literature.

6.3.3 Benefit to the Policy maker

Several suggestions can be offered to the agricultural management and farmers. Firstly, the results of this study suggest that the self-sufficiency of the food basket can be secured through the provision of basic necessities and optimal use of natural, financial, and human resources, coupled with the use of modern technology and investment of expertise in each zone.

It is recommended for the authorities to compile accurate data on strategic crops production in the whole country to facilitate researchers to carry out scientific studies. Due to low capital, choosing the crops resistant to drought and salinity with the use of the modern techniques of irrigation can help reduce imports of the strategic crops.

Agricultural policies revolve around the main goals of increasing productivity and income growth, especially in farm zones, enhancing food security and equity, emphasizing irrigation to introduce stability in the agricultural output, commercializing and intensifying the production especially among farmers, and enhancing environmental sustainability. The key areas of policy concern, therefore, include an increase in agricultural productivity and income, especially in farm zones, emphasis on irrigation to reduce over-reliance on rain-fed agriculture in the face of the limited potential agricultural land, and the diversification into non-traditional agricultural commodities.

Finally, the government has to promote and encourage a better understanding and appreciation of the natural environment and how social and economic development affects farmers.

6.4 Research Limitations

As with other research works, despite the best effort given to conduct this research, we acknowledge that this research has still a number of limitations. We have excluded two types of crops which are sugar beet and sugar cane, because of lack of data availability.

6.5 Future Work

This research needs to shed more light on the status of agriculture and its impact on food security and farmers. Due to land deterioration, desertification, high salinity, and the absence of effective planning, the agricultural sector has suffered considerably in Iraq, which affects significantly farmers, especially the peasant farmers.

This study did not include the direct and indirect costs of land requirements due to lack of available data. So, for future works could integrate these costs into the calculation of the benefit in the agricultural sector.

In future research, the proposed approach can be enhanced to test the performance of more than two sub-intervals to achieve the best weight for solving MODM problems in the inexact decision environment (uncertain matter).

In future research, approximation techniques can be used to solve the problem of agricultural production strategy such as genetic algorithm or tabu search.

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