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# The Use of Surface Runoff to Improve Degraded Rangelands by Creating Shrub Pastures

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**Abstract:** Field experiments were conducted at Sanganeh Research Station at North-east of Iran to determining runoff production, soil accumulated moisture and develop semiempirical model to determine the best plant row spacing for reclamation and optimum production of degraded rangelands under natural precipitation. Runoff production and soil accumulated moisture were determined in 80 experimental plot on different combination of soil type, vegetation cover and slop gradient, during autumn, winter and spring precipitations during 1996-2005. Results from 90 precipitation events with various magnitude and intensity indicated that, soil accumulated moisture was not considerable in September to November period and the amount of evapotranspiration was more than precipitation up to 6 fold. The average of soil accumulated moisture, evapotranspiration and surface runoff in winter were calculated around 64, 33 and 3% of precipitation, respectively. In spring, the average of evapotranspiration, infiltration and runoff were 62, 36 and 2% of the rainfalls, respectively. The resulted values for moisture accumulation in the soil and surface runoff on the experimental plots make it possible to estimate the potential deficit of moisture and assess the water supply of the plant. Experimental data was used to develop a semiempirical model for determining the best plant row spacing for optimum production and water requirement of pastures. Generally we concluded that there is a strong possibility for reclamation of eroded rangelands using surface runoff in arid and semi arid regions.

**Key words:** Reclamation, semi-arid rangelands, rainwater harvesting, semiempirical model

## INTRODUCTION

More than 30% of the earth's land area has characterized as arid and semi-arid regions (Hassani *et al*., 2008). Historically, wide areas of Iran had been covered with forests and rich rangelands (Rangavar *et al*., 2004). Fast increasing of human's food requirements, population, climatic conditions and overgrazing are important factors that affect the eroded areas and rangeland's species composition in semi-arid ecosystems (Solaimani and Hadian Amiri, 2008; Hassani *et al*., 2008). Degradation of great area of rangelands in North-east of Iran (Khorasan Province) due to environmental and human factors is an example of this evident. Approximately, 41.7% of Khorasan land surface are rangelands, 12.5 million hectare, with production of 90-312 kg ha$^{-1}$ dry weight on average. The majority of these areas are classified as medium to poor rangelands. The rest of Khorasan land area, are desert rangelands (Zadbar *et al*., 2007). Earlier studies have revealed that, traditional grazing can reduce diversity of plants in poor soil (Anderson and Hoffman, 2007). For this reason, in the majority of Khorasan

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Areas, decreaser plants have replaced with increaser ones (*Peganum harmala* and *Sophora* pachycarpa). That has resulted to fodder shortage and other serious problems in that region. Therefore, it is essential to reclaim degraded rangelands by scientific and economic methods.

Precipitation is the only source of moisture supply for rangelands. Therefore, it is necessary to use this potential factor for reclaiming degraded rangelands (Wylie *et al*., 1992). Recent studies in Iran shows that, the total amount of annual precipitation is about 430 billion $m^3$, out of which about 20% is lost in the form of flash floods (Foltz, 2002). Water and soil characteristics in arid and semi-arid regions are in a form that rain in non-growing and at the beginning of growing seasons is reserved in soil so that deep rooted permanent plants can utilize this water source during the growing season (Karabulut, 2002).

Many studies have discussed about the runoff behavior of different land use types and the effects of land use change on runoff production (Dagnachew *et al*., 2003; Dunjo *et al*., 2004). Some of the fodder shrubs species can be developed under cultivation in arid zones between 200 and 400 mm of mean annual rainfall. However, when mean annual rainfall drops below 200 mm, additional water from runoff is essential for improving production (Abu-Zanat *et al*., 2004).

Rainwater harvesting and its use for rangelands improvement can be a common method in arid and semi-arid regions. Many researches in Central Asia and deserts around Caspian Sea in Russia have been carried out in field of rangeland improvement in arid and semi-arid regions using rainwater harvesting. Results of these researches indicated that agroclimatological approach for reclamation is the most suitable scientific and economic method. Using valuable fodder shrubs in degraded rangelands as a protective green belt and applying surface runoff as well as restoring moisture in soil, enable us to increase plant products up to the potential of each region. Applying this method, the fodder products have been increased together with achievements in natural regeneration of fodder plant species (Nurberdiev and Reizvikh, 1992). Compatible shrubs in arid regions could considerably change the conditions of ecosystems in which they are planted (Farrell, 1990). These plants species with C4 photosynthetic pathway has been found to be a valuable component of arid region’s nature where they can also photosynthesize in moisture and temperature stress (Pyankov and Mokronosov, 1991). The consistency of production in these areas is resulted from actual potential of shrubs in the ecosystem. Compared to other plants, the root of shrub species penetrates deeply in soil, improve soil structure and have influence on nutrient cycling and soil moisture (Gliessman, 1990).

Researches performed for recognition of water and soil resources potential in arid regions in the Middle East, has shown that the average rainfall reservation during non-plant growing season i.e., winter, has been 55, 77, 70 and 2% in loamy sand, sandy, sandy loam and loamy rangelands, respectively. In another research, the runoff coefficient has been determined to be about 8% for steppe deserts in Russia and 5% for lower-side of Volga and desert regions of Caspian Sea (Artykov, 1987). According to the study in a nearby field (Chahchahe), the average of runoff coefficient from November to February has been measured to be about 2% (Rangavar *et al*., 2004). Based on agroclimatologic approach, reclamation of degraded rangelands depends on relation between runoff productivity, soil accumulation capacity and required moisture of phytomeliorants (Rangavar *et al*., 2004). The amount of surface runoff potential requirement for meeting the plant moisture storage in rangelands differs with geographic properties of different regions. The main objectives of this research were to measure surface runoff and soil accumulated moisture to estimating additional water requirement for rangelands reclamation. On the basis of this research, a semiempirical model was also developed in order to the best plant row spacing for optimum production and water requirement of pastures.

## MATERIALS AND METHODS

### Station Description

This research was performed to evaluate in real time runoff phenomenon. Experimental runoff measurement plots were used to determine the required coefficients and indices. The research station is located between 60°, 13',47" Northern latitudes and 36°, 41', 17" Eastern longitudes in the 100 km Northeast of Mashhad, Khorasan Province, Iran, with altitude of 700 m above sea level. Figure 1 shows the situation of Sanganeh research station on Iran's map.

Land type of the research station is plateau and slope ranging from 1 to 50%. The soil cover of runoff plots in Sangane station is mainly represented by Gray-Cinnamonic soil, Sierozems, Lithosols and Regosols. Soil's gravels content, acidity, electrical conductivity, lime, organic matters and gypsum content varied from 0 to 40, 7.2 to 8.3, 1 to 8 dS $m^{-1}$, 0.3 to 10.4, 0.8 to 3.3 and 0 to 19%, respectively. Variability of rainfall from year to year is very high. On average, in wetter year, 10-12 rainfall periods are happened. In the drier years only 4-6 rainfall periods are experienced. The average annual rainfall is about 250 mm and climate is semi-arid by using Demartonne method. Dominant vegetation cover type is *Poa bulbosa* and *Artemisia sieberi*. In some patches other species such as *Carex stenphylla* and *Salsola aucheri* are companion plants with dominant species. The percentage of vegetation cover in different parts of the station and plots varies from 0 to 50%. Suitable place for runoff measurement was selected based on the slope, vegetation cover and top soil which have the most important role in runoff production. Considering above mentioned factors, 80 experimental runoff measurement plots with 2 m width and 5, 10, 15, 20 and 25 m lengths were constructed and divided into 23 categories. Each plot was hydrogeologically isolated for collecting and analyzing precipitation runoff separately. Steel tanks were also considered at the end of each plot for collecting runoff. Two recording rain gauge were used for collecting rain data. Figure 2 shows three kinds of runoff measurement plots with different conditions and dimensions.

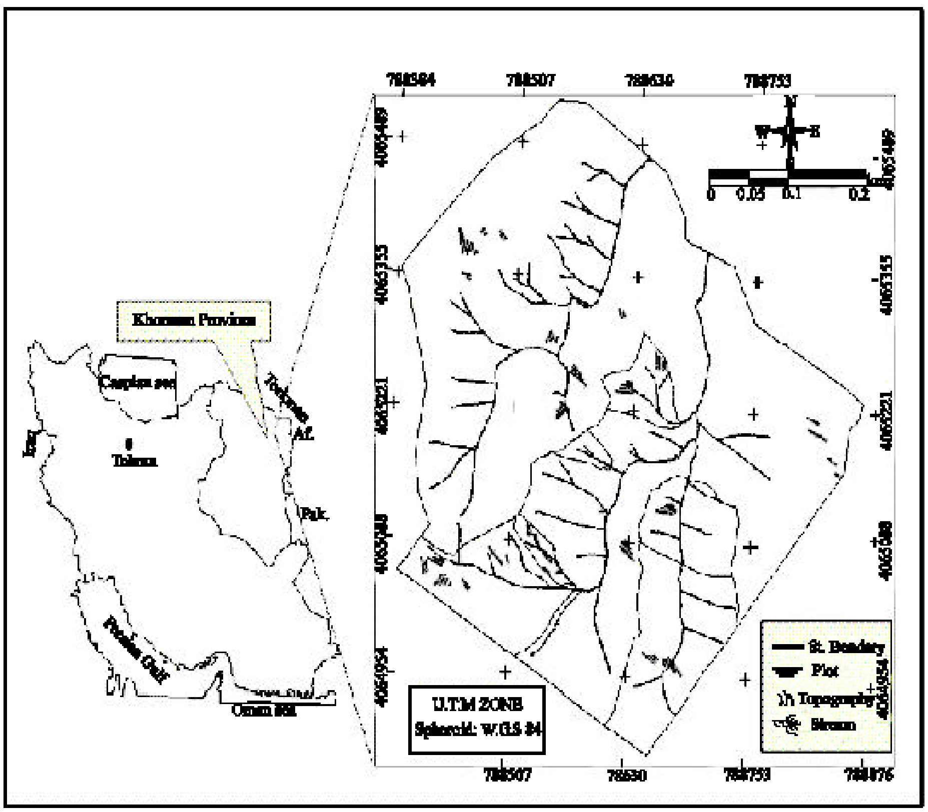


Fig. 1: Situation of Sanganeh research station on Iran's map

Fig. 2: Three kinds of experimental runoff measurement plots in different conditions

**Theory of Modeling**

Reclamation of degraded rangelands based on agroclimatological approach needs some information about moisture content, seed germination requirement and growth and viability of phytomeliorants. Actual moisture content accumulated (mm) in furrows and utilized by phytomeliorants per year $FE_0$ was estimated by Eq. 1 (Rangavar *et al*., 2004):

$$FE_0 = (P_1K_a)+[P_2(1-K_r)-W] \quad (1)$$

where, $P_1$ is the amount of precipitation in the autumn-winter (mm), $P_2$ is the amount of precipitation in the spring (mm), $K_a$ is the coefficient of moisture accumulation in the soil, $K_r$ is runoff coefficient in spring period, W is the amount of soil moisture remained from end of previous inactive growing period (mm), that it was negligible for our study and ignored.

For calculating the parameter of moisture adequacy of phytomeliorants, it is very important to know the moisture requirements of these plants in different years. Rychko (1994) calculated and appraised the water and heat parameters for hydroclimatic zoning of the Chu arid region of Kirghizestan. Zoning was performed based on the average of established zonal parametric natural moistering (K and W) and elements of the moisture and heat resources in the active growing period of vegetation expressed in Eq. 2 and 3.

$$K = P+(V_i-V_f)+R_g \quad (2)$$

$$W = E_0 \, [P+(V_i-V_f)+R_g] \quad (3)$$

where, P is the precipitation (mm), $V_i$ and $V_f$ are the amount of reserved moisture along the rooting zone (mm), $R_g$ is the amount of moisture in rooting zone supplied by ground water table (mm), $E_0$ is the evaporability or the maximum total evaporation of agrocoenosis (mm).

To simplify evaporability determination, following equation has been established based on total daily average temperature of the air (Rychko, 1994).

$$E_0 = 0.30\, t \quad (4)$$

where, $E_0$ is the evaporability during vegetation growth period (mm) and t is the sum of daily average air temperature in the same period (°C).

For the present case study the optimal total evaporation, $E_0$, corresponds approximately to the demand of the rangeland plants for moisture in a specific year. Consequently, the ratio between the actual amounts of moisture spent in a given year on the total evaporation and the required amount of moisture for the maximum total evaporation in the same year, expresses the value of the coefficient of moisture adequacy for the phytomeliorants ($K_{ma}$) in the moisture accumulating furrows (Eq. 5):

$$K_{ma} = \frac{(P_1K_a) + [P_2(1-K_r)]}{0.30 \times T_{(5-20°C)}} \quad (5)$$

where, $0.30\times T_{5\text{-}20°C}$ is the total evaporation, $E_0$ is 0.30 T, during active vegetation growth period in arid rangelands within the limits of the average daily temperature of 5-20°C (Nurberdiev and Reizvikh, 1992).

The accumulation coefficient of the autumn-winter precipitation ($K_a$) in the moisture accumulating furrows was calculated by Eq. 6:

$$K_a = P+S-I \quad (6)$$

where, $\sum P$ is the sum of precipitation in the given case (mm), I is total evaporation from the moment of one precipitation to the following case (mm), S is surface runoff from the inter-row space into the moisture accumulating furrows (mm).

The amount of precipitation runoff (S) from rangeland surface (mm) is determined by Eq. 7:

$$S = \left[H_w\left(\frac{10^4}{A_r}\right)^{-1}\right]A_s^{-1} \quad (7)$$

where, $H_w$ is the height of water in reservoir (mm), $A_r$ is reservoir area (cm$^2$) and $A_s$ is the area of the runoff plot (m$^2$).

Consequently, the runoff coefficient ($K_r$) is determined by Eq. 8:

$$K_r = \left\{\left[H_w\left(\frac{10^4}{A_r}\right)^{-1}\right]A_s^{-1}\right\}\left(\sum P\right)^{-1} \quad (8)$$

**Measurements**

The amount of precipitations in different seasons and related runoff were measured directly during 1996-2005 in Sanganeh research station. Consumed moisture for total evaporation was calculated by Rychko (1994) method.

## RESULTS AND DISCUSSION

Table 1 shows average runoff coefficients, evaporation and accumulation moisture in soil subjected to 90 precipitation events during 1996-2005 in Sanganeh research station. In early June when the weather is hot and dry, the soil moisture changed from 1.2-1.3% in the 0-5 cm layer, to 2-4% at a depth of 15 cm, 4-8% at a depth of 60 cm and 7% at a depth of 100 cm. It serves as an evidence of the fact that the active life of plants discontinues because the soil moisture was much lower than the wilting point. The results of evaporation, soil moisture and runoff from 90 precipitation events (with different intensity) obtained from 23 groups of experimental runoff measurement plots showed that during autumn there was not considerable moisture in soil and evaporation was three to six times more than amount of rainfall. Moisture accumulated in soil from the beginning of winter, were 47% in Dec.,

Table 1: Coefficients of accumulation ($K_a$), evaporation ($K_i$) and runoff ($K_r$) in Sanganeh station, during winter and spring (1996-2005)

| Characteristics of experimental runoff measurement plots | Area (m$^2$) | Winter $K_a$ | Winter $K_i$ | Winter $K_r$ | Spring $K_a$ | Spring $K_i$ | Spring $K_r$ |
|---|---|---|---|---|---|---|---|
| Rangelands with 5 to 10% slope, | 10 | 0.64 | 0.33 | 0.01 | 0.36 | 0.62 | 0.01 |
| different geographical directions, | 20 | 0.65 | 0.33 | 0.03 | 0.36 | 0.62 | 0.01 |
| Lithosols soil, 10 to 20% vegetation | 30 | 0.64 | 0.33 | 0.03 | 0.36 | 0.62 | 0.01 |
| cover such as *Poa bulbosa*, | 40 | 0.64 | 0.33 | 0.04 | 0.36 | 0.62 | 0.01 |
| *Artemisia sieberi*, *Carex* | 50 | 0.66 | 0.33 | 0.04 | 0.36 | 0.62 | 0.01 |
| *Stenphylla* and *Salsola* sp., | Average | 0.65 | 0.33 | 0.03 | 0.36 | 0.62 | 0.01 |
| comprising 5 experimental plots | | | | | | | |
| Rangelands with 10 to 15% slope, | 10 | 0.63 | 0.33 | 0.02 | 0.36 | 0.62 | 0.02 |
| different geographical directions, | 20 | 0.63 | 0.33 | 0.03 | 0.35 | 0.62 | 0.03 |
| Regosols soil, 3 to 50% vegetation | 30 | 0.65 | 0.33 | 0.03 | 0.37 | 0.62 | 0.01 |
| cover such as *Poa bulbosa*, | 40 | 0.66 | 0.33 | 0.04 | 0.37 | 0.62 | 0.01 |
| *Artemisia sieberi*, *Carex stenphylla* and | 50 | - | - | - | - | - | - |
| *Salsola* sp., comprising 9 experimental plots | Average | 0.64 | 0.33 | 0.03 | 0.36 | 0.62 | 0.02 |
| There were 9 experimental plots in this | 10 | 0.60 | 0.33 | 0.06 | 0.33 | 0.62 | 0.05 |
| sub-group, more than 20% slope and | 20 | 0.60 | 0.33 | 0.05 | 0.35 | 0.62 | 0.03 |
| without vegetation cover, the rest of | 30 | - | - | - | - | - | - |
| characteristics were similar to group 2 | 40 | 0.63 | 0.33 | 0.04 | 0.37 | 0.62 | 0.01 |
| | Average | 0.61 | 0.33 | 0.05 | 0.35 | 0.62 | 0.03 |
| Rangelands with 10 to 17% slope, | 10 | 0.63 | 0.33 | 0.02 | 0.37 | 0.62 | 0.01 |
| different geographical directions, | 20 | 0.63 | 0.33 | 0.03 | 0.36 | 0.62 | 0.00 |
| deep Regosols soil, rich vegetation | 30 | 0.64 | 0.33 | 0.03 | 0.37 | 0.62 | 0.00 |
| cover of species such as *Poa bulbosa*, | 40 | 0.65 | 0.33 | 0.04 | 0.37 | 0.62 | 0.01 |
| *Artemisia sieberi*, *Carex stenphylla* and | 50 | 0.66 | 0.33 | 0.04 | 0.37 | 0.62 | 0.00 |
| *Salsola* sp., comprising 8 experimental plots | Average | 0.64 | 0.33 | 0.03 | 0.37 | 0.62 | 0.00 |
| There were 2 experimental plots in this | 10 | 0.65 | 0.33 | 0.02 | 0.37 | 0.62 | 0.00 |
| sub-group. Vegetation cover was | 20 | 0.65 | 0.33 | 0.02 | 0.37 | 0.62 | 0.00 |
| *Carex stenphylla* and other | 30 | 0.65 | 0.33 | 0.02 | 0.37 | 0.62 | 0.00 |
| characteristics were similar to group 3 | 40 | 0.65 | 0.33 | 0.02 | 0.37 | 0.62 | 0.00 |
| | Average | 0.65 | 0.33 | 0.02 | 0.37 | 0.62 | 0.00 |
| Two experimental plots with very low slope | 10 | 0.65 | 0.33 | 0.02 | 0.36 | 0.62 | 0.02 |
| 1 to 3% | 20 | 0.65 | 0.33 | 0.02 | 0.37 | 0.62 | 0.01 |
| | 30 | 0.65 | 0.33 | 0.02 | 0.36 | 0.62 | 0.00 |
| | Average | 0.66 | 0.33 | 0.02 | 0.36 | 0.62 | 0.01 |
| Rangelands with lack of soil and | 10 | 0.65 | 0.33 | 0.02 | 0.35 | 0.62 | 0.03 |
| appropriate vegetation cover, covered | 20 | 0.67 | 0.33 | 0.02 | 0.37 | 0.62 | 0.01 |
| with gravel and slope 3 to 8% | Average | 0.66 | 0.33 | 0.02 | 0.36 | 0.62 | 0.02 |
| Average parameters for the region | | 0.64 | 0.33 | 0.03 | 0.36 | 0.62 | 0.02 |

Table 2: Average long term climatic parameters and their distribution in Mashhad climatological station

| Climatological parameters | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sep. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temperature (°C) | 2.4 | 3.5 | 8 | 14 | 19 | 24.8 | 27 | 25 | 20.7 | 14 | 10 | 4.5 |
| Amount of precipitation (mm) | 33 | 43 | 59 | 53 | 31 | 7 | 0 | 0 | 5 | 6 | 11 | 28 |
| Amount of evaporation (mm) | 7 | 10 | 23 | 43 | 57 | - | - | - | - | 43 | 31 | 15 |
| Evaporation contribution (%) | 21 | 25 | 39 | 78 | - | - | - | - | - | - | - | 52 |
| Amount of surface runoff (mm) | 0.3 | 0.3 | 0.2 | 0.2 | - | - | - | - | - | 0.3 | 0.3 | 0.4 |
| Runoff coefficient (%) | 3.0 | 3.0 | 2.0 | 2.0 | - | - | - | - | - | 2.0 | 2.0 | 3.0 |
| Amount of soil moisture (mm) | 23 | 32 | 35 | 10 | - | - | - | - | - | - | - | 13 |
| Soil moisture (mm) (%) | 70 | 75 | 56 | 18 | - | - | - | - | - | - | - | 47 |

70% in Jan. and 75% in Feb. with respect to total precipitations. The average of consumed moisture in winter was 33% and the amount of runoff was estimated as 3%. In spring time, the amount of precipitation was noticeable and average evaporation was 62% in Mar. and Apr. Water infiltrated in to the soil was changed to 36 and 2% was used for surface runoff. Table 2 for example shows the exerted achieved results from this research to the average long term climatic parameters in the nearest climatological station i.e., Mashhad.

The comparison of amount of surface runoff and soil accumulated moisture obtained from this research is correspond with the similar study in the central Asian countries, steppe deserts and desert regions of Caspian Sea in Russia. This shows, an existing climatic potential in different regions for reclamation of degraded rangelands or creating artificial pastures.

These results are in agreement with those obtained from central Asian countries, steppe deserts and desert regions of Caspian Sea in Russia (Artykov, 1987).

The accumulated moisture and runoff coefficients obtained from the experimental runoff measurement plots in various years make it possible to calculate the deficiency of the precipitation compared to optimal moisture for the phytoameiorants. Based on results, one can simulate the most rational schemes for creating shrub pasture plantings in various agroclimatic regions of Khorasan Province.

Amount of precipitation deficit ($D_r$) of a specific agroclimatic district needed for the stable growth and development of phytoameliorants on the moisture accumulating furrows can be expressed by the difference between the required and the actual amount of precipitation in the given district, plus the surface runoff. This can be expressed in Eq. 9:

$$D_r = 0.30 \times T_{(5-20^\circ C)} - [(P_1 K_a) + P_2] \tag{9}$$

Finally, the model of Optimal Moisture Adequacy (OMA) for the phytomeliorants can be expressed in Eq 10:

$$OMA = \frac{[(P_1 K_a) + P_2] + Dr}{0.30 \times T_{(5-20^\circ C)}} = 1.0 \tag{10}$$

The deficiency of the atmospheric precipitation for the optimal moisture adequacy of phytomeliorants in various agroclimatic regions can be replenished by the surface runoff resulted from atmospheric precipitation. The data shown in Table 3, allow us to select the proper inter row spacing that provides an additional water for the growth and development of phytomeliorants in pastures.

For instance, based on data obtained from Gharatikan meteorological station (near the research station), average rainfall during autumn-winter and spring are 80 and 125 mm, respectively. The required amount of moisture in the active vegetation period of the phytoameiorants is 260 mm. By using the Eq. 9, the precipitation deficit is 83 mm. So, the average runoff with different values of runoff coefficient ($K_r$) and the inter row spacing, provides 83 mm of additional water for the plants in the spring time. Using Table 3 for $K_r = 0.02$ and regarding 125 mm spring rainfall, the runoff generated from 30 to 40 m interval, can provided deficit moisture for the optimal moisture adequacy of phytomeliorants.

## CONCLUSION

Agroclimatic approach proposed in the present research could be an efficient pathway to improve the degraded rangelands productivity. It helps forecasting and determining the seed inter row spacing and providing the optimum use of surface runoff. Plant water requirement shortage in soil can be reduced by using the surface runoff. A model was elaborated to calculate the optimum water supply using the surface runoff properties for North-East of Iran (Khorasan Province). The model is also applicable for forecasting the possibilities of rangeland productivity improvement up to its optimal level. A range of standard criteria was proposed for calculation of the optimum water supply with

Table 3: Possible runoff volume with different values of inter row spacing runoff coefficient and precipitation, (distance between seeds in row, 1 m)

| Inter row spacing (m) | Runoff coefficient ($K_r$) | Volume of runoff with precipitation in spring (Feb-May), (mm) 50 | 75 | 100 | 125 | 150 | 175 | 200 | 225 | 250 |
|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 0.01 | 5 | 7.5 | 10 | 12.5 | 15 | 17.5 | 20 | 22.5 | 25 |
| 20 | | 10 | 15.0 | 20 | 25.0 | 30 | 35.0 | 40 | 45.0 | 50 |
| 30 | | 15 | 22.5 | 30 | 37.5 | 45 | 52.5 | 60 | 67.5 | 75 |
| 40 | | 25 | 30.0 | 40 | 50.0 | 60 | 70.0 | 80 | 90.0 | 100 |
| 50 | | 25 | 37.5 | 50 | 62.5 | 75 | 87.5 | 100 | 112.5 | 125 |
| 10 | 0.02 | 10 | 15.0 | 20 | 25.0 | 30 | 35.0 | 40 | 45.0 | 55 |
| 20 | | 20 | 30.0 | 40 | 50.0 | 60 | 70.0 | 80 | 90.0 | 110 |
| 30 | | 30 | 45.0 | 60 | 75.0 | 90 | 105.0 | 120 | 135.0 | 150 |
| 40 | | 40 | 60.0 | 80 | 100.0 | 120 | 140.0 | 160 | 180.0 | 200 |
| 50 | | 50 | 75.0 | 100 | 125.0 | 150 | 175.0 | 200 | 255.0 | 250 |
| 10 | 0.03 | 15 | 22.5 | 30 | 37.5 | 45 | 52.5 | 60 | 67.5 | 75 |
| 20 | | 30 | 45.0 | 60 | 75.0 | 90 | 105.0 | 120 | 135.0 | 150 |
| 30 | | 45 | 67.5 | 90 | 112.5 | 135 | 157.5 | 180 | 202.5 | 225 |
| 40 | | 60 | 90.0 | 120 | 150.0 | 180 | 210.0 | 240 | 270.0 | 300 |
| 50 | | 75 | 112.5 | 150 | 187.5 | 225 | 262.5 | 300 | 337.5 | 375 |
| 10 | 0.04 | 20 | 30.0 | 40 | 50.0 | 60 | 70.0 | 80 | 90.0 | 100 |
| 20 | | 42 | 60.0 | 80 | 100.0 | 120 | 140.0 | 160 | 180.0 | 200 |
| 30 | | 60 | 90.0 | 120 | 150.0 | 180 | 210.0 | 240 | 270.0 | 300 |
| 40 | | 80 | 120.0 | 160 | 200.0 | 240 | 280.0 | 320 | 360.0 | 400 |
| 50 | | 100 | 150.0 | 200 | 255.0 | 300 | 350.0 | 400 | 450.0 | 450 |
| 10 | 0.05 | 25 | 37.5 | 50 | 62.5 | 75 | 87.5 | 100 | 112.5 | 125 |
| 20 | | 50 | 75.0 | 100 | 125.0 | 150 | 175.0 | 200 | 225.0 | 250 |
| 30 | | 75 | 112.5 | 150 | 187.0 | 225 | 262.5 | 300 | 337.5 | 375 |
| 40 | | 100 | 150.0 | 200 | 250.0 | 300 | 350.0 | 400 | 450.0 | 500 |
| 50 | | 125 | 187.5 | 250 | 312.5 | 375 | 437.5 | 400 | 562.5 | 625 |
| 10 | 0.06 | 30 | 45.0 | 60 | 75.0 | 90 | 105.0 | 120 | 135.0 | 150 |
| 20 | | 60 | 90.0 | 120 | 150.0 | 180 | 210.0 | 240 | 270.0 | 300 |
| 30 | | 90 | 135.0 | 180 | 225.0 | 270 | 315.0 | 360 | 405.0 | 450 |
| 40 | | 120 | 180.0 | 240 | 300.0 | 360 | 420.0 | 480 | 450.0 | 600 |
| 50 | | 150 | 225.0 | 300 | 375.0 | 450 | 525.0 | 600 | 675.0 | 750 |
| 10 | 0.07 | 35 | 52.5 | 70 | 87.5 | 105 | 122.5 | 140 | 157.5 | 175 |
| 20 | | 70 | 105.0 | 140 | 175.0 | 210 | 245.0 | 280 | 315.0 | 350 |
| 30 | | 105 | 157.5 | 210 | 262.5 | 315 | 367.5 | 420 | 472.5 | 525 |
| 40 | | 140 | 210.0 | 280 | 350.0 | 420 | 490.0 | 560 | 630.0 | 700 |
| 50 | | 175 | 262.5 | 350 | 437.5 | 525 | 612.5 | 700 | 787.5 | 875 |
| 10 | 0.08 | 40 | 60.0 | 80 | 100.0 | 120 | 140.0 | 160 | 180.0 | 200 |
| 20 | | 80 | 120.0 | 160 | 200.0 | 240 | 280.0 | 320 | 360.0 | 400 |
| 30 | | 120 | 180.0 | 240 | 300.0 | 360 | 420.0 | 480 | 540.0 | 600 |
| 40 | | 160 | 240.0 | 320 | 400.0 | 480 | 560.0 | 640 | 720.0 | 800 |
| 50 | | 200 | 300.0 | 400 | 500.0 | 600 | 700.0 | 800 | 900.0 | 1000 |
| 10 | 0.09 | 45 | 67.5 | 90 | 112.5 | 135 | 157.5 | 180 | 202.5 | 225 |
| 20 | | 90 | 135.0 | 180 | 225.0 | 270 | 315.0 | 360 | 405.0 | 450 |
| 30 | | 135 | 202.5 | 270 | 337.5 | 405 | 472.5 | 540 | 607.5 | 675 |
| 40 | | 180 | 270.0 | 360 | 450.0 | 540 | 630.0 | 720 | 810.0 | 900 |
| 50 | | 225 | 337.5 | 450 | 562.5 | 675 | 787.5 | 900 | 1012.5 | 1125 |

respect to inter row spacing (Table 3). The proposed model can be applicable to calculate the duration of vegetation period in respect to water supply.

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