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Studies on Potassium Chloride Based – Controlled Release Fertilizer Made From Sand – Cement Matrix

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Abstract: *Sand matrix based KCl controlled to release fertilizer is made and tested. The parameters of the study are initial fraction of KCl, fractional binder, Fractional inert, Diameter of the pellet and Particle size of the sand. The release of fertilizer from the pellet depended on the compositional parameters of the study. Based on Fick`s second law, a model was developed for the sand matrix fertilizers without coatings. Simulated data onto the model was agreeing well with experimental values.*
The developed equations are as follows:
$k = 3.29\, f_{kcl}^{0.155}\ f_c^{0.27}\ f_s^{0.19} (D_{P/} d_{sp})^{0.067}$

Keywords: *Plant nutrients, Fertilizer, controlled release, potassium chloride, sand, cement.*

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I. INTRODUCTION

Application of fertilizers is inevitable in the modern farm practice to get better yields. Fertilizers add nutrients to the plants those are not adequately supplied by the soil. Fertilizers are classified into two broad groups namely organic and inorganic. Organic fertilizers are derived from living resources like plant or animal. For example: manure, sewage sludge, blood meal, cotton seed meal and bone meal etc. Chemical fertilizers are manufactured synthetically and have many advantages like it could be manufactured at a very fast rate and also at low cost. The fertilizer could be supplied to the plant at a very faster rate but sometimes the release is too fast need to be controlled for several reasons as discussed below. Since the solubility of chemical fertilizers is very high leads to the condition of abundant supply of nutrient to the plant which in turn causes root burn and finally damage the plant. Increased intake of fertilizers is highly susceptible for the attack of pest. In addition to the problems mentioned above, cost of the produce is high with the increased use of fertilizer. The other unwanted conditions are loss of fertilizer by way of leaching leads to the ground water pollution. To overcome the above problems the use of controlled release fertilizers are recommended.Controlled release fertilizers are broadly defined as products that release nutrients to the soil for plant uptake at a pre-determined time and rate.

The application of controlled release fertilizers have following objectives
1. To improve the yield and reduce the cost of production.
2. To increase the nutrient efficiency and quality of the produce.
3. Reduction of plant toxicity and stress.
4. Substantial reduction in ground water pollution and water bodies.
5. Reduction of the labor cost for the application of fertilizer.

Application of controlled release fertilizer could achieve the following advantages:
1. Root burn can be avoided with the application of controlled release fertilizers even at the increased quantities of fertilizers supplied.
2. Fertilizers are released at a slower rate throughout the season; so that plants could take up most of the nutrients without much waste by way of leaching.
3. Reduced seed or seedling damage from high local concentrations of salts
4. Reduced leaf burn from heavy rates of surface application.

Application of controlled release fertilizers has several advantages. Despite the several advantages of controlled release fertilizers, only about 0.15% [64] of the total fertilizers consumption is controlled release fertilizers. This is mainly due to the very high cost of Controlled release fertilizers and lack of proper legislation in many parts of the world. Hence, the development of cost effective controlled release fertilizers have been a never ending quest for scientific community and a delight to the farmers as it offers several advantages over conventional fertilizers.

Several methodologies have been visualized and adopted for the preparation of controlled release fertilizers. But works on cost effective methods are meager. In pursuance of the task, several strategies have been followed. They are the literature pertaining to model development was also incorporated. The literature obtained is classified into sections as mentioned hereunder.

1. Chemically combined form of controlled release fertilizers (1-11).
2. Fertilizers embedded in inert matrix. (12-23).
3. Fertilizers with permeable coating (24-53).
4. Fertilizers with enzymes which inhibit the release rates such as nitrification inhibitors and other release retarding agents (54-58).
5. Use of Natural organics that decays slowly due to microbial action and release the fertilizers slowly (59-64).

In India, the farming community made several attempts to develop the controlled release fertilizers and practiced. The methods they adopted were tar coated urea; neem cake mixed with urea and urea coated with neem seed extract and were practiced. The farmers found difficulty in the preparation of tar coated urea and urea coated with neem extract as it resulted uneven and uncoated urea. For the case where urea mixed with neem cake has very low retention capacity because of its high porosity. The practice of neem extract coated urea was failed because of tedious procedure required for it. The methods available so far failed due to one or other reasons. Due to the above reasons an attempt is made in the present study to develop a controlled release fertilizer. The aim of the study is to develop cost effective controlled release potassium chloride fertilizer and evaluate its release rate and release fraction with time. It is further proposed to develop a model and compare the results with the model developed. Potassium chloride, sand and cement system was envisaged, with which controlled release fertilizer pellets are made with sand matrix and cement as a binder. The sand is present everywhere on the earth and is available to the farmers at free or negligible cost, so that the controlled release fertilizers could be prepared at less cost. Among the several binders considered for the pellets preparation, cement was chosen because of its availability at moderate costs. It also has very good binding capacity with sand in the preparation of aggregate. As the materials used for the preparation of the aggregate are familiar to the farmers, the procedure developed can be easily implemented. The pellets prepared are of various composition of KCl, sand and cement. The binder fraction in pellet was maintained in the range from 0.05 to 0.3. However lower binder fractions were favored on cost consideration. The binder fractions beyond 0.3 were found to be unsuitable as the pellets so made were unable to release the KCl. The data are analyzed and the results obtained are presented in terms of time Vs fraction of fertilizer retained in pellet (X_A) and release rate ($-r_A$). The results revealed that the pellets prepared in the present study could last up to 18 days. Equations developed for the pellets without coating. Without Coating: $k = 3.29 f_{kcl}^{0.155} f_c^{0.27} f_s^{0.19} (D_{P/} d_{sp})^{0.067}$

II. MATERIALS AND METHODS

Materials used in the present study are potassium chloride as fertilizer, sand as inert material and cement as binding agent. Potassium chloride utilized in the present study is an analytical reagent whereas sand is of river bed origin washed number of times followed by drying in oven at 110^oC for four hours. Cement utilized in the preparation of pellet is Portland cement. Properties and uses of various other materials utilized in the present study are presented hereunder. Potassium chloride is fertilizer or active ingredient in the present study. Analytical grade Potassium Chloride was incorporated in the pellet. It is a primary nutrient and is necessary for the healthy growth of the plant. Potassium chloride (KCl) is a fertilizer which is most conveniently expressed as K_2O. It is made by the reaction of hydrochloric (muriate) acid on potassium containing materials. It contains about 63.17% K_2O and K content of about 52.44%. It is also known as the muriate of potash. Potassium is readily absorbed and may accumulate in plant tissue greater amount than actual crop requirement. Potassium is relatively mobile in acidic sands under high rainfall conditions. Particularly it is mobile where the application of ammonium salts is more. In some cases, soluble potassium salts may be toxic if ionic concentration is high enough to interfere with water uptake by the crop. Under these conditions, controlled release potassium is beneficial. KCl is highly soluble in water as it readily dissociate in water, is liable for loss with water either by seepage or by drainage. Hence KCl has been selected for the development of controlled release fertilizer. Controlled release fertilizer pellets were prepared with varying proportions KCl, inert and binder proportions.

Sand is selected as inert matrix or barrier material for the release since it is cheap and shows a tendency to form aggregate with cement, makes it suitable for the matrix material in the present study. It is cheap and easily available for farmers as it may be procured from neighboring streams. It is generally a part of soil, so that no unwanted residue is left in the field unlike controlled release fertilizers made with polymer coating. Sand matrix has the advantage of negligible cost as it can be procured from neighboring streams at meager cost.

Several binding agents were visualized for the study. Among them sodium silicate, tar, cement, lime and plaster of paris are prominent. But Cement binder was selected for the study as it is available abundantly to farmers at fairly cheaper price. Hence cement sand system was selected for the study.

III. EXPERIMENTAL PROCEDURE

Controlled release potassium chloride fertilizer pellets were made with sand- cement composite as an inert matrix. Cement was chosen as binder because of its availability and low cost. The initial fraction of Potassium Chloride in the pellets was varied as 5, 10, 15, 20, 25 and 30 percent. Cement composition was varied as 5, 10, 15, 20, 25 and 30 percent. The sand composition was varied as the binder and inert materials together contribute to inert matrix. The particle size of sand was also varied as it alters the porosity of the pellet which affects the diffusion rate. The sand particle sizes of 250μm, 212μm and 106μm were used for the preparation of pellets. The ranges of variables covered in the present study are presented as table-1. In the present study, the pellets of Potassium Chloride (KCl, sand &cement system) were prepared by mixing Potassium Chloride with sand and cement in the ratios of 5:95, 10:90, 15:85, 20:80, 25:75, 30:70. The inert composition was also varied to obtain varied strength to the pellets. The proportions of the sand-cement - fertilizer ratios are maintained as 70:30, 75:25, 80:20, 85:15, and 90:10, 95:5. The ingredients of the pellet were mixed with minimum amount of water in a ceramic crucible and moulded into spherical pellets. The mould sizes were varied as 1cm, 0.75cm, and 0.5cm. Larger particle sand sizes are made as they are not suitable for fertilizer applications. Small size pellets were not attempted as they are limited to shorter time of release. The size of the pellet was also limited by the size of the constituent sand particles. The pellets were cured and dried in shade for 10 days. The procedure was repeated to prepare pellets with different sizes sand particle. Pellets of known composition were taken in separate 500ml beakers to which 200ml of water was added. The leaching takes place as the time progresses. The solution was stirred gently and 1ml of the leach ant sample was taken and transferred into a conical flask to which 10ml of distilled water was added. One ml of distilled water was added soon after the leach ant sample was taken out of the beaker. The beaker was closed with a lid to avoid loss of water by evaporation. Similar procedure was repeated for the pellets in other beakers also. The samples were tested for KCl content by volumetric analysis by titrating against silver nitrate solution. Samples of leachant were collected from time to time and tested for its KCl concentration. The time verses concentration of potassium chloride in the leach liquor was obtained for the pellets with and without coating. The concentration data was taken for 20 days for the pellets without coating. The release data was extended for a maximum period 40 days in the case of pellets with coating.

IV. RESULTS AND DISCUSSION

Controlled release fertilizers are classified as follows:

Natural Organics: Fertilizers like compost contain nutrient values like nitrogen, phosphorus, potassium and other nutrients in combined state and when decomposed it is released as the fertilizer. Natural Inorganic: Some minerals like fluorappetite are the source of phosphate. As it is, these rocky aggregates are insoluble in water but in course of time the rock will disintegrate the minerals will liberate slowly and makes the phosphate available to plant but the release is very slow. The rock is made to react with sulfuric acid to form super phosphate which can be considered as a controlled release fertilizer.

Synthetic Fertilizers: Synthetic fertilizers are highly soluble in water and release nutrients at high rate. These fertilizers are sometimes modified to retard the release.

A. Fertilizer without any modification

B. Controlled Release Fertilizer are coated controlled release fertilizer, chemically modified controlled release fertilizer, matrix base controlled release fertilizer, controlled release fertilizers using enzymatic inhibition.

The term controlled release fertilizer refers to the fertilizer that release nutrient to an extended period. The main objective of the study is to minimize the cost of fertilizer and to extend the period of release. Sometimes aspirations are cast to produce a fertilizer to release at a predetermined time and rate. The controlled release fertilizers could be made with several strategies but the following two are in practice. Coated controlled release fertilizers: Several types of materials have been used for coating and tested for their release rates, Sulfur coated urea, neem oil coated urea and polymer coated urea are few among them. Polymers of several types as coating materials have been under study. Chemically modified controlled release fertilizers: In this type release rate of fertilizer is decreased by altering the molecular structure to form a new compound. Ex: Urea formaldehyde, Isobutylidene di urea (IBDU), Crotonylidene di urea (CDU), trimethylene tetra urea oxamide, glycouril, and ammelide are some nitrogen based controlled release fertilizers. Magnesium ammonium phosphate ($MgNH_4PO_4$) is a slowly soluble source of nitrogen and phosphorous. Guanyl urea sulfate (GUS) and

Guanyl urea phosphate (GUP) are readily soluble in water but are absorbed in soil colloids transforming it into mineralization and have slow release character. Among all these fertilizers sulfur coated urea is improved and favored to go for commercial production by some companies but due to the high cost its use is limited to very low percent of total production.

Importance of Kcl Based Controlled Release Fertilizer

Plant nutrient potash is normally applied as potassium chloride or muriate of potash. As potassium chloride is ionic in nature, dissociate completely and is liable to loose either through drainage or seepage. It is envisaged to develop potassic control release fertilizer by fixing it in an inert matrix. Several inert matrix materials were envisaged among them are sand (10), fly ash (9), organic compost (50) etc. In the present study sand is selected as matrix material as it is easily available to farmers at no cost. The binder is compatible to sand in making aggregate. Though the cement is a manufactured product, it is available at low cost when compared to other type of binders.

In the present study, potassium chloride was selected as active ingredient of the controlled release fertilizer. Controlled release fertilizers of potassium chloride with sand-cement matrix were made and tested for their release rate. Time versus concentration of KCl data in leach ant were obtained, from which fraction of fertilizer retained in the pellet (X_A) are computed. The range of parameters of the study is presented in the table 1. The studies were also carried on the pellets coated with benzoic acid, naphthalene and wood polish separately. The release data for the coated pellets were obtained from the experimental study. The X_A versus time are computed from the concentration versus time data.

Table-1 Range of variables covered in the study

Variable	Maximum	Minimum
Sand,%	85	55
Cement, %	30	5
KCl, %	30	5
Sand particle size, µm	250	106
Pellet diameter, cm	0.5	1

Controlled release potassium chloride fertilizer pellets are made by following the procedure outlined in the chapter materials and methods. The release data obtained are in terms of concentration of potassium chloride versus time, is nearly similar in most of the cases and shown as fig. 1.

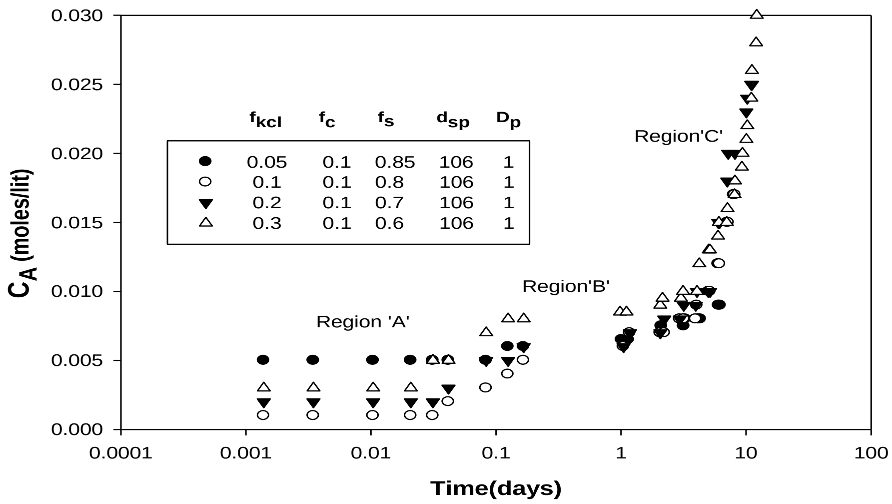

Fig.1. Variation of C_A with time(days) - Effect of initial fractional KCl

The figure reveals concentration of fertilizer in the leach ant increases with time. Observation of fig. 1 reveals three regions. The first region is initial region i.e. region 'A' where the release of fertilizer is large in short interval. It can be attributed to the fact that certain quantity of fertilizer reside in large pores are transported out of the pellet. The next region is the slow release region i.e. region 'B' which is due to increased resistance to mass transfer may be micro pore diffusion and hence decreasing mass transport conditions prevail. The third region is the fast release region i.e. region 'C' potassium chloride present in the micro pores has to diffuse through and reach macro pores where the resistance to diffusion is very low. On the other hand the fertilizer core of the pellet diminishes increases the resistance to release. The combined effect is manifested in the region. The calculated data consisted of fraction of potassium chloride retained in the pellet (X_A), rate of release ($-r_A$) of potassium chloride and other factors.

Fractional fertilizer retained in the pellet is X_A and it is computed using the following expression.

$$X_A = \frac{\text{moles of KCl present in the pellet at any time}}{\text{moles of KCl initially present in the pellet}} = \frac{N_A}{N_{A0}}$$

Moles of KCl present in the pellet at any time (N_A) = $N_{A0} - n_A$

$$X_A = \frac{N_{A0} - n_A}{N_{A0}}$$

Where N_{A0}: Moles of KCl initially present in the pellet

n_A : Moles of KCl in the leach ant at anytime

N_A: Moles of KCl present in the pellet at any time

The release rate ($-r_A$) is computed by adopting the following procedure

$$-r_A = \frac{1}{A}\frac{dX_A}{dt}$$

Where $X_A = ao+a_1t + a_2t^2 + a_3 t^3$

A = surface area of the pellet.

$$\frac{dX_A}{dt} = a_1 + 2a_2 t + 3a_3 t^2$$

$$-r_A = (a_1 + 2a_2 t + 3a_3 t^2)/A$$

Sand matrix based potassium chloride (KCl) controlled release fertilizer is made and experimented in accordance with the procedure outlined in the chapter materials and methods. The results are analyzed in terms of parameters of the system namely fractional potassium chloride, (f_{KCl}), fractional binder ($f_{b,}$), fractional inert(f_s), diameter of the pellet(D_p), particle size of the sand(d_{sp}). The release of fertilizer from the pellet depends on the composition of the pellet. The data are analyzed from the graphs of X_A versus time.

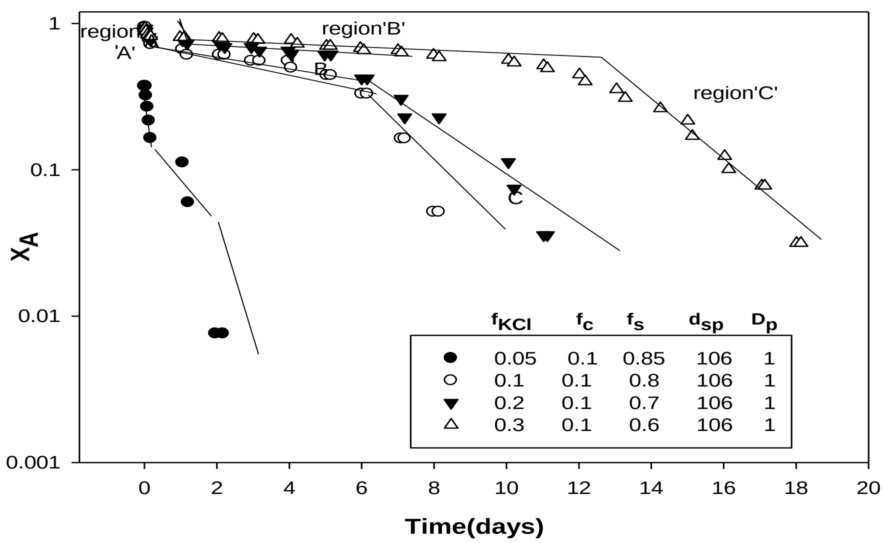

Fig.2.Variation of X_A with time(days)- Effect of initial fractional KCl

Effect of initial fraction of potassium chloride:

Initial fraction of potassium chloride in the pellet has marked influence on the KCl release. Fig. 2. drawn as fractional fertilizer retained in the pellet (X_A) versus time. It reveals that the X_A is decreasing with time. The release is sudden and large; the initial release period lasted for about 1 hour from there onwards the release is relatively slow and gradual. The trend continued for longer period depending upon the initial fraction of the KCl. The release may be due to the migration of KCl from the inner layers to the outer layer during the course of drying and also that is present in the large size pores of the pellet. For initial fractions of 0.2 and 0.3 slow release region 'B' lasted for 5 to 13days. Larger the initial KCl fraction greater the slow release region and it is very important as it releases the fertilizer slowly and steadily and making the fertilizer available to the plant.

This particular region constitutes a major portion of the release curve. The slope of this region determines the release rate. The slow release region is followed by another i.e. fast release region 'C' where the release rate is faster than the earlier region. This region lasts for few more days. Fig. 2 reveals the effect of initial fractional Potassium chloride content. Initial KCl fraction was varied from 0.05 to 0.3, but the pellets with potassium chloride fraction above 0.3 developed cracks in the pellets after drying indicating poor mechanical strength. Therefore, present study is limited to 0.05 to 0.3 of initial fractional KCl. Potassium chloride content in the pellet has considerable affect on release rates. The pellets with fertilizer fractions with 0.3, 0.2 and 0.1 the release is non linear in nature with clear distinction between region 'B' and region 'C'. In case of 0.05 initial fraction of KCl fraction the release rate is almost uniform. Among these four fractions, 0.3 is best because of slow release nature. It also provides lower initial release fraction and contains maximum fertilizer.

The fig. 2 reveals that there is continuous release of potassium chloride with time. There are three regions were observed from the graph. The first region is the region A where 10-20% of Potassium chloride present in the pellet, released within first one hour. The remaining 80% was released over the period 18 days. The regions 'B' and 'C' could be observed clearly from graph. The release mechanisms are different for each region. In the first region the availability of potassium chloride in the pellet to release is abundant; it may be due to the availability of potassium chloride in macro pores and diffuses with less resistance. The region 'B' extends for longer time and it follows 1st order. In the region 'C', potassium chloride present in the micro pores has to diffuse through and reach macro pores where the resistance to diffusion is very high. On the other hand the fertilizer core of the pellet diminishes reduces the resistance to release. The combined effect is manifested in this region.

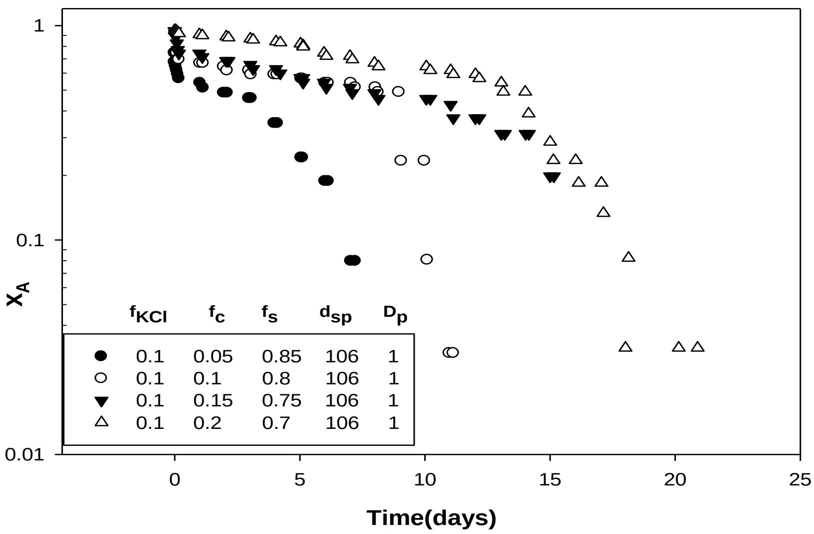

Fig.3. Variation of X_A with time(days) - Effect of fractional binder

Effect of fractional binder:

A graph is drawn for X_A versus time with binder fraction as parameter and shown as fig. 3. The binder fraction was varied from 0.05 to 0.2. The fractional potassium chloride content was maintained at a constant value of 0.1. The figure reveals that the pellet with 0.05 fraction cement releases KCl faster when compared to those of higher cement fractions. The pellets with lower fractions of binder offer loose porous structure. The fertilizer granules might not be coated with cement layer that may be allowing water to penetrate through the pellet with ease. Consequently the system facilitates faster release of the fertilizer. Though the release period is low, the pellets with lower cement fractions may be favored because of cost consideration. It may also be favored due to the possible disintegration of the pellets after release. The fractional release is nearly complete for the pellets having 0.05, 0.1 binder fractions but for higher fraction the release was not complete during the period of study. For higher binder fractions the fertilizer release was continued up to 20 days. In some cases, pellets with longer release period may be preferred in spite of higher cost. Further studies are necessary towards enhancing the release period at higher binder fractions and to provide alternative technologies.

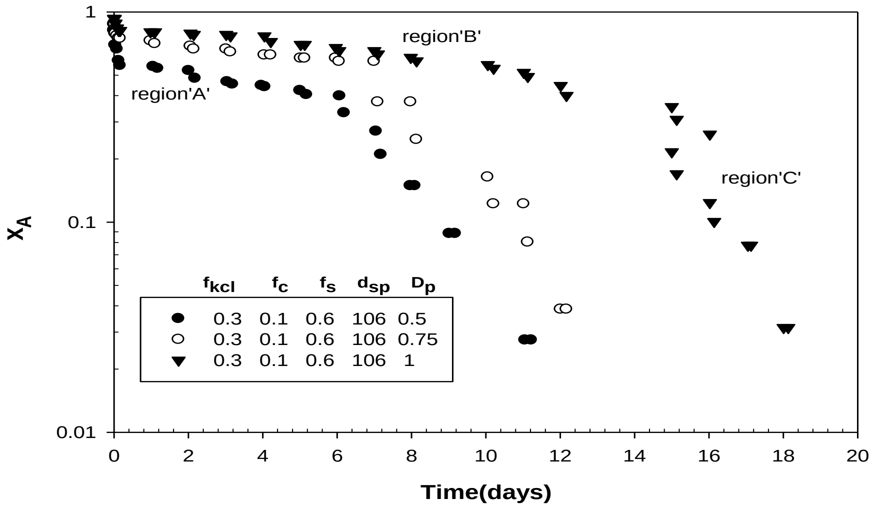

Fig: 4. variation of X_A with time(days)- Effect of pellet diameter

Effect of pellet diameter

A graph is drawn as X_A versus time and shown as fig. 4. The figure reveals that fractional fertilizer retained in the pellet decreased with time. Higher diameter pellets retarded the release because of longer distances the fertilizer has to travel through pores of the pellet. The initial fraction released was also affected by the diameter. Larger size pellets showed the lower initial release fraction. The rate of release is high for smaller diameter pellets when compared to larger ones. It can be observed from the slope of the lines for the region 'B' or region C. The region B is the longest one for any pellet. In this region the fertilizer has to travel through the pores of the pellet hence greater resistances to release is encountered and slow release is observed. The release is faster in the fast release region/region C for all the pellets. For the pellet 1 cm diameter, the fast release region begins lately when compared to 0.5 cm pellets. The release rates are low for larger size pellets. The release period was extended from 11 days to 18 days as the diameter varied from 0.5 cm to 1 cm.

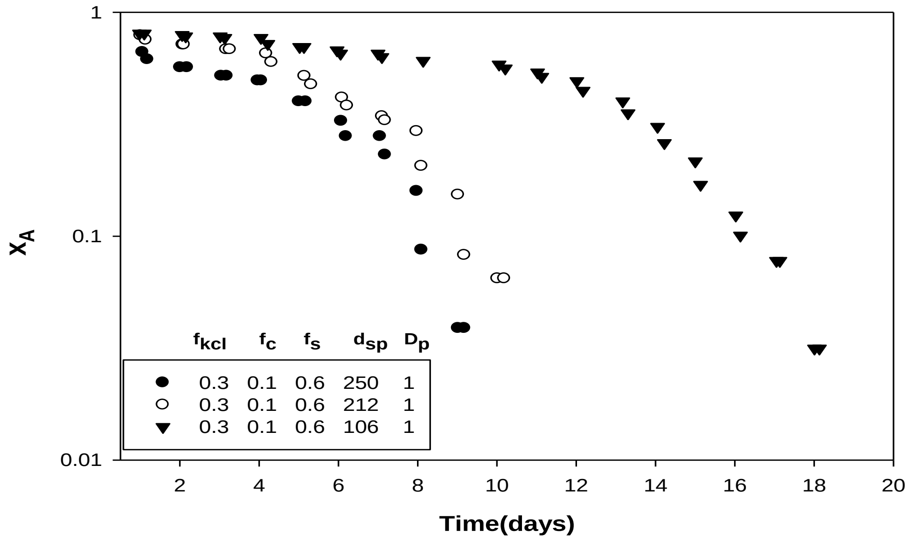

Fig: 5. variation of X_A with time(days)- Effect of sand particle size

Effect of particle size of the sand:

The constituent sand particle size has a significant effect on release of fertilizer. A graph is drawn as X_A versus time for different particle sizes and shown in fig. 5. The figure reveals that X_A is decreasing with time. The decrease is relatively slow and follows first order kinetics in the region 'B' and with a specific rate constant. The region extended from 7 to 14 days. As the particle size varied from 106μm to 250μm the release in the latter region continued with a rapid decrease in X_A and with a different rate constant indicating a characteristic change in regime. The fractional fertilizer content retained in the pellet at this changeover regime is different for different pellets. It ranges 0.5 to 0.2 as the particle size varies from 106µm to 250 µm. The release period extended as the particle size decreased. In the present study, pellets made of 106µm sand particles exhibited a better release period hence it is recommended. Further lower size particles have not been tried as their availability in nature is less and may be difficult to procure for the farmers.

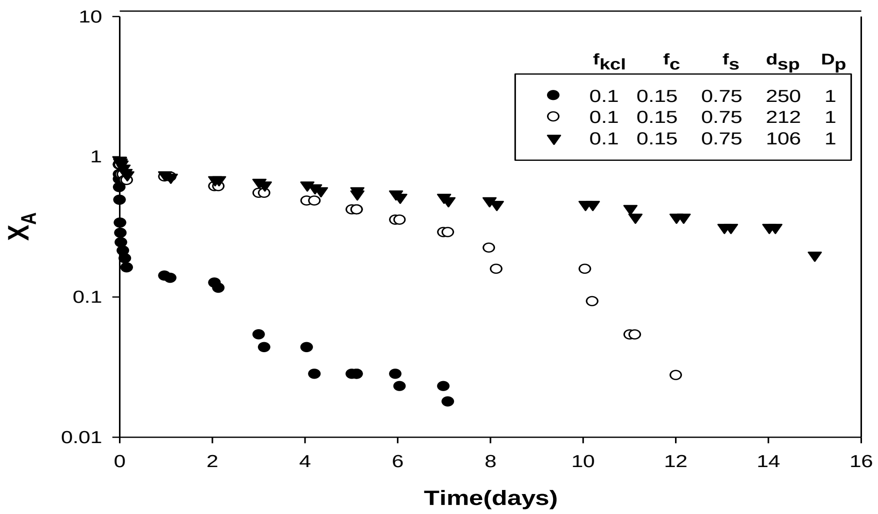

Fig. 6.Variation of X_A with time(days) -Effect of sand particle size

The initial release is increasingly high for larger sand particle size and can be seen from fig. 6. At low initial fertilizer fraction the release periods are relatively low. Hence it is recommended to choose pellets with higher initial fertilizer fraction. In the present study maximum initial fraction of fertilizer covered is 30%.

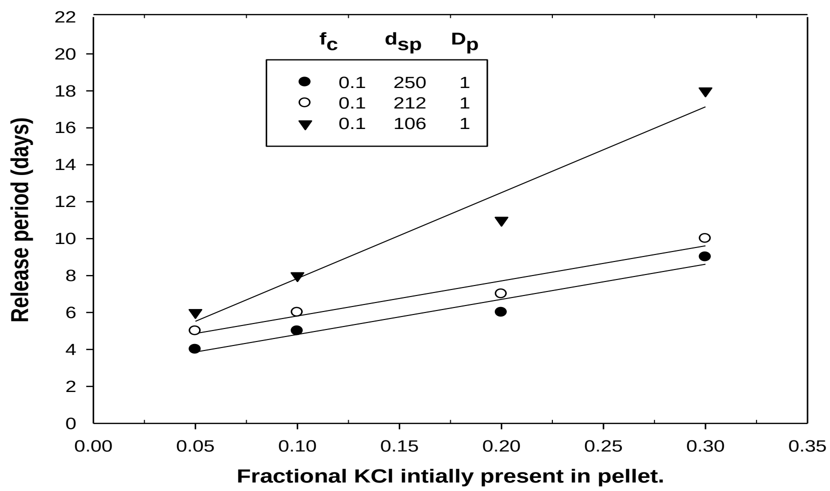

Fig.7.Variation of release period with fractional KCl initially present in the pellet- Effect of sand particle size.

A graph is drawn as fractional KCl initially present in the pellet against release period and shown as fig.7 with particle diameter as parameter. The figure reveals that the release is retarded and the release period extended with the increase in initial KCl fraction. The release period was also extended as the sand particle size is decreased.

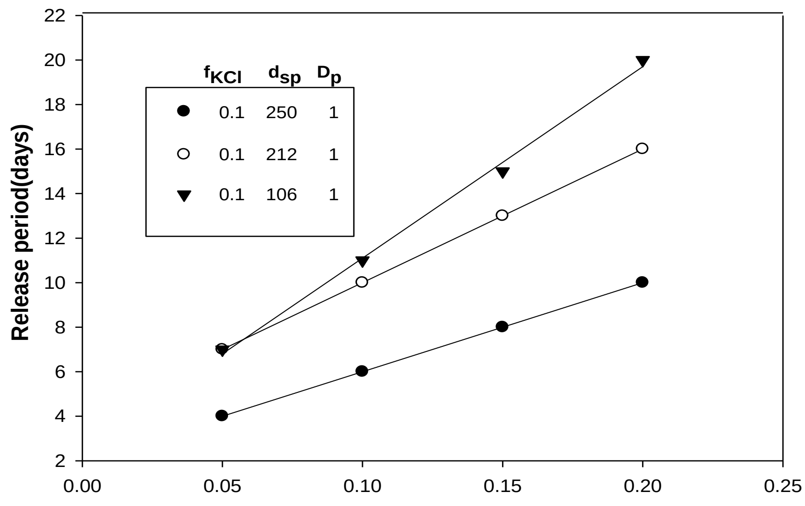

Fig.8.Variation of release period with binder fraction - Effect of sand particle size

Fig. 8 is a graph drawn as binder fraction against release period. The figure reveals as the binder fraction increases the release period is extended. The binder fraction is directly proportional to the release period. Smaller the particle size greater the release period. Therefore it is recommended to use the smallest possible size sand particle for the preparation of the controlled release fertilizer.

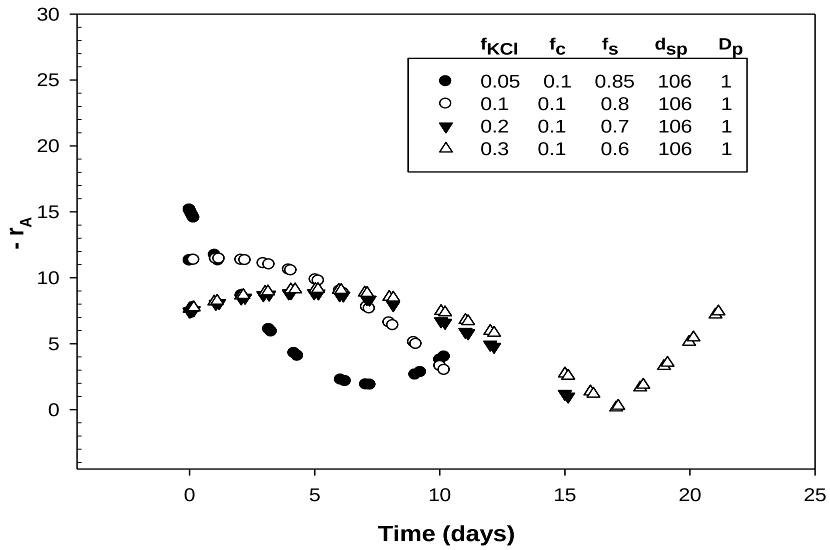

Fig.9.Variation of $-r_A$ with Time(days)- Effect of initial fractional KCl.

A graph is drawn as release rate $-r_A$ with time and shown as fig. 9 with fractional KCl as parameter. The figure reveals that the release rate gradually decreases followed by an increase. The trend is similar for all the pellets within the range of parameters covered in the study.

Model Development for pellets without coating:

An empirical model is developed based on law of mass action and presented as follows. Time versus concentration of leach liquor generated out of the experiments is used for analysis. From the measured concentrations, fractional fertilizer retained in the pellet is calculated according to the procedure mentioned below.

Fractional fertilizer retained in the pellet is X_A and is calculated as

$$X_A = \frac{\text{moles of KCl present in the pellet at any time}}{\text{moles of KCl initially present in the pellet}} = \frac{N_A}{N_{A0}}$$

Moles of KCl present in the pellet at any time (N_A) = $N_{A0} - n_A$

$$X_A = \frac{N_{A0} - n_A}{N_{A0}}$$

Where N_{A0}: Moles of KCl initially present in the pellet

n_A : Moles of KCl in the leachant at anytime

N_A: Moles of KCl present in the pellet at any time

Graphs are drawn as X_A versus time. On regression analysis, the data is fitted into a polynomial equation. The coefficients of polynomial together coefficient of regression and pellet compositions are presented in the table

Mass transfer rates are computed following the procedure outlined below.

$$X_A = ao + a_1 t + a_2 t^2 + a_3 t^3$$

$$\frac{dX_A}{dt} = a_1 + 2a_2 t + 3a_3 t^2$$

$$-r_A = \frac{1}{A}\frac{dX_A}{dt} = (a_1 + 2a_2 t + 3a_3 t^2)/A$$

Where A is the surface area of the pellet through which mass transfer takes place and $-r_A$ is release rate at which the fertilizer transfers to the leach ant.

A graph is drawn as $-r_A$ versus X_A on log - log scale, from which linear equations are resulted of the following format

$$-r_A = k X_A^n$$

$$\text{Log}(-r_A) = \log k + n.\log X_A.$$

On regression analysis the coefficients of the equation are computed together with coefficient of regression. Where n is the exponent or the order of release expression. The constant b_0 is interpreted as log k, and hence the rate constant k is obtained. The exponents are largely near to zero thereby one can ascertain that order of release rate is of zero order except few samples. For most of the samples, the rate law follows fractional orders as mentioned in the table 2.

The rate constants are independent of the fertilizer remained in the pellet but depend on the properties of pellet namely f_{KCl}, f_c, f_s, D_p, d_{sp}

Therefore

$k \alpha \; f_{KCl}, f_c, f_s, D_p, d_{sp}$

On regression analysis of the data the following expression is obtained.

$k = K_o \; f_{KCl}^{n1} f_C^{n2}, fs^{n3}, (D_P/d_{sp})^n$

Without coating: $k= 3.29 f_{kcl}^{0.155} f_c^{0.27} f_s^{0.19} (D_P/d_{sp})^{0.067}$

Average deviation = 11.035 Standard deviation = 15.273

V. CONCLUSIONS

1. Sand matrix based controlled release potassium chloride fertilizer could prepared.
2. Spherical fertilizer pellets were made and diameters of the pellets were varied from 0.5cm to 1cm. The release was extended from 11 to 18 days as the pellet diameter increased from 0.5 to 1 cm. Small diameter pellets are generally favored as they spread into more area but the release period is limited to 11days while that for larger diameter pellets are extended 18 days.
3. Cement was selected as binder and its fraction in the pellet was varied from 0.05 to 0.20. Pellets with binder fraction above 0.05 are found to be stable. The pellets with 0.15 to 0.2 binder fraction offered longer release period. Pellets with 0.1 to 0.15 binder fractions are recommended as they release sufficiently for longer period and also economical. These fertilizers disintegrate and mix with soil without altering soil characteristics.

4. KCl fraction in the fertilizer pellets could be varied from 0.05 to 0.3 safely without any breakage. Pellets having KCl fraction beyond 0.3 are unstable hence not suitable for the preparation of pellet. Pellets with 0.3 KCl fractions released the fertilizer fairly longer period up to 18 days and it also provides relatively low initial release fraction. Higher the fraction initial fractional KCl in the pellet longer the release period.
5. Sand particle size in the pellet was varied from 106 µm to 250µm.The pellet prepared with 106 µm size sand particles offered longer release period i.e. up to 18 days.
6. The release studies are evaluated in stagnant liquids but the actual release period in the field conditions may be high. The actual release period may lasts for several months.
   The model equation developed for the pellets without coating:
   $k=3.29\ f_{kcl}^{0.155}\ fc0.27\ f_s^{0.19}\ (d_p/D_{sp})^{0.067}$
7. Further study is required in the field level. Agronomic evaluation of the fertilizer is another necessity.

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NOMENCLATURE

f_{KCl}	:	Fractional KCl initially present in the pellet
f_s	:	Fractional sand(Inert Matrix) present In The Pellet
f_c	:	Fractional binder i.e., cement.
f_d	:	Fractional diameter of the Pellet
D_p	:	Diameter of The Sphere (Pellet), cm
d_{sp}	:	Sand Particle Size, μm
C_A	:	Concentration of KCl in Leached Solution, mol/l
N_{A0}	:	Moles of KCl Initially Present In The Pellet
n_A	:	Moles of KCl in The Leached Solution at Time, t
N	:	Exponential
N_A	:	Moles of KCl in The Pellet at Time, t
t	:	Time, days
A	:	Surface Area of The Pellet, cm^2
k	:	rate constant
$-r_A$	:	Release rate of KCl from the pellet,
X_A	:	Fractional KCl retained in The Pellet at any Time Calculated from The Experimental Data
X_f	:	Function of KCl
X_c	:	Function of Cement
X_s	:	Function of Sand

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