Fast growing population in many countries is one of the reasons for enormous increasing demand for food. Cost-benefit ratio for bringing new land under cultivation is smaller than that of increasing production of already cultivated land. Increase of food production in the available cultivated land is depending upon the maintenance of the soil health. Continuously growing of a same crop over years in the same cultivated area leads to ill health of the soil and increase in various pest and diseases. To overcome the problem of ill health one can use alternate methods like intercropping, relay cropping, mixed cropping and so on. Many researchers have indicated that sole (say maize) crop will be problematic in the long run, further they have advised to go for intercropping which are beneficial, preferably by having legume as component crop.

Table 1.1 revealed that the maize crop is alarmingly increased over the rest of the major cereal crops. Maize cultivation area has been increased to an extent of 32.5 per cent, where increase in production is not appreciable i.e., to the extent of 4.2 per cent. This slow increase in production is might be due to continuous growing of the same crop which is exhaustive.

In order to increase the productivity in maize an attempt has been made by involving pulse as a component crop in intercropping. Green gram and black gram are short duration crops (maximum of 70-75 days) where as maize is 120-130 days crop. Initially both are sown at the same date with defined row ratio (table 3.1). Pulses such as green gram or black gram will come for harvest by the time maize will come to flowering stage, till that time maize consumption for its nutrition was limited. After
certain period nutrition requirement by maize will be more and waste materials of pulses remains can become manure for maize.

Analyses of intercropping data is not complete without a comparison between the performance of the intercrops to that of the component sole crop using various biological or economic or statistical indices such as Analysis of variance (ANOVA), Cost benefit ratio (B:C ratio ), Land equivalent ratio (LER), Area time equivalent ratio (ATER), Crop performance ratio (CPR), period based crop performance ratio (CPRT), Aggressivity index, Correlation analysis, Response surface methodology (RSM), Stability and Sustainability analysis and Energy equivalent ratio etc.

Since no information is available on recommendable row ratio of intercropping with proper weed control technology in the Bhadra command area of Karnataka, the study of Statistical and Economic evaluation of intercropping of maize with urd bean- a study in Bhadra command area of Karnataka is attempted.

The attempt of this study has been made to assess the influence of different row ratio of intercropping along with effectiveness of weed control methods on significance in yield, economically advantageous, well performing and adaptability to all environment and dominant crop of the intercropping system

With the intention for evaluating the intercropping row ratio, present investigation has been proposed with the following objectives.

1. To study statistically and economically optimum/viable row ratio of the maize-urdbean intercropping in Bhadra command area of Karnataka
2. To study association of yield attributing parameters with the yield under different row ratios of intercropping

3. To evaluate the energy use efficiency under different row ratio

4. To evaluate sustainability of the intercropping

5. Statistical and economic evaluation of crop weed interaction

Three year data generated during kharif seasons of 2003 to 2005 under rain fed situation at Agricultural Research Station, Kathalagere under the jurisdiction of the University of Agricultural Sciences, Bengalooru has been considered. Designed five objectives have been evaluated to identify suitable geometry of intercrop of Maize and Urdbean which can provide maximum productivity and to ascertain appropriate weed control measure which could minimize weed by giving optimum productivity.

**Evaluation of the Objective 1** “To study statistically and economically optimum/viable row ratio of the maize-urdbean intercropping in Bhadra command area of Karnataka” has been done using statistical analysis/ economical/biological indices as listed in 4.1. Some analyses were performed based on the replicated CEY values and some are performed based on the actual values.

**Evaluation of productivity for sole/intercropping**

To identify significantly superior row ratio intercropping which could provide higher productivity, replicated year wise data has been subjected to analysis of variance after testing for the homogeneity of variances using Bartlett test. Result in table 4.1.1 indicated homogeneity of variances between the periods of experimentation (both main plot and sub plot). This suggested analyzing the data for the combined analysis of variance.
Differences between weed control treatments, sole/intercropping treatments and interaction between both the components were found to be significant as revealed in table 4.1.2

Results of split plot ANOVA using regular combined (pooled) analysis presented are in table 4.1.3 indicated that intercropping of Maize and Urd in the row ratio of 2:2 recorded significantly superior productivity (maize equivalent yield) of maize with an average of 69.85 q/ha compared to 2:1 and 1:1 row ratios. This indicated that, intercropping with wider row ratio of 2:2 is significantly more beneficial compared to other row ratios tried and sole crops.

Result for multiple comparisons of interaction components (W*IC) presented 4.1.4 indicated that productivity is more in the combination of intercropping row ratios with integrated weed control treatment of Alachlor @ 1.5kg/ha + Hand weeding at 40 DAS. The productivity is particularly more in the 2:2 (80.30 q/ha) row ratio of intercropping combination with the above weed control treatment. This higher productivity is found to be significantly superior over the productivity of the remaining combinations.

**Cost benefit ratio for sole/intercropping**

Sole/Intercropping were evaluated using cost benefit ratio to ascertain economically feasible row ratio which could provide higher net returns for the cost of cultivation made during the cropping period.

Replicated B: C ratios were tested for assumptions of normality, results by Shapiro-Wilk test for testing of normality in table 4.1.8 showed non-normality in data for the year 2004 and 2005. Further Friedman’s two-way analysis of variance test has been performed, test showed non significant result (table 4.1.9) between the B: C ratios of different sole/intercropping treatments.
The results in table 4.1.9 indicated that highest B: C ratio of 1.987 for the intercropping treatment of maize and urd bean (2:2). It could be also be observed that, same row ratios intercropping were noticed to be realizing higher net returns (table 4.1.9) over the sole crops. Net returns realized were 24219.386, 23358.25 and 20275.583 rupees respectively in 2:2, 2:1 and 1:1 over sole crop of maize.

From the observed results it could be informed that, intercropping are more remunerative compared to sole maize. Among the intercropping treatments paired row of maize with two row of urd bean (2:2) has provided higher gross return, net returns and B: C ratio indicating superiority of having wider ratio of intercropping. It implies that farming community can have better monetary returns by having the intercropping of 2:2 row ratio compared to other intercropping and sole maize.

**Land equivalent ratio (LER) for intercropping**

Intercropping were evaluated using LER to ascertain the row ratio which could effectively utilize natural resources and cause for the higher productivity.

Result in table 4.1.11 confirms assumptions of normality for the data sets, results in table 4.1.12 exhibits homogeneity of variances. Results of pooled analysis of variance performed presented in table 4.1.13 indicated significant difference between the intercropping row ratios.

Paired row of maize with two rows of maize (2:2) recorded higher value of LER (1.545). LER values for 2:2 intercropping row ratio is significantly superior over 1:1 row ratio intercropping. Its (2:2 intercropping row ratio) superiority has been of reflected by recording
highest productivity (maize equivalent yield) of 69. 848 q/ha compared to 67.638 and 62.288 q/ha of intercropping row ratio (table 4.1.3).

From this it could be inferred that, Paired row of maize with two rows of urd bean (2:2) realized significantly superior productivity with optimum utilization (LER = 1.545) of natural resources such as radiant energy, available moisture, water, air and so on.

**Area time equivalent ratio (ATER) for intercropping**

Land Equivalent Ratio discussed above is frequently inappropriate because cropping system duration is not included in its calculation; Area time equivalent ratio has been worked out, as it considers duration of both the crops of the system.

Test for the normality by Shapiro-Wilk test presented in table 4.1.15 exhibited non normality in data set 2004. Friedman’s two-way analysis of variance has been carried to know significant differences between the intercropping.

Results in table 4.1.16 revealed significant differences among the intercropping for ATER values. The results indicated that highest ATER value of 1.355 for the intercropping treatment of maize and urd bean (2:2) followed by ATER value of 1.338 and 1.204 for maize and urd bean (2:1), maize and urd bean (1:1) row ratio intercropping respectively.

From the above results it could be inferred that, intercropping row ratios exhibited ATER values more than 1.00 indicating that intercropping are more productive with the utilization of the natural resources. Among the intercropping row ratios, Paired row of maize with two rows of maize (2:2) realized more productivity with its optimum utilization of natural resources such as solar radiant, available moisture, water, air and so on. Maize equivalent yield realized is 69.85 q/ha in 2:2
row ratio which is significantly more compared to the yield of 67.64 and 62.29 q/ha in 2:1 and 1:1 row ratios respectively (table 4.1.3).

**Crop performance ratio (CPR) for intercropping**

Land equivalent ratio (LER) is the most widely adopted indices for evaluating the optimum resource utilizing intercropping system. It has got the constraint that, it is unable to account relative duration of each component in the intercrop spent. Area time equivalency ratio (ATER) solved this problem, since it has considered duration into consideration. However, neither LER nor ATER can account for the physiological or physical basis for the intercropping performance. The crop performance ratio (CPR) is more appropriate in this regard.

Test for normality by Shapiro-Wilk test showed non normality for 2004 data (table 4.1.18). Friedman’s two-way analysis of variance (table 4.1.19) showed significant differences among the intercropping.

The results in table 4.1.19 indicated that, highest CPR value of 1.950 for the intercropping treatment of maize and urd bean (2:2) compared to the other row ratios. This indicated that among the different intercropping row ratios evaluated for the performance, paired row of maize with two rows (2:2) is noticed to be performing well. Same row ratio intercropping crop performance is reflects with significantly higher values for MEY, B: C ratio, LER and ATER.

This better performance result is observed in view of the different unit area occupied by the crop. In view of the paired row ratio compared to 2:1 and 1:1 row ratios, per unit area increases and this benefit has resulted in still better CPR ratio in it and this resulted in much more productivity (69.847q/ha) in that intercropping compare to 2:1 and 1:1 row ratios which have 67.636 and 62.286 q/ha respectively (table 4.1.3).
Period based crop performance ratio (CPRT) for intercropping

Evaluation with crop performance ratio (CPR) has been done only with the area occupied by the crops only, duration of both crops not considered. Since, performance of the main crop is also due to the remains of the component crop. CPR ‘adjusted for time’; (CPRT) is more efficient where the component crops differ in growth duration.

Results presented in table 4.1.21 clearly indicated that, data of 2003 only showing the presence of normality. Non parametric Friedman’s two-way analysis of variance has been employed to ascertain the significant differences between the treatments imposed in the experiment.

Results presented in table 4.1.22 revealed that, significant differences observed between the intercropping treatments. The results indicated that highest CPRT value of 1.749 for the intercropping treatment of maize and urd bean (2:2) compared to the other row ratios. This indicated that among the different intercropping row ratios evaluated for the performance, paired row of maize with two rows (2:2) urd bean is noticed to be well performing.

This better performance result is observed in view of the different unit area occupied by the crops and also varied duration of the crops.

Aggressivity index for intercropping

Aggressivity is an important tool to determine the competitive ability of a crop when grown in association with another crop. It shows the relationship between dominant and dominated crop grown together, especially when any of the two offers competition.

Results presented in the table 4.1.24 revealed that, aggressivity values in all the three years were found to follow normality. This
suggested using parametric test based on the procedures of two-way analysis variance. Table 4.1.25 revealed that, variances between the years for both the components (intercropping and weed control practices) found to be homogeneous; this has enabled to perform regular combined analysis of variances.

From the results presented in table 4.1.28 it could be observed that, significance differences observed between the mean aggressivity values. Dominance of the main crop (maize) in the intercropping of maize against urd bean can be realized from the above results.

Dominance of the main crop (maize) in intercropping are reflected in the table 4.1.27 with its yield values of 54.190, 55.874 and 56.860 q/ha in 1:1, 2:1 and 2:2 intercropping over 52.417 q/ha of sole maize.

**Evaluation of the objective 2** “To study association of yield attributing parameters with the yield under different row ratios of intercropping” has been done by having the suitable methodologies of Correlation analysis and Response surface analysis.

**Correlation analysis**

Many studies are being done to know the extent of relationship of yield with its attributing characters under sole crops only. Since limited information is available on the correlation of yield and its attributing characters of a main crop under intercropping, this objective has been attempt to study its significance by having the intercropping of Maize-Urd bean.

Correlation coefficient for maize yield (actual) and its attributing characters such as Cob weight (gms), 100 seed weight (gms), Stover yield (ton/ha) and Plant height (cm) for sole maize, maize in 1:1, 2:1 and 2:2 row ratios of maize and urdbean intercropping were worked, as it has
been considered as the main crop. Similar correlation coefficients for the urdbean in the intercropping not attempted, since it has been considered as a component crop and soil property enricher.

Among the weed control practices namely hand weeding, Alachlor @ 2kg/ha, and Integrated weed control practices, imposition of Alachlor @ 1.5kg/ha + hand weeding at 40 days after sowing in intercropping row ratios revealed better values for grain yield and for the yield attributing characters compared to sole cropping. This indicated advantage of intercropping due to better row spacing and having of the companion crop (urd bean). From the table 4.2.1 it could also be noticed that, among the intercroppings, paired row of maize with two (2:2) rows of urd bean has realized enhanced values for all the characters over the 2:1 and 1:1 row ratio system and also over the sole cropping.

Hand weeding at 25 days after sowing, chemical weeding by Alachlor @ 2 kg/ha and integrated weed control practice of Alachlor @ 1.5kg/ha + hand weeding at 40 days after sowing minimized the weeds to a greater extent, providing of wider row ratio and remains of the companion crop (Urd bean) after its harvest caused for substantial increase in values of yield and its attributing characters compared to sole crop. This helps in having better positive relation (table 4.2.2) of maize yield with more of its attributing characters in the intercropping row ratios. Weed control treatment of 2:2 exhibited positive correlation of yield with all the yield attributing characters. This may be due to wider row spacing provided in that row ratio intercropping.

**Response surface analysis for intercropping**

Response surface methodology tells the average response to the input factor. It is a combination of experimental regression analysis and
statistical inferences. Here different degree polynomials were used to identify best fit which explain response.

Table 4.2.3 revealed that, \( R^2 \) value for linear and quadratic are 0.844 and 0.989. F statistic is showing significant result for the quadratic polynomial and further fitting is not made. Quadratic polynomial has been considered as the appropriate polynomial to estimate the optimum responses for the different treatments.

\[ \hat{Y} = 2.661 + 30.413x - 3.434x^2 \quad (R^2 = 0.989) \]

From the table 4.2.4 it could be noticed that, responses realized by the quadratic polynomial are near to the observed yield. This is confirmed by the \( R^2 \) (0.989). From the results of the RSM it could be observed that quadratic polynomial found to be the most appropriate fit and the fitted model revealed optimum productivity in the 2:2 row ratio of intercropping.

**Evaluation of the objective 3** “To evaluate the energy use efficiency under different row ratio” has been made using the energy use efficiency.

**Energy use efficiency**

The profitability of a farm business tends to increase as the energy-use efficiency improves; therefore producers have an incentive to adopt energy efficient practices. Increasing the energy-use efficiency in the agricultural sector will become more vital in the future, as producers attempt to increase their output without increasing the size of their crop land.

The input energy is the total inputs of all the components needed for cultivation practices in the respective treatments. The components
includes maize, urdbean seeds, FYM, fertilizers, plant protection chemicals (pesticides and weedicides), machinery for cultivation, labour utilized for land preparation to threshing and fuel consumed for spraying and bullock pair for inter cultivation.

Results in 4.3.3 revealed that, EUE values for each crop under each of the year are showing normality and Bartlett test result in table 4.3.4 showed homogeneity in variances in data set. Analysis of variance results presented in tables 4.3.5 and 4.3.6 revealed that, there are non significant differences between the EUE values sole maize, 1:1, 2:1 and 2:2 row ratio for each crop (maize as well as urdbean). This indicated that, output energy are on par. However it could be noticed that energy ratio is more in 2:2 followed by 2:1, 1:1 and sole crop. This indicated that 2:2 ratio is more efficient in terms of providing better output energy for the imposed input energy. In case of urdbean, results in table 4.3.6 revealed, energy use efficiency in 2:1 is more followed by other treatments 2:2, 1:1 and sole crop. The row ratio of 2:2 and 2:1 ratios noticed to have more energy use efficient than others, it is due to lesser inputs used in case of these treatments. The results indicated that because of the available natural resources usage of the input components is less for the maximum output.

Based on the earlier workers results and results of the present study it could be inferred that, intercropping have recorded higher EUE compare to the sole crops. This has resulted in higher productivity realized in them.
**Evaluation of the objective 4** “To evaluate sustainability of the intercropping” has been attempted by Stability analysis and Yield Sustainability index.

**Stability analysis**

Normally analysis of variance will be performed to identify a significant treatment. When the data is generated over years, analysis of variance may not provide justifiable conclusion about a treatment tried over years (Rajendra Kaur *et al* 1992). To achieve this, stability analysis is found to be more meaningful statistical tool.

To identify the stable treatment over the three years, stability analysis was carried out by employing linear regression model as per the procedure of Eberhart and Russell (1966). Only after ascertaining the significance of treatment x year interaction in the two way analysis of variance, the data was further subjected to stability analysis.

Since significance of treatment x year interaction in the two way analysis of variance was noticed in table 4.3, the data was further subjected to stability analysis. From Table 4.4 it could also be noticed that the intercrop treatments consisting of maize-urdbean (1:1) and maize-urdbean (2:2) has regression coefficient \(b_i\) not significantly deviating from unity and has mean yield greater than population mean yield. This indicated that these two are well adapted to all environments.

**Yield Sustainability index**

System of agriculture will not be sustainable unless the productivity and quality of the soil are continuously maintained. Continuous growing of sole crop particularly maize will barren the land and soil may become unproductive. One of the practices to enhance the soil productivity is to have intercropping with legumes. This will provide
sustainability in the productivity. A high YSI indicates a more progressive management practice capable of producing high yields over the years of experimentation. Yield Sustainability Index (YSI) or Sustainable Yield Index (SYI) values used to evaluate a treatment which could provide sustainability in yield.

From table 4.4.4 it could be observed that, SYI values calculated for period 2004 and 2005 were fail to follow the assumptions of normality. Friedman’s two-way analysis of variance (table 4.4.5) revealed that, significant differences observed between the sole/intercropping treatments among the SYI values.

It could be observed that Paired row of maize with two rows of Urd bean (2:2) is more sustainable since it has recorded higher SYI values compared to other sole/intercropping treatments. This sustainability has been reflected productivity of 69.85 q/ha (table 4.1.3) in the same intercropping treatment compared to other systems of intercropping. The sustainability of the treatment has been noticed in the consistent increase performance in all the year of experimentation. Sustainability in productivity may be due to the growing of legume crop as a component of the intercropping.

**Evaluation of the objective 5** “Statistical and economic evaluation of crop weed interaction” has been attempted by considering some of the suitable tools which are used in the evaluation of intercropping in objective 1 to 4.

In the split analysis of variance four weed control treatments namely Weedy check, Hand weeding at 25 DAS, Alachlor @ 2kg/ha and Alachlor @ 1.5kg/ha + Hand weeding at 40 DAS have been considered in the main plot and 5 sole/intercropping row ratio treatments are considered in the sub plot. Summary of the sole/intercropping row ratio
treatments and interaction of them with the weed control practices are discussed under objective 1-4 wherever possible

**Evaluation of productivity for weed control practices**

With confirmation of the homogeneity of variances using Bartlett test (table 4.1.1), pooled Split plot analysis of variance for main plot factor (weed control practices) performed (table 4.1.2). Result showed significant difference between the weed control practices

Table 4.5.1 revealed the results of productivity realized under different weed control practices. Integrated weed management with Alachlor @ 1.5kg/ha + Hand weeding at 40.DAS is more beneficial compare to the rest of the practices imposed. It realized 65.24q/ha over the other treatments. This indicated that integrated weed management is always beneficial. It has realized 69.51, 30.98 and 14.59 percent more yield compared to Weedy check, Hand weeding at 25 DAS, Alachlor @ 2kg/ha respectively (table 4.5.1).

Combination of this integrated weed control practice with 2:2 intercropping row ratio has realized higher productivity of 80.30 q/ha (table 4.1.4) which is superior over rest of the combinations. This indicated that, integrated weed management with Alachlor @ 1.5kg/ha + Hand weeding at 40 DAS is more beneficial compare to the rest of the practices imposed.

**Cost benefit ratio for weed control practices**

Table 4.1.8 revealed that, B: C ratios calculated for period 2003 only were found to follow the assumptions of normality. Friedman’s two-way analysis of variance has been performed and from the results of the test in table 4.5.2, significant difference observed between the weed control practices observed.
Among the weed control practice, on an average economic feasibility is noticed in Alachlor @ 2kg/ha followed by Alachlor @ 1.5kg/ha + Hand weeding at 40 DAS. This indicated that either chemical weed control or integrated weed control practices are more remunerative compared to the others.

Superiority of these have been reflected through higher productivity realized by them with 61.84 and 65.24 q/ha (table 4.5.1). Wider row intercropping tried with the combination of chemical or integrated weed control practices are economically feasible as perceived by the B : C ratio ( 2.070 and 1.705 B: C ratio : table 4.5.2).

**Land equivalent ratio (LER) for weed control practices**

With the confirmation of normality of the LER values in table 4.1.11, homogeneity of variance in table 4.1.12. Results in table 4.1.13 for pooled split analysis of variance indicated significant differences between the weed control practices.

Weed control practices such as Hand weeding at 25 DAS, Alachlor @2kg/ha and Alachlor @ 1.5kg/ha + Hand weeding at 40.DAS recorded better LER values compared to weedy check. Among the weed control treatments Alachlor @2kg/ha recorded significantly higher LER value of 1.57, this indicated plot receiving this treatment has effectively utilized the natural resources more effectively. Better B: C ratio is also recorded for the same treatment (table 4.5.2).

Combination of Hand weeding at 25 DAS, Alachlor @2kg/ha and Alachlor @ 1.5kg/ha + Hand weeding at 40.DAS with the intercropping treatments Maize and Urd bean (2:1) and Maize and Urd bean (2:2) recorded higher LER values as perceived by the table 4.1.10.
Crop performance ratio (CPR) for weed control practices

Using the Crop Performance Ratio (CPR) weed control treatments which are imposed in combination with the intercropping performance has been ascertained.

Table 4.1.18 clearly indicated that, out of three year data, data of 2003 fail to show normality. Non parametric Friedman’s two-way analysis of variance has been employed, result of the test presented in table 4.5.4 shows significant difference between the CPR values among the weed control practices.

The results indicated that highest CPR value of 1.928 and 1.776 for the weed control treatments Alachlor @ 2kg/ha and Alachlor @ 1.5kg/ha + Hand weeding at 40 DAS. This indicated that among the different weed control treatments evaluated for the performance, either chemical or the integrated weed control treatment is noticed to be well performing with yield value of 61.84 and 65.24 q/ha as observed in table 4.5.1.

Combination of these two with the wider row ratio 2:1 and 2:2 performed better, among the combinations Alachlor @ 1.5kg/ha + Hand weeding at 40 DAS with 2:2 row ratio intercropping crop performed better (table 4.1.4).

Response surface analysis for weed control practices

Response surface methodology tells the average response to the input factor. Here different degree polynomials were used to identify best fit which explain response.

The coefficients, F statistic and R² values for the respective polynomials are presented in table 4.5.5, R² value for linear and quadratic are 0.796 and 0.962. F statistic is showing significant result
for the quadratic polynomial and further fitting is not attempted. Second degree polynomial has higher $R^2$ of 0.962 compare to 0.796 of linear and is found to be significant, it has been considered as the appropriate polynomial to estimate the optimum responses for the different treatments.

$$Y_{hat} = 14.05 + 29.59x - 4.255x^2 \ (R^2 = 0.962)$$

Results in table 4.5.6 indicated that, responses realized by the quadratic polynomial are near to the observed yield. This is confirmed by the $R^2\ (0.962)$. 