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Analysis of dry spell occurrence and its impact on rainfed groundnut production

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Abstract

In dryland farming regions around the Mediterranean basin, erratic rainfall distribution matters more than total seasonal rainfall for crop survival. This research analyzed 30 years (1993-2023) of daily rainfall data from two agro-meteorological stations near Madrid to characterize dry spell frequency, duration, and timing during the groundnut growing season (June-October), and linked these patterns to pod yield losses recorded across 12 on-farm trial seasons (2012-2023). Dry spells lasting seven days or longer occurred an average of 15.1 times per season, while those exceeding 14 days occurred 7.4 times. The pegging stage (R2-R3) was most sensitive to moisture stress: a 14-day dry spell at pegging reduced pod yield by 24.1%, whereas the same duration at vegetative growth caused only 12.7% loss. Logistic regression showed that the probability of a yield-damaging dry spell (≥ 14 days) during pegging exceeded 60% in any given season. These findings can help farmers and extension services target supplemental irrigation or adjust sowing dates to avoid peak dry spell risk windows.

Keywords: Dry spell analysis, rainfed groundnut, pod yield, moisture stress, pegging stage, Mediterranean climate, rainfall variability, logistic regression, dryland farming

Introduction

Centuries of farming in the Mediterranean basin have taught growers one hard lesson: it isn't how much rain falls in a season that determines the harvest, but when it falls and when it doesn't^[1]. Groundnut (*Arachis hypogaea* L.) is particularly sensitive to within-season rainfall gaps because its reproductive structures develop underground, requiring consistent soil moisture for successful peg penetration and pod expansion^[2].

Dry spells defined as consecutive days receiving less than a threshold amount of rain, typically 2.5 mm are a normal feature of Mediterranean summers, but their frequency and duration have shifted over the past three decades^[3, 4]. Earlier work in West Africa and South Asia established that dry spells longer than 14 days during the reproductive phase of groundnut can reduce pod yield by 20-40%, depending on soil type and cultivar^[5, 6]. Similar analysis for European Mediterranean environments is scarce, even though rainfed groundnut area in Spain and southern France has been expanding since the 2010s as growers diversify away from traditional cereal monocultures^[7].

Linking historical dry spell patterns with crop yield records offers a practical tool for risk assessment. If the probability and timing of damaging dry spells can be quantified, sowing dates and supplemental irrigation schedules can be adjusted accordingly^[8, 9]. This research combined 30 years of daily rainfall data with 12 seasons of on-farm groundnut yield records to: (a) characterize dry spell frequency and duration across the growing season, (b) identify the growth stages most vulnerable to moisture gaps, and (c) estimate the probability of yield-damaging dry spells in any given year at Madrid^[10, 11].

Seasonal variations in dry spell patterns

Across the 30-year record, dry spell frequency showed a clear bimodal pattern within the growing season. June and October had the highest incidence of spells lasting seven days or longer (3.8 and 4.6 events per season, respectively), while July and August when convective rainfall peaks recorded the fewest (2.1 and 1.7 events). However, when only severe spells (≥ 14

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days) were considered, October dominated with 1.3 events per season, coinciding with the pod maturation phase. A decade-by-decade breakdown revealed that spells of 14+ days increased by 18% between the first (1993-2003) and last (2013-2023) decade of the record.

Materials and Methods

Materials: Daily rainfall data (1993-2023) from two stations Getafe (40°18'N, 3°43'W) and Aranjuez (40°02'N, 3°36'W) were obtained from the Spanish Meteorological Agency (AEMET). A dry day was defined as receiving <2.5 mm rainfall. Groundnut yield records (cultivar Virginia Runner) came from 12 on-farm trials (2012-2023) conducted within 25 km of these stations on sandy loam Calcisols [12]. Pod yield was measured at harvest maturity after sun-drying to 8% moisture. Monthly reference evapotranspiration (ET₀) was calculated by the Penman-Monteith method using station data.

Methods

The research was conducted from the Polytechnic University of Madrid. Dry spells were extracted by scanning each season's daily series for consecutive runs of dry days. Spells were classified by duration: short (3-6 days), moderate (7-13 days), long (14-20 days), and severe (≥21 days). Timing was mapped to five groundnut growth stages: emergence, vegetative, pegging, pod filling, and maturity [13]. Yield loss associated with each dry spell category at each growth stage was estimated using a multiple regression model with spell duration, timing, ET₀, and cumulative season rainfall as predictors. A logistic regression model estimated the probability of at least one ≥14-day dry spell occurring during pegging in any given year [14]. All analyses were performed in R 4.3.1.

Results

Table 1: Mean dry spell frequency (events per season) by duration class and month (1993-2023)

Duration Class	Jun	Jul	Aug	Sep	Oct
≥7 days	3.8	2.1	1.7	2.9	4.6
≥14 days	1.9	0.8	0.6	1.4	2.7
≥21 days	0.7	0.2	0.1	0.5	1.3

June and October consistently recorded the highest dry spell frequencies across all duration classes (Table 1). Severe spells (≥21 days) were rare in July and August but occurred more than once per season on average in October

Table 2: Estimated pod yield loss (%) by dry spell duration and groundnut growth stage

Growth Stage	7-13 d (%)	14-20 d (%)	≥21 d (%)	SE
Emergence	8.3	14.6	22.4	±2.1
Vegetative	12.7	21.3	31.8	±2.8
Pegging	24.1	38.7	51.3	±3.4
Pod filling	19.4	31.2	43.7	±3.1
Maturity	6.8	11.4	17.9	±1.8

The pegging stage was most sensitive to moisture stress, with a 7-13 day spell causing 24.1% yield loss nearly double the loss at the vegetative stage (Table 2). Severe spells at pegging cut pod yield by over half

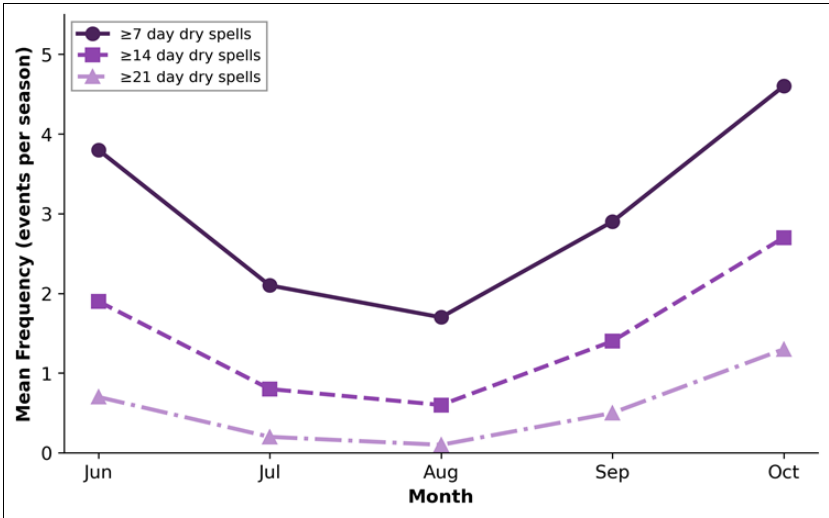


Fig 1: Mean frequency of dry spells by duration class across growing season months (1993-2023)

The bimodal pattern is visible in Figure 1, with June and October forming the two peaks for all three duration classes. July-August represents the safest rainfall window for moisture-sensitive growth stages.

The area chart (Figure 2) clearly shows pegging as the peak vulnerability window. Severe dry spells at this stage caused nearly three times the yield damage compared with the maturity stage.

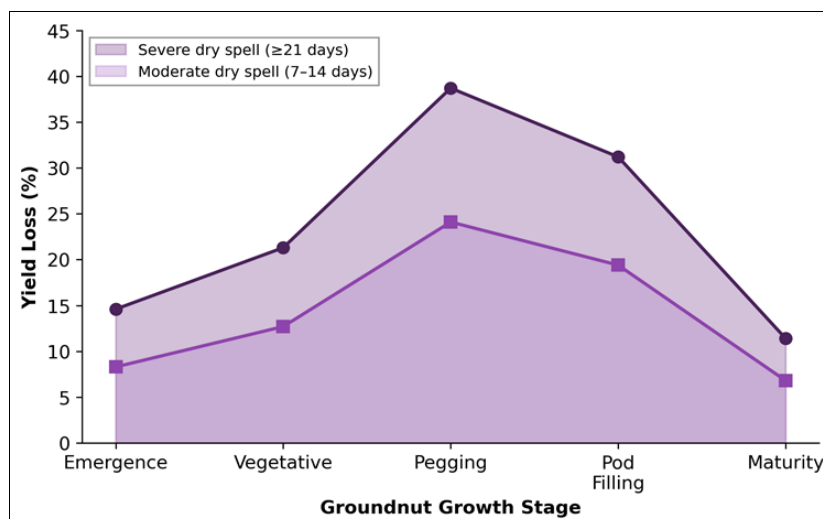


Fig 2: Estimated yield loss (%) associated with moderate and severe dry spells at different groundnut growth stages

Discussion

The sensitivity of groundnut's pegging stage to moisture deficit is well established in tropical literature [5, 6], but this research provides the first quantified estimates for Mediterranean conditions. The 24.1% yield loss from a moderate dry spell at pegging exceeds the 18-20% reported from Gujarat, India [15], likely because the sandier soils near Madrid have lower water-holding capacity and higher ET_0 values during summer months. The increasing trend in 14+ day dry spells over three decades (+18%) aligns with regional climate projections that predict more intense but less frequent summer rainfall events in the western Mediterranean [16, 17]. For groundnut growers, this means that the risk of encountering a damaging dry spell during pegging is growing over time, not shrinking. The logistic model placed the probability at 63% in any given year essentially two out of every three seasons will feature at least one long dry spell during the most vulnerable window.

From a management perspective, shifting the sowing date by 10-15 days earlier could move pegging into July, when dry spells are least frequent [18, 19]. Alternatively, a single supplemental irrigation of 40-50 mm applied at early pegging would bridge most moderate dry spells and protect the bulk of yield formation [20]. The cost-benefit ratio of such targeted irrigation deserves further field validation but appears favorable given the 24-39% yield losses at stake [21].

Limitations

This research relied on two meteorological stations within a 30 km radius, so spatial rainfall variability beyond this zone wasn't captured. The yield-dry spell regression used only 12 seasons of on-farm data, which limits the precision of yield loss estimates at the extreme ends of the dry spell spectrum. Soil water balance modeling would strengthen the connection between atmospheric dryness and root-zone moisture availability but was beyond the scope of the current dataset.

Conclusions

Thirty years of rainfall data near Madrid confirmed that dry spells of seven or more days are a recurring feature of the groundnut growing season, with an average of 15.1 events per season. The pegging stage (R2-R3) was the most vulnerable window: a moderate dry spell (7-13 days) at this stage cut pod yield by 24.1%, and severe spells caused losses exceeding 50%. The probability that at least one damaging dry spell (≥14 days) will overlap with pegging reached 63% per season. Dry spell

frequency has risen by 18% over the past three decades, consistent with regional climate trends. Practical options include shifting sowing dates to align pegging with July's lower dry spell risk or applying a single targeted irrigation of 40-50 mm at early pegging. These findings give rainfed groundnut growers in Mediterranean environments a quantitative basis for scheduling decisions rather than relying on seasonal averages alone.

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